American Society of Plumbing Engineers

Plumbing Engineering Design Handbook

A Plumbing Engineer's Guide to System Design and Specifications

Volume 1

Fundamentals of Plumbing Engineering

American Society of Plumbing Engineers
8614 W. Catalpa Avenue, Suite 1007
Chicago, IL 60656-1116

The ASPE *Plumbing Engineering Design Handbook* is designed to provide accurate and authoritative information for the design and specification of plumbing systems. The publisher makes no guarantees or warranties, expressed or implied, regarding the data and information contained in this publication. All data and information are provided with the understanding that the publisher is not engaged in rendering legal, consulting, engineering, or other professional services. If legal, consulting, or engineering advice or other expert assistance is required, the services of a competent professional should be engaged.

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Plumbing Engineering Design Handbook

Volume 1

Fundamentals of Plumbing Engineering

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About ASPE

The American Society of Plumbing Engineers (ASPE) is the international organization for professionals skilled in the design and specification of plumbing systems. ASPE is dedicated to the advancement of the science of plumbing engineering, to the professional growth and advancement of its members, and to the health, welfare, and safety of the public.

The Society disseminates technical data and information, sponsors activities that facilitate interaction with fellow professionals, and, through research and education programs, expands the base of knowledge of the plumbing engineering industry. ASPE members are leaders in innovative plumbing design, effective materials and energy use, and the application of advanced techniques from around the world.

Worldwide Membership — ASPE was founded in 1964 and currently has 7,500 members. Spanning the globe, members are located in the United States, Canada, Asia, Mexico, South America, the South Pacific, Australia, and Europe. They represent an extensive network of experienced engineers, designers, contractors, educators, code officials, and manufacturers interested in furthering their careers, their profession, and the industry. ASPE is at the forefront of technology. In addition, ASPE represents members and promotes the profession among all segments of the construction industry.

ASPE Membership Communication — All members belong to ASPE worldwide and have the opportunity to belong and participate in one of the 62 state, provincial or local chapters throughout the U.S. and Canada. ASPE chapters provide the major communication links and the first line of services and programs for the individual member. Communications with the membership is enhanced through the Society's bimonthly magazine, *Plumbing Systems and Design,* and the bimonthly newsletter ASPE *Report* which is incorporated as part of the magazine.

Technical Publications — The Society maintains a comprehensive publishing program, spearheaded by the profession's basic reference text, the ASPE *Plumbing Engineering Design Handbook*. The *Plumbing Engineering Design Handbook,* encompassing 47 chapters in four volumes, provides comprehensive details of the accepted practices and design criteria used in the field of plumbing engineering. New additions that will shortly join ASPE's published library of professional technical manuals and handbooks include: *Pharmaceutical Facilities Design Manual, Electronic Facilities Design Manual, Health Care Facilities and Hospitals Design Manual,* and *Water Reuse Design Manual*.

Convention and Technical Symposium — The Society hosts biennial Conventions in even-numbered years and Technical Symposia in odd-numbered years to allow professional plumbing engineers and designers to improve their skills, learn original concepts, and make important networking contacts to help them stay abreast of current trends and technologies. In conjunction with each Convention there is an Engineered Plumbing Exposition, the greatest, largest gathering of plumbing engineering and design products, equipment, and services. Everything from pipes to pumps to fixtures, from compressors to computers to consulting services is on display, giving engineers and specifiers the opportunity to view the newest and most innovative materials and equipment available to them.

Certified in Plumbing Design — ASPE sponsors a national certification program for engineers and designers of plumbing systems, which carries the designation "Certified in Plumbing Design" or CPD. The certification program provides the profession, the plumbing industry, and the general public with a single, comprehensive qualification of professional competence for engineers and designers of plumbing systems. The CPD, designed exclusively by and for plumbing engineers, tests hundreds of engineers and designers at centers throughout the United States biennially. Created to provide a single, uniform national credential in the field of engineered plumbing systems, the CPD program is not in any way connected to state-regulated Professional Engineer (P.E.) registration.

ASPE Research Foundation — The ASPE Research Foundation, established in 1976, is the only independent, impartial organization involved in plumbing engineering and design research. The science of plumbing engineering affects everything… from the quality of our drinking water to the conservation of our water resources to the building codes for plumbing systems. Our lives are impacted daily by the advances made in plumbing engineering technology through the Foundation's research and development.

American Society of Plumbing Engineers
Plumbing Engineering Design Handbook
(4 Volumes — 47 Chapters)

Volume 2 Plumbing Systems (Estimated date: Fall 2005)

Chapter 1 Sanitary Drainage Systems
2 Gray-Water Systems
3 Vents and Venting Systems
4 Storm-Drainage Systems
5 Cold-Water Systems
6 Domestic Water-Heating System
7 Fuel-Gas Piping Systems
8 Private Sewage-Disposal Systems
9 Private Water Systems
10 Vacuum Systems
11 Pure Water, Systems
12 Lab-Waste Systems

Volume 3 Special Plumbing Systems (Estimated date: Fall 2006)

Chapter 1 Fire Protection Systems
2 Plumbing Design for Health-Care Facilities
3 Industrial Waste-Water Treatment
4 Irrigation Systems
5 Reflecting Pools and Fountains
6 Public Swimming Pools
7 Gasoline and Diesel-Oil Systems
8 Steam and Condensate Systems
9 Compressed Air Systems
10 Site Utility Systems

Volume 4 Plumbing Components and Equipment (Estimated revision date: Fall 2007)

Chapter 1 Plumbing Fixtures
2 Piping Systems
3 Valves
4 Pumps
5 Piping Insulation
6 Hangers and Supports
7 Vibration Isolation
8 Grease Interceptors
9 Cross Connection Control
10 Water Treatment
11 Thermal Expansion
12 Potable Water Coolers and Central Water Systems
13 Bioremediation Pretreatment Systems

(The chapters and subjects listed for these volume are subject to modification, adjustment and change. The contents shown for each volume are proposed and may not represent the final contents of the volume. A final listing of included chapters for each volume will appear in the actual publication.)

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1 Formulas, Symbols and Terminology

FORMULAE COMMONLY USED IN PLUMBING ENGINEERING

For the convenience of ASPE members, the Society has gathered some of the basic formulae commonly referred to and utilized in plumbing engineering and design. It is *extremely important* to convert to values of the proper units whenever using these equations.

Take note that gravitational acceleration and gravitational constant have the same numerical value, but the units are not the same. This term is frequently left out of equations with no effect to the numerical value. However, the units will not be dimensionally correct and do not cancel out. Due to the English system of measurement utilizing pounds to indicate mass and force, pounds-mass (lbm) and pounds-force (lbf) are used to distinguish between the two.

This is not an issue for The International System of Units (SI). Equations listed in parenthesis () are used to represent equations that are unit-system specific to SI units and differ when using English units.

Equation 1-1, the Manning Formula Used for determining the velocity (V) of uniform flow (defined as the flow that is achieved in open channels of constant shape and size and uniform slope) in sloping drains. Note that the slope of the water surface is equal to the slope of the channel, and that the flows in such open channels do not depend on the pressure applied to the water but on the gravitational force induced by the slope of the drain and the height of the water in that drain.

Equation 1-1

$$V = \frac{1.486\ R^{2/3}\ S^{1/2}}{n}$$

where

V = Velocity of flow, ft/s (m/s)
n = Coefficient representing roughness of pipe surface, degree of fouling, and pipe diameter
R = Hydraulic radius, ft (m)
S = Hydraulic slope of surface of flow, ft/ft (m/m)

The hydraulic radius (R) can be calculated using Equation 1-3. The roughness coefficient (n) and several values for the hydraulic radii are given in Baumeister and Marks's "Standard Handbook for Mechanical Engineers."

Equation 1-2, Rate of flow Used for determining the amount of water passing through a pipe. This quantity of water, for a given time, depends on the cross-sectional area of the pipe and the velocity of the water.

Equation 1-2

$$Q = AV$$

where

Q = Flow rate of water, ft^3/s (m^3/s)
A = Cross-sectional area of pipe, ft^2 (m^2)
V = Flow velocity of water, ft/s (m/s)

(a) Therefore, substituting Equation 1-2 in Equation 1-1, the Manning Formula can be represented as follows:

Equation 1-2a

$$Q = \frac{1.486\ AR^{2/3}\ S^{1/2}}{n}$$

Equation 1-3, Hydraulic radius (R) Usually referred to as the hydraulic mean depth of flow, the ratio of the cross-sectional area of flow to the wetted perimeter of pipe surface.

Equation 1-3

$$R = \text{Area of flow/Wetted perimeter}$$

For half-full (HF) and full-flow (FF) conditions, the hydraulic radii can be represented as:

Equation 1-3a

$$R_{HF} = R_{FF} = \frac{D}{4}$$

where

D = Diameter of pipe, ft (m)
R_{HF} = Hydraulic radius, half-full condition, ft (m)

RFF = Hydraulic radius, full-flow condition, ft (m)

Equation 1-4, Water flow in pipes Two types of water flow exist: Laminar and turbulent. Each type is characterized by the Reynolds number, a dimensionless quantity. The physical characteristics of the water, the velocity of the flow, and the internal diameter of the pipe are factors for consideration, and the Reynolds number is represented as:

Equation 1-4

$$Re = \frac{VD\rho}{\mu g_c}$$

where

Re = Reynolds number, dimensionless
V = Velocity of flow, ft/s (m/s)
D = Diameter of pipe, ft (m)
ρ = Density, lbm/ft^3 (kg/m^3)
μ = Absolute viscosity of fluid, lb-s/ft^2 (m^2/s)
g_c = Gravitational Contstant, 32.2 lbm-ft/lbf-s^2

Values of viscosity are tabulated in the ASHRAE "Handbook of Fundamentals." In laminar flow, the fluid particles move in layers in straight parallel paths, the viscosity of the fluid is dominant, and its upper limit is represented by Re = 2000. In turbulent flow, the fluid particles move in a haphazard fashion in all directions, the path of an individual fluid particle is not possible to trace, and Re is above 4000. Flows with Re between 2000 and 4000 are classified as critical flows. Re is necessary to calculate friction coefficients which, in turn, are used to determine pressure losses.

Equation 1-5, Friction head loss Whenever flow occurs, a continuous pressure loss exists along the piping in the direction of flow, and this head loss is affected by the density of the fluid, its temperature, the pipe roughness, the length of the run, and the fluid velocity. The friction head loss is represented by Darcy's Friction Formula:

Equation 1-5

$$h = \frac{fLV^2}{2gD}$$

where

h = Friction head loss, ft (m)
f = Friction coefficient, dimensionless
L = Length of pipe, ft (m)
V = Velocity of flow, ft/s (m/s)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)
D = Internal diameter of pipe, ft (m)

(a) The static head is the pressure (P) exerted at any point by the height of the substance above that point. To convert from feet (m) of head to pounds per square inch (kPa or kg/m^2), the following relationship is used:

Equation 1-5a

$$P = \frac{\gamma h}{144}$$

where

P = Pressure, lbf/in^2 (kPa)
γ = Specific Weight of substance, lbf/ft^3 (N/m^3)
h = Static head, ft (m)

(b) Therefore, Equation 1-5 may be represented as:

Equation 1-5b

$$P = \frac{\gamma fLV^2}{288gD}$$

(c) To convert pressure in meters of head to pressure in kilopascals, use

Equation 1-5c

$$kPa = 9.81 \text{ (m head)}$$

(d) To calculate the friction loss, the Hazen-Williams Formula is used:

Equation 1-5d

$$h = 0.002082L\left(\frac{100}{C}\right)^{1.85}\left(\frac{q^{1.8}}{d^{4.8655}}\right)$$

where

C = Friction factor for Hazen-Williams
q = Flow rate, gpm (L/s)
d = Actual inside diameter of pipe, in. (mm)
L = Length of pipe, ft (m)
f = Friction factor

Values for f and C are tabulated in Baumeister and Marks's "Handbook for Mechanical Engineers."

Equation 1-6, Potential energy (PE) Defined as the energy of a body due to its elevation above a given level and expressed as:

Equation 1-6

$$PE = Wh = \frac{mgh}{g_c}$$

$$(PE = Wh)$$

where

PE = Potential energy, ft-lbf (J)
W = Weight of body, lbf (N)
h = Height above level, ft (m)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)
g_c = Gravitational constant, 32.2 lbm-ft/lbf-s^2

Equation 1-7, Kinetic energy (KE) Defined as the energy of a body due to its motion and expressed as:

Equation 1-7

$$KE = \frac{mV^2}{2g_c} = \frac{WV^2}{2g}$$

$$\left(KE = \frac{mV^2}{2}\right)$$

where

KE = Kinetic energy, ft-lbf (J)
m = Mass of body, lbm (kg)
V = Velocity, ft/s (m/s)

W = Weight of body, lbf (kg)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 /s^2)
g_c = Gravitational constant, 32.2 lbm-ft/lbf-s^2

Equation 1-8, Flow at outlet Can be determined by using the following relationship:

Equation 1-8

$$Q = 29.87 C_d d^2 P^{1/2}$$

where
Q = Flow at outlet, gpm (L/s)
C_d = Discharge Coefficient
d = Inside diameter of outlet, in. (mm)
P = Flow pressure, lbf/in^2 (kPa)

The discharge coefficient (C_d) may be obtained from Baumeister and Marks's "Handbook for Mechanical Engineers."

Equation 1-9, Length of vent piping Can be determined by combining Darcy's Friction Formula (Equation 1-5) and the flow equation and is expressed as:

Equation 1-9

$$L = \frac{2226 d^5}{f Q^2}$$

where
L = Length of pipe, ft (m)
d = Diameter of pipe, in. (mm)
f = Friction coefficient, dimensionless
Q = Rate of flow, gpm (L/s)

Equation 1-10, Stacks

(a) Terminal velocity

Equation 1-10a

$$V_T = 3 \left(\frac{Q}{d}\right)^{2/5}$$

where
V_T = Terminal velocity in stack, ft/s (m/s)
Q = Rate of flow, gpm (L/s)
d = Diameter of stack, in. (mm)

(b) Terminal length

Equation 1-10b

$$L_T = 0.052\, V_T^2$$

where
L_T = Terminal length below point of flow entry, ft (m)

(c) Capacity

Equation 1-10c

$$Q = 27.8\, r^{5/3}\, d^{8/3}$$

where
Q = Maximum permissible flow rate in stack, gpm (L/s)
r = Ratio of cross-sectional area of the sheet of water to cross-sectional area of stack.
d = Diameter of stack, in. (mm)

Equation 1-11, Flow rate in fixture drain The flow rate in a fixture drain should equal the flow rate at the fixture outlet and is expressed as:

Equation 1-11

$$Q = 13.17\, d^2 h^{1/2}$$

where
Q = Discharge flow rate, gpm (L/s)
d = Diameter of outlet orifice, in. (mm)
h = Mean vertical height of water surface above the point of outlet orifice, ft (m)

Equation 1-12, Pipe expansion and contraction All pipes that are subject to temperature changes expand and contract. Piping expands with an increase in temperature and contracts with a decrease in temperature. The rate of change in length due to temperature is referred to as the expansion coefficient. The changes in length can be calculated by using the following relation:

Equation 1-12

$$L_2 - L_1 = C_E L_1 (T_2 - T_1)$$

where
L_2 = Final length of pipe, ft (m)
L_1 = Initial length of pipe, ft (m)
C_E = Coefficient of expansion of material (A material's expansion coefficient may be obtained from the ASHRAE "Handbook of Fundamentals.")
T_2 = Final temperature, °F (°C)
T_1 = Initial temperature, °F (°C)

Equation 1-13, Various formulae for areas and volumes, in ft^2 (m^2) and ft^3 (m^3), respectively.

Equation 1-13a, Square (See Figure 1-1.)

A = bh

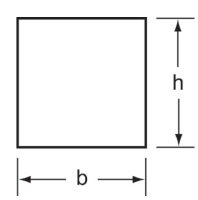


Figure 1-1 Square

Equation 1-13b, Rectangle (See Figure 1-2.)

A = bh

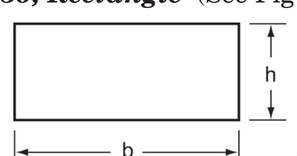


Figure 1-2 Rectangle

Equation 1-13c, Rhombus (See Figure 1-3.)

$$A = bh$$

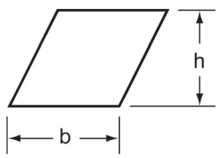


Figure 1-3 Rhombus

Equation 1-13d, Rhomboid (See Figure 1-4.)

$$A = bh$$

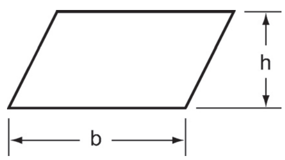


Figure 1-4 Rhomboid

Equation 1-13e, Trapezoid (See Figure 1-5.)

$$A = \frac{h\,(a + b)}{2}$$

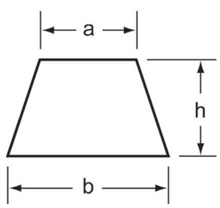


Figure 1-5 Trapezoid

Equation 1-13f, Trapezium (See Figure 1-6.)

$$A = \frac{(H + h)a + bh + cH}{2}$$

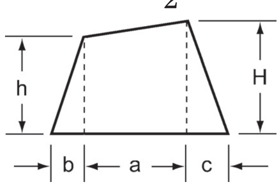


Figure 1-6 Trapezium

Equation 1-13g, Right-angle triangle (See Figure 1-7.)

$$A = \frac{bh}{2}$$

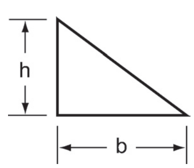


Figure 1-7 Right-Angle Triangle

Equation 1-13h, Isosceles triangle (See Figure 1-8.)

$$A = \frac{bh}{2}$$

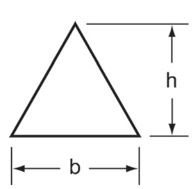


Figure 1-8 Isosceles Triangle

Equation 1-13i, Ellipse (See Figure 1-9.)

$$A = \pi ab$$

where
$a = D$
$b = d$

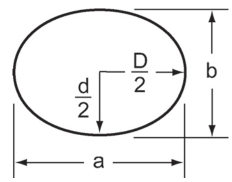


Figure 1-9 Ellipse

Equation 1-13j, Cylinder (See Figure 1-10.)

$$A = \pi Dh$$

$$V = \pi R^2h$$

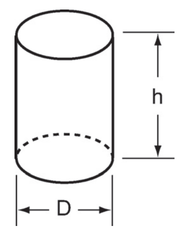


Figure 1-10 Cylinder

Equation 1-13k, Cube or rectangular solid (See Figure 1-11.)

$$V = whl$$

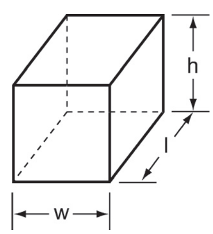


Figure 1-11 Cube or Rectangular Solid

Equation 1-13l, Pyramid (See Figure 1-12.)

$$V = \frac{abh}{3}$$

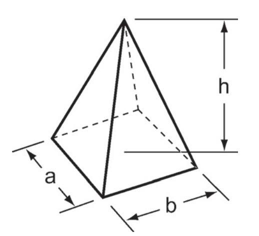


Figure 1-12 Pyramid

Equation 1-13m, Cone (See Figure 1-13.)

$$A = \frac{\pi Ds}{2}$$

$$V = \frac{\pi R^2h}{3}$$

where
$D = b$
$R = \frac{b}{2}$

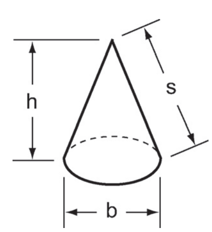


Figure 1-13 Cone

Equation 1-13n, Circle (See Figure 1-14.)

$$C = 2\pi R$$

Equation 1-13o, Circle (See Figure 1-14.)

$A = \pi R^2$

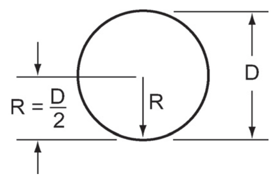


Figure 1-14 Circle

Equation 1-13p, Triangle[3] (See Figure 1-15.)

Known: 2 angles
Required: Third angle
Solution: $A = 180° - (B + C)$

Equation 1-13q, Triangle[3] (See Figure 1-15.)

Known: 3 sides
Required: Any angle
Solution: $\cos A = \dfrac{b^2 + c^2 - a^2}{2bc}$

Equation 1-13r, Triangle[3] (See Figure 1-15.)

Known: 2 sides and included angle
Required: Third side
Solution: $c = (a^2 + b^2 - 2ab \cos C)^{½}$

Equation 1-13s, Triangle[3] (See Figure 1-15.)

Known: 2 sides and included angle
Required: Third angle
Solution: $\tan A = \dfrac{a \sin C}{b - a \cos C}$

Equation 1-13t, Triangle[3] (See Figure 1-15.)

Known: 2 sides and excluded angle
Required: Third side
Solution: $c = b \cos A \pm (a^2 - b^2 \sin^2 A)^{½}$

Equation 1-13u, Triangle[3] (See Figure 1-15.)

Known: 1 side and adjacent angles
Required: Adjacent side
Solution: $c = \dfrac{a \sin C}{\sin A}$

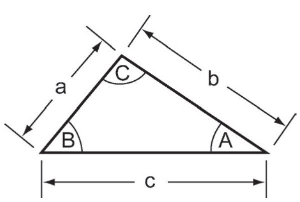


Figure 1-15 Triangle

Equation 1-14, Flow rate in outlet With Equation 1-11, we determined that the flow rate (Q) in the outlet should be equal to the flow rate in the fixture drain. The maximum discharge rate is expressed as:

Equation 1-14

$$Q_D = c_D Q_I$$

where

Q_D = Actual discharge quantity, gpm (L/s)
c_D = Discharge coefficient
Q_I = Ideal discharge quantity, gpm (L/s)

The discharge coefficients (c_D) may be obtained from Baumeister and Marks's "Handbook for Mechanical Engineers."

Equation 1-15, Gravity circulation This principle is used to keep the sanitary system free of foul odors and the growth of slime and fungi. The circulation is induced by the pressure difference between the outdoor air and the air in the vent piping. This pressure difference is due to the difference in temperature (T) and density (ρ) between the two and the height (h) of the air column in the vent piping. The gravity circulation is determined by using the following formula:

Equation 1-15

$$P = 0.1925 (\gamma_O - \gamma_I) h_s$$

where

P = Natural draft pressure, in. (mm)
γ_O = Specific Weight of outside air, lbf/ft^3 (N/m^3)
γ_I = Specific Weight of air in pipe, lbf/ft^3 (N/m^3)
h_s = Height of air column in stack, ft (m)

The outside and inside air densities (ρ_O and ρ_I) may be obtained from the ASHRAE "Handbook of Fundamentals."

Equation 1-16, Velocity head (h) When the water in a piping system is at rest, it has potential energy (PE). When the water in a piping system is flowing, it has kinetic energy (KE). For the water to flow, some of the potential energy (PE) must be converted to kinetic energy (KE). The decrease in potential energy (static head) is referred to as the velocity head (h) and is expressed as:

Equation 1-16

$$h = \frac{V^2}{2g}$$

where

h = Height of the fall, ft (m)
V = Velocity at any moment, ft/s (m/s)
g = Gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2)

Equation 1-17, Bernoulli's Equation Since energy cannot be created or destroyed, Bernoulli developed a theorem to express this energy conservation. It is represented by the following equation:

Equation 1-17

$$E_T = \frac{Zg}{g_c} + \frac{P}{\rho} + \frac{V^2}{2g_c}$$

$$\left(E_T = Zg + \frac{P}{\rho} + \frac{V^2}{2}\right)$$

where

E_T = Total energy ft-lbf/lbm (J/kg)
Z = Height of point above datum, ft (m)
P = Pressure, lbf/ft^2 (kPa)
ρ = Density, lbm/ft^3 (N/m^3)
V = Velocity, ft/s (m/s)

g = Gravitational acceleration, 32.2 ft/s² (9.8 m/s²)
g_c = Gravitational constant, 32.2 lbm-ft/lbf-s²

(a) For two points in the system, Equation 1-17 can be expressed as:

Equation 1-17a

$$\frac{Z_1 g}{g_c} + P_{1/\rho} + \frac{V_1^2}{2g_c} = \frac{Z_2 g}{g_c} + \frac{P_2}{\rho} + \frac{V_2^2}{2g_c}$$

Subscripts 1 and 2 represent points in the system.

Equation 1-18, Friction head (h_f) When water flows in a pipe, friction is produced by the rubbing of water particles against each other and against the walls of the pipe. This causes a pressure loss in the line of flow, called the friction head, which is expressed by using Bernoulli's equation:

Equation 1-18

$$h_f = \left(\frac{Z_1 g}{g_c} + h_1 + \frac{V_1^2}{2g_c}\right) - \left(\frac{Z_2 g}{g_c} + h_2 + \frac{V_2^2}{2g_c}\right)$$

where
h_f = Friction head, ft (m)
Z = Height of point, ft (m)
h = P/ρ = static head or height of liquid column, ft (m)
V = Velocity at outlet, ft/s (m/s)
g = Gravitational acceleration, 32.2 ft/s² (9.8 m/s²)
g_c = Gravitational constant, 32.2 lbm ft/lbf·s²

Subscripts 1 and 2 represent points in the system.

Equation 1-19, Flow from outlets This velocity can be expressed by the following:

Equation 1-19

$$V = C_D\,(2gh)^{1/2}$$

where
V = Velocity at outlet, ft/s (m/s)
C_D = Coefficient of discharge (usually 0.67)
g = Gravitational acceleration, 32.2 ft/s² (9.8 m/s²)
h = Static head or height of liquid column, ft (m)

Equation 1-20, Hydraulic shock The magnitude of the pressure wave can be expressed by the following relationship:

Equation 1-20

$$P = \frac{\gamma\, a dV}{144g}$$

where
P = Pressure in excess of flow pressure, lb/in² (kPa)
γ = Specific weight of liquid, lbf/ft³ (N/m³)
a = Velocity of propagation of elastic vibration in the pipe, ft/s (m/s)
dV = Change in flow velocity, ft/s (m/s)
g = Gravitational acceleration, 32.2 ft/s² (9.8 m/s²)

(a) The velocity of propagation of elastic vibration in the pipe can be defined as:

Equation 1-20a

$$a = \frac{4660}{(1 + KB)^{1/2}}$$

where
a = Propagation velocity, ft/s (m/s)
4660 = Velocity of sound in water, ft/s (m/s)
K = Ratio of modulus of elasticity of fluid to modulus of elasticity of pipe
B = Ratio of pipe diameter to wall thickness

The values for specific weights (γ), K, and B are given or can be calculated from the ASHRAE "Handbook of Fundamentals."

(b) The time interval required for the pressure wave to travel back and forth in the pipe can be expressed as:

Equation 1-20b

$$t = \frac{2L}{a}$$

where
t = Time interval, s
L = Length of pipe from point of closure to point of relief, ft (m)

Equation 1-21, Pump affinity laws Affinity laws describe the relationships among the capacity, head, brake horsepower, speed, and impeller diameter of a given pump.

The first law states the performance data of constant impeller diameter with change in speed.

Equation 1-21a

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \text{ and } \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

$$\text{and } \frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3$$

$$\text{or } \frac{N_1}{N_2} = \frac{Q_1}{Q_2} = \left(\frac{H_1}{H_2}\right)^{1/2} = \left(\frac{BHP_1}{BHP_2}\right)^{1/3}$$

where
Q = Capacity, gpm (m³/H)
N = Speed, rpm (r/s)
H = Head, ft (m)
BHP = Brake horspower, W

The second law assumes the performance data of constant speed with change in diameter of the impeller.

Equation 1-21b

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \text{ and } \frac{H_1}{H_2} = \frac{D_1^2}{D_2^2} \text{ and } \frac{BHP_1}{BHP_2} = \frac{D_1^3}{D_2^3}$$

$$\text{or } \frac{D_1}{D_2} = \frac{Q_1}{Q_2} = \left(\frac{H_1}{H_2}\right)^{1/2} = \left(\frac{BHP_1}{BHP_2}\right)^{1/3}$$

where
D = Impeller diameter, in. (m)

Equation 1-22, Pump efficiency The efficiency of a pump is represented by the following equation:

Equation 1-22

$$Ep = \frac{WH}{BHP}$$

where

Ep = Pump efficiency as a decimal equivalent

WHP = Water horsepower derived from:

$$WHP = \text{ft Hd} \times \frac{\text{gal}}{\text{min}} \times \frac{8.33\text{ lb}}{\text{gal}} \times \frac{\text{HP}}{33{,}000\text{ ft-lb/min}}$$

BHP = Brake horsepower input to pump

From Equation 1-22, the brake horsepower can be represented as:

Equation 1-22a

$$BHP = \frac{WHP}{Ep} \text{ or } \frac{\text{ft Hd} \times \text{gpm}}{3960 \times Ep}$$

Equation 1-23, Rational method of storm design Calculates the peak storm-water runoff.

Equation 1-23

$$Q = CIA$$

where

Q = Runoff, ft^3/s (m^3/s)

C = Runoff coefficient (surface roughness in drained area)

I = Rainfall intensity, in/h (mm/h)

A = Drainage area, acres (m^2)

Equation 1-24, Spitzglass Formula Used to size gas piping in systems operating at a pressure of less than 1 psi.

Equation 1-24

$$Q = 3550 \left(\frac{d^5}{1 + \frac{3.6}{d} + 0.03d}\right)^{1/2} \left(\frac{h}{SL}\right)^{1/2}$$

where

Q = Flow rate, ft^3/h (m^3/h)

d = Diameter of pipe, in. (mm)

h = Pressure drop over length, in. wc

S = Specific gravity

L = Length of pipe, ft (m)

Equation 1-25, Weymouth Formula Used to size gas piping in systems operating at a pressure in excess of 1 psi.

Equation 1-25

$$Q = 28.05 \left[\frac{(P_1^2 - P_2^2)\, d^{16/3}}{SL}\right]^{1/2}$$

where

Q = Flow rate, ft^3/h (m^3/h)

P_1 = Initial gas pressure, psi

P_2 = Final gas pressure, psi

d = Diameter of pipe, in. (mm)

S = Specific gravity

L = Length of pipe, mi (km)

Equation 1-26, Slope The slope of a pipe is representted by the following formula:

$$s = \frac{h}{l}$$

$$h = l \times s$$

$$l = \frac{h}{s}$$

where

s = Slope, in./ft (mm/m)

h = Fall, in. (m)

l = Length, ft (m)

Equation 1-27, Discharge from Rectangular Weir with end contractions:

$$Q = 1494.6\,(L\text{-}0.2H)H^{1.5}$$

where

Q = Rate of flow, ft^3/s (m^3/s)

L = Length of weir opening, ft (Should be longer than 2H)

H = Head of water, ft (m)

a = Should be at least 3H (Refer to Volume 2 Chapter 4 Storm-Drainage Systems (Table 4-5) of "Plumbing Engineering Design Handbook" for diagram.)

Equation 1-28, Heat Loss Formula:

$$q = \frac{T_p - T_a}{\frac{1}{\pi D_1 h_i} + \frac{\ln\left(\frac{D_2}{D_1}\right)}{2\pi k} + \frac{1}{\pi D_2 h_{co}} + \frac{1}{\pi D_2 h_o}}$$

where

q = Heat loss per unit length of pipe, BTU/h × ft (W/m)

T_p = Maintenance temperautre desired, °F (°C)

T_a = Design ambient temperature, °F (°C)

D_1 = Inside diameter of the insulation, ft (m)

h_i = Inside air-contact coefficient from pipe to inside insulation surface, BTU/h × ft^2 × °F (W/m^2 × °C)

D_2 = Outside diameter of the insulation, ft (m)

k = Thermal conductivity of the insulation evaluated at its mean temperature, BTU/h × ft × °F (W/m^2 × °C)

h_{co} = Inside air contact coefficient of weather barrier, BTU/h × ft^2 × °F (W/m^2 × °C)

h_o = Outside air film coefficient from weather barrier to ambient, BTU/h × ft^2 × °F (W/m^2 × °C)

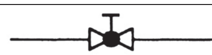
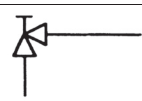
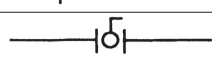
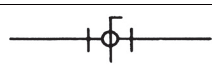
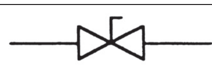
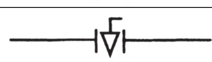
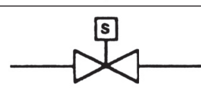
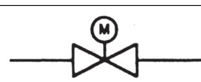
SYMBOLS

The standardized plumbing and piping-related symbols in Tables 1-1 and 1-2 and the abbreviations in Table 1-3 have been tabulated by the American Society of Plumbing Engineers for use in the design and preparation of drawings. Users of these symbols are cautioned that some governmental agencies, industry groups, and other clients may have a list of symbols that are required for their projects. All symbols should be applied with a consideration for drafting and clarity if drawings are to be reduced.

Table 1-1 Standard Plumbing and Piping Symbols

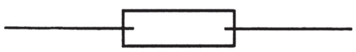
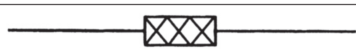
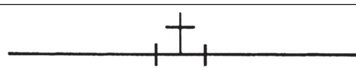
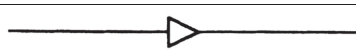
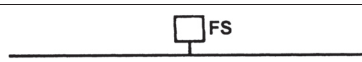
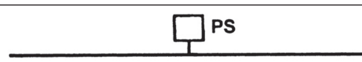
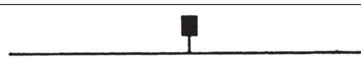
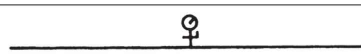
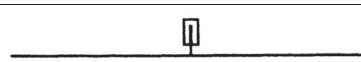
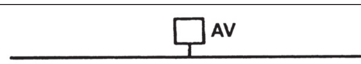
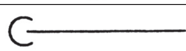
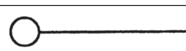
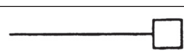
Symbol	Description	Abbreviation
——— SD ———	Storm drain, rainwater drain	SD, ST
—— —— SSD ——	Subsoil drain, footing drain	SSD
——— SS ———	Soil, waste, or sanitary sewer	S, W, SAN, SS
— — — — — — — — — —	Vent	V
——— AW ———	Acid waste	AW
— — — — AV — — — — —	Acid vent	AV
——— D ———	Indirect drain	D
——— PD ———	Pump discharge line	PD
——— – ———	Cold water	CW
——— – – ———	Hot water supply (140°F)[a]	HW
——— – – – ———	Hot water recirculating (140°F)[a]	HWR
——— TW ———	Tempered water (temp. °F)[b]	TEMP. HW, TW
——— TWR ———	Tempered water recirculating (temp. °F)[b]	TEMP. HWR, TWR
——— DWS ———	(Chilled) drinking water supply	DWS
——— DWR ———	(Chilled) drinking water recirculating	DWR
——— SCW ———	Soft cold water	SCW
——— CD ———	Condensate drain	CD
——— DI ———	Distilled water	DI
——— DE ———	Deionized water	DE
——— RO ———	Reverse osmosis water	RO
——— CWS ———	Chilled water supply	CWS
——— CWR ———	Chilled water return	CWR
——— LS ———	Lawn sprinkler supply	LS
——— F ———	Fire protection water supply	F
——— G ———	Gas–low-pressure	G
——— MG ———	Gas–medium-pressure	MG
——— HG ———	Gas–high-pressure	HG
— — — — GV — — — — —	Gas vent	GV
——— FOS ———	Fuel oil supply	FOS
——— FOR ———	Fuel oil return	FOR
— — — — FOV — — — — —	Fuel oil vent	FOV
——— LO ———	Lubricating oil	LO
— — — — LOV — — — — —	Lubricating oil vent	LOV
——— WO ———	Waste oil	WO
— — — — WOV — — — —	Waste oil vent	WOV
——— O_2 ———	Oxygen	O_2
——— LO_2 ———	Liquid oxygen	LO_2
——— A ———	Compressed air[c]	A
——— X#A ———	Compressed air–X#[c]	X#A
——— MA ———	Medical compressed air	MA
——— LA ———	Laboratory compressed air	LA
——— HPCA ———	High pressure compressed air	HPCA

(CONTINUED)

Table 1-1 Standard Plumbing and Piping Symbols (continued)		
Symbol	**Description**	**Abbreviation**
—— HHWS ——	(Heating) hot water supply	HHWS
—— HHWR ——	(Heating) hot water return	HHWR
—— V ——	Vacuum	VAC
—— NPCW ——	Non-potable cold water	NPCW
—— NPHW ——	Non-potable hot water	NPHW
—— NPHWR ——	Non-potable hot water return	NPHWR
—— MV ——	Medical vacuum	MV
—— SV ——	Surgical vacuum	SV
—— LV ——	Laboratory vacuum	LV
—— N_2 ——	Nitrogen	N_2
—— N_2O ——	Nitrous oxide	N_2O
—— CO_2 ——	Carbon dioxide	CO_2
—— WVC ——	Wet vacuum cleaning	WVC
—— DVC ——	Dry vacuum cleaning	DVC
—— LPS ——	Low-pressure steam supply	LPS
— — — — LPC — — — —	Low-pressure condensate	LPC
—— MPS ——	Medium-pressure steam supply	MPS
— — — — MPC — — — —	Medium-pressure condensate	MPC
—— HPS ——	High-pressure steam supply	HPS
— — — — HPC — — — —	High-pressure condensate	HPC
— — — — ATV — — — —	Atmospheric vent (steam or hot vapor)	ATV
	Gate valve	GV
	Globe valve	GLV
	Angle valve	AV
	Ball valve	BV
	Butterfly valve	BFV
	Gas cock, gas stop	
	Balancing valve (specify type)	BLV
	Check valve	CV
	Plug valve	PV
	Solenoid valve	
	Motor-operated valve (specify type)	
	Pressure-reducing valve	PRV

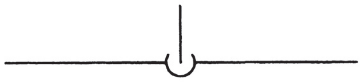
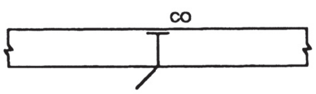
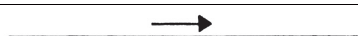
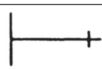
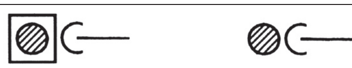
(CONTINUED)

Table 1-1 Standard Plumbing and Piping Symbols (continued)

Symbol	Description	Abbreviation
	Pressure-relief valve	RV
	Temperature-pressure-relief valve	TPV
	Backflow preventer	RZBP
	Hose bibb	HB
	Recessed-box hose bibb or wall hydrant	WH
	Valve in yard box (valve type symbol as required for valve use)	YB
	Union (screwed)	
	Union (flanged)	
	Strainer (specify type)	
	Pipe anchor	PA
	Pipe guide	
	Expansion joint	EJ
	Flexible connector	FC
	Tee	
	Concentric reducer	
	Eccentric reducer	
	Aquastat	
	Flow switch	FS
	Pressure switch	PS
	Water hammer arrester	WHA
	Pressure gauge with gauge cock	PG
	Thermometer (specify type)	
	Automatic air vent	AAV
	Valve in riser (type as specified or noted)	
	Riser down (elbow)	
	Riser up (elbow)	
	Air chamber	AC

(CONTINUED)

Table 1-1 Standard Plumbing and Piping Symbols (continued)

Symbol	Description	Abbreviation
	Rise or drop	
	Branch–top connection	
	Branch–bottom connection	
	Branch–side connection	
	Cap on end of pipe	
	Cleanout plug	CO
	Floor cleanout	FCO
	Wall cleanout	WCO
	Yard cleanout or cleanout to grade	CO
	Drain (all types) (specify)	D
	Pitch down or up–in direction of arrow	
	Flow–in direction of arrow	
	Point of connection	POC
	Outlet (specify type)	
	Steam trap (all types)	
	Floor drain with p-trap	FD

a Hot water (140°F) and hot water return (140°F). Use for normal hot water distribution system, usually but not necessarily (140°F). Change temperature designation if required.
b Hot water (temp. °F) and hot water return (temp. °F). Use for any domestic hot water system (e.g., tempered or sanitizing) required in addition to the normal system (see note "a" above). Insert system supply temperature where "temp." is indicated.
c Compressed air and compressed air X#. Use pressure designations (X#) when compressed air is to be distributed at more than one pressure.

Table 1-2 Standard Fire-Protection Piping Symbols

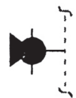
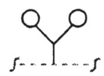
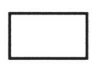
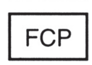
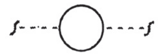
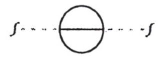
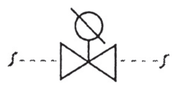
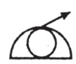
Referent (Synonym)	Symbol	Comments
Water supply and distribution symbols		
Mains, pipe		
Riser		
Hydrants		
Public hydrant, two hose outlets		Indicate size,[a] type of thread, or connection.
Public hydrant, two hose outlets, and pumper connection		Indicate size,[a] type of thread, or connection.
Wall hydrant, two hose outlets		Indicate size,[a] type of thread, or connection.
Fire department connections		
Siamese fire department connection		Specify type, size, and angle.
Free-standing siamese ire department connection		Sidewalk or pit type, specify size.
Fire pumps		
Fire pump		Free-standing. Specify number and sizes of outlets.
Test header		Wall
Symbols for control panels		
Control panel		Basic shape
(a)		Fire alarm control panel
Symbols for fire extinguishing system		
Symbols for various types of extinguishing systems[b]		
Supplementary symbols		
Fully sprinklered space		
Partially sprinklered space		
Nonsprinklered space		

Table 1-2 Standard Fire-Protection Piping Symbols (continued)

Referent (Synonym)	Symbol	Comments
Symbols for fire sprinkler heads		
Upright sprinkler[c]		
Pendent sprinkler[c, d]		
Upright sprinkler, nippled up		
Pendent sprinkler, on drop nipple[c, d]		
Sidewall sprinkler[c]		
Symbols for piping, valves, control devices, and hangers[e]		
Pipe hanger		This symbol is a diagonal stroke imposed on the pipe that it supports.
Alarm check valve		Specify size, direction of flow.
Dry pipe valve		Specify size.
Deluge valve		Specify size and type.
Preaction valve		Specify size and type.
Symbols for portable fire extinguishers		
Portable fire extinguisher		Portable fire extinguisher
Symbols for firefighting equipment		
Hose station, dry standpipe		
Hose station, changed standpipe		

Source: National Fire Protection Association (NFPA), Standard 170.

[a] Symbol element can be utilized in any combination to fit the type of hydrant.

[b] These symbols are intended for use in identifying the type of system installed to protect an area within a building.

[c] Temperature rating of sprinkler and other characteristics can be shown via legends where a limited number of an individual type of sprinkler is called for by the design.

[d] Can notate "DP" on drawing and/or in specifications where dry pendent sprinklers are employed.

[e] See also NFPA Standard 170, Section 5-4, for related symbols.

Table 1-3 Abbreviations for Text, Drawings, and Computer Programs

Term	Text	Drawings	Program
Above finished floor	–	AFF	–
Absolute	abs	ABS	ABS
Accumulat(-e, -or)	acc	ACCUM	ACCUM
Air condition(-ing, -ed)	–	AIR COND	–
Air-conditioning unit(s)	–	ACU	ACU
Air-handling unit	–	AHU	AHU
Air horsepower	ahp	AHP	AHP
Alteration	altrn	ALTRN	–
Alternating current	ac	AC	AC
Altitude	alt	ALT	ALT
Ambient	amb	AMB	AMB
American National Standards Institute[a]	ANSI	ANSI	–
American wire gage	AWG	AWG	–
Ampere (amp, amps)	amp	AMP	AMP, AMPS
Angle	–	–	ANG
Angle of incidence	–	–	ANGI
Apparatus dew point	adp	ADP	ADP
Approximate	approx.	APPROX	–
Area	–	–	A
Atmosphere	atm	ATM	–
Average	avg	AVG	AVG
Azimuth	az	AZ	AZ
Azimuth, solar	–	–	SAZ
Azimuth, wall	–	–	WAZ
Baromet(-er, -ric)	baro	BARO	–
Bill of material	b/m	BOM	–
Boiling point	bp	BP	BP
Brake horsepower	bhp	BHP	BHP
Brown & Sharpe wire gage	B&S	B&S	–
British thermal unit	Btu	BTU	BTU
Celsius	°C	°C	°C
Center to center	c to c	C TO C	–
Circuit	ckt	CKT	CKT
Clockwise	cw	CW	–
Coefficient	coeff.	COEF	COEF
Coefficient, valve flow	C_v	$\mathrm{C_v}$	CV
Coil	–	–	COIL
Compressor	cprsr	CMPR	CMPR
Condens(-er, -ing, -ation)	cond	COND	COND
Conductance	–	–	C
Conductivity	cndct	CNDCT	K
Conductors, number of (3)	3/c	3/c	–
Contact factor	–	–	CF
Cooling load	clg load	CLG LOAD	CLOAD
Counterclockwise	ccw	CCW	–
Cubic feet	ft^3	CU FT	CUFT, CFT
Cubic inch	in^3	CU IN	CUIN, CIN
Cubic feet per minute	cfm	CFM	CFM
cfm, standard conditions	scfm	SCFM	SCFM
			(CONTINUED)

Term	Text	Drawings	Program
Cubic ft per sec, standard	scfs	SCFS	SCFS
Decibel	dB	DB	DB
Degree	deg. or °	DEG or °	DEG
Density	dens	DENS	RHO
Depth or deep	dp	DP	DPTH
Dew-point temperature	dpt	DPT	DPT
Diameter	dia.	DIA	DIA
Diameter, inside	ID	ID	ID
Diameter, outside	OD	OD	OD
Difference or delta	diff., Δ	DIFF	D, DELTA
Diffuse radiation	–	–	DFRAD
Direct current	dc	DC	DC
Direct radiation	dir radn	DIR RADN	DIRAD
Dry	–	–	DRY
Dry-bulb temperature	dbt	DBT	DB, DBT
Effectiveness	–	–	EFT
Effective temperature[b]	ET*	ET*	ET
Efficiency	eff	EFF	EFF
Efficiency, fin	–	–	FEFF
Efficiency, surface	–	–	SEFF
Electromotive force	emf	EMF	–
Elevation	elev.	EL	ELEV
Entering	entr	ENT	ENT
Entering air temperature	EAT	EAT	EAT
Entering water temperature	EWT	EWT	EWT
Enthalpy	–	–	H
Entropy	–	–	S
Equivalent direct radiation	edr	EDR	–
Equivalent feet	eqiv ft	EQIV FT	EQFT
Equivalent inches	eqiv in	EQIV IN	EQIN
Evaporat(-e, -ing, -ed, -or)	evap	EVAP	EVAP
Expansion	exp	EXP	XPAN
Face area	fa	FA	FA
Face to face	f to f	F to F	–
Face velocity	fvel	FVEL	FV
Factor, correction	–	–	CFAC, CFACT
Factor, friction	–	–	FFACT, FF
Fahrenheit	°F	°F	F
Fan	–	–	FAN
Feet per minute	fpm	FPM	FPM
Feet per second	fps	FPS	FPS
Film coefficient, inside[c]	–	–	FI, HI
Film coefficient, outside[c]	–	–	FO, HO
Flow rate, air	–	–	QAR, QAIR
Flow rate, fluid	–	–	QFL
Flow rate, gas	–	–	QGA, QGAS
Foot or feet	ft	FT	FT
Foot-pound	ft-lb	FT LB	–
Freezing point	fp	FP	FP
			(CONTINUED)

Table 1-3 Abbreviations for Text, Drawings, and Computer Programs (con't)

Term	Text	Drawings	Program
Frequency	Hz	HZ	–
Gage or gauge	ga	GA	GA, GAGE
Gallons	gal	GAL	GAL
Gallons per hour	gph	GPH	GPH
gph, standard	std gph	SGPH	SGPH
Gallons per day	gpd	GPD	GPD
Grains	gr	GR	GR
Gravitational constant	*g*	G	G
Greatest temperature difference	GTD	GTD	GTD
Head	hd	HD	HD
Heat	–	–	HT
Heater	–	–	HTR
Heat gain	HG	HG	HG, HEATG
Heat gain, latent	LHG	LHG	HGL
Heat gain, sensible	SHG	SHG	HGS
Heat loss	–	–	HL, HEATL
Heat transfer	–	–	Q
Heat transfer coefficient	*U*	U	U
Height	hgt	HGT	HGT, HT
High-pressure steam	hps	HPS	HPS
High-temperature hot water	hthw	HTHW	HTHW
Horsepower	hp	HP	HP
Hour(s)	h	HR	HR
Humidity ratio	W	W	W
Humidity, relative	rh	RH	RH
Incident angle	–	–	INANG
Indicated horsepower	ihp	IHP	–
International Pipe Std.	IPS	IPS	–
Iron pipe size	ips	IPS	–
Kelvin	K	K	K
Kilowatt	kW	kW	KW
Kilowatt hour	kWh	KWH	KWH
Latent heat	LH	LH	LH, LHEAT
Least mean temp. difference[d]	LMTD	LMTD	LMTD
Least temperature difference[d]	LTD	LTD	LTD
Leaving air temperature	lat	LAT	LAT
Leaving water temperature	lwt	LWT	LWT
Length	lg	LG	LG, L
Linear feet	lin ft	LF	LF
Liquid	liq	LIQ	LIQ
Logarithm (natural)	ln	LN	LN
Logarithm to base 10	log	LOG	LOG
Low-pressure steam	lps	LPS	LPS
Low-temperature hot water	lthw	LTHW	LTHW
Mach number	Mach	MACH	–
Mass flow rate	mfr	MFR	MFR
Maximum	max.	MAX	MAX
Mean effective temperature	MET	MET	MET
Mean temp. difference	MTD	MTD	MTD

(CONTINUED)

Term	Text	Drawings	Program
Medium-pressure steam	mps	MPS	MPS
Medium-temperature hot water	mthw	MTHW	MTHW
Mercury	Hg	HG	HG
Miles per hour	mph	MPH	MPH
Minimum	min.	MIN	MIN
Noise criteria	NC	NC	–
Normally closed	n c	N C	–
Normally open	n o	N O	–
Not applicable	na	N/A	–
Not in contract	n i c	N I C	–
Not to scale	–	NTS	–
Number	no.	NO	N, NO
Number of circuits	–	–	NC
Number of tubes	–	–	NT
Ounce	oz	OZ	OZ
Outside air	oa	OA	OA
Parts per million	ppm	PPM	PPM
Percent	%	%	PCT
Phase (electrical)	ph	PH	–
Pipe	–	–	PIPE
Pounds	lb	LBS	LBS
Pounds per square foot	psf	PSF	PSF
psf absolute	psfa	PSFA	PSFA
psf gage	psfg	PSFG	PSFG
Pounds per square inch	psi	PSI	PSI
psi absolute	psia	PSIA	PSIA
psi gage	psig	PSIG	PSIG
Pressure	–	PRESS	PRES, P
Pressure, barometric	baro pr	BARO PR	BP
Pressure, critical	–	–	CRIP
Pressure drop or difference	PD	PD	PD, DELTP
Pressure, dynamic (velocity)	vp	VP	VP
Pressure, static	sp	SP	SP
Pressure, vapor	vap pr	VAP PR	VAP
Primary	pri	PRI	PRIM
Quart	qt	QT	QT
Radian	–	–	RAD
Radiat(-e, -or)	–	RAD	–
Radiation	–	RADN	RAD
Radius	–	–	R
Rankine	°R	°R	R
Receiver	rcvr	RCVR	REC
Recirculate	recirc.	RECIRC	RCIR, RECIR
Refrigerant (12, 22, etc.)	R-12, R-22	R12, R22	R12, R22
Relative humidity	rh	RH	RH
Resist(-ance, -ivity, -or)	res	RES	RES, OHMS
Return air	ra	RA	RA
Revolutions	rev	REV	REV
Revolutions per minute	rpm	RPM	RPM

(CONTINUED)

Table 1-3 Abbreviations for Text, Drawings, and Computer Programs (con't)

Term	Text	Drawings	Program
Revolutions per second	rps	RPS	RPS
Roughness	rgh	RGH	RGH, E
Safety factor	sf	SF	SF
Saturation	sat.	SAT	SAT
Saybolt seconds Furol	ssf	SSF	SSF
Saybolt seconds Universal	ssu	SSU	SSU
Sea level	sl	SL	SE
Second	s	s	SEC
Sensible heat	SH	SH	SH
Sensible heat gain	SHG	SHG	SHG
Sensible heat ratio	SHR	SHR	SHR
Shading coefficient	–	–	SC
Shaft horsepower	sft hp	SFT HP	SHP
Solar	–	–	SOL
Specification	spec	SPEC	–
Specific gravity	SG	SG	–
Specific heat	sp ht	SP HT	C
sp ht at constant pressure	c_p	c_p	CP
sp ht at constant volume	c_v	c_v	CV
Specific volume	sp vol	SP VOL	V, CVOL
Square	sq.	SQ	SQ
Standard	std	STD	STD
Standard time meridian	–	–	STM
Static pressure	SP	SP	SP
Suction	suct.	SUCT	SUCT, SUC
Summ(-er, -ary, -ation)	–	–	SUM
Supply	sply	SPLY	SUP, SPLY
Supply air	sa	SA	SA
Surface	–	–	SUR, S
Surface, dry	–	–	SURD
Surface, wet	–	–	SURW
System	–	–	SYS
Tabulat(-e, -ion)	tab	TAB	TAB
Tee	–	–	TEE
Temperature	temp.	TEMP	T, TEMP
Temperature difference	TD, Δt	TD	TD, TDIF
Temperature entering	TE	TE	TE, TENT
Temperature leaving	TL	TL	TL, TLEA
Thermal conductivity	k	K	K
Thermal expansion coeff.	–	–	TXPC
Thermal resistance	R	R	RES, R
Thermocouple	tc	TC	TC, TCPL
Thermostat	T STAT	T STAT	T STAT
Thick(-ness)	thkns	THKNS	THK
Thousand circular mils	Mcm	MCM	MCM
Thousand cubic feet	Mcf	MCF	MCF
Thousand foot-pounds	kip ft	KIP FT	KIPFT
Thousand pounds	kip	KIP	KIP
Time	–	T	T
			(CONTINUED)
Ton	–	–	TON
Tons of refrigeration	tons	TONS	TONS
Total	–	–	TOT
Total heat	tot ht	TOT HT	–
Transmissivity	–	–	TAU
U-factor	–	–	U
Unit	–	–	UNIT
Vacuum	vac	VAC	VAC
Valve	v	V	VLV
Vapor proof	vap prf	VAP PRF	–
Variable	var	VAR	VAR
Variable air volume	VAV	VAV	VAV
Velocity	vel.	VEL	VEL, V
Velocity, wind	w vel.	W VEL	W VEL
Ventilation, vent	vent	VENT	VENT
Vertical	vert.	VERT	VERT
Viscosity	visc	VISC	MU, VISC
Volt	V	V	E, VOLTS
Volt ampere	VA	VA	VA
Volume	vol.	VOL	VOL
Volumetric flow rate	–	–	VFR
Wall	–	–	W, WAL
Water	–	–	WTR
Watt	W	W	WAT, W
Watt-hour	Wh	WH	WHR
Weight	wt	WT	WT
Wet bulb	wb	WB	WB
Wet-bulb temperature	wbt	WBT	WBT
Width	–	–	WI
Wind	–	–	WD
Wind direction	wdir	WDIR	WDIR
Wind pressure	wpr	WPR	WP, WPRES
Yard	yd	YD	YD
Year	yr	YR	YR
Zone	z	Z	Z, ZN

Source: ASHRAE, 1997, *Handbook of fundamentals.*
[a]Abbreviations of most proper names use capital letters in both text and drawings.
[b]The asterisk (*) is used with "ET," effective temperature.
[c]These are surface heat transfer coefficients.
[d]The letter "L" is also used for "logarithm of" these temperature differences in computer programming.

PLUMBING TERMINOLOGY[4]

The following list of definitions and abbreviations that are frequently used in the plumbing industry has been compiled by the American Society of Plumbing Engineers for use by those working in this and related fields.

ABS Abbreviation for “acrylonitrile-butadiene-styrene.”

Absolute pressure The total pressure measured from absolute vacuum. It equals the sum of gauge pressure and atmospheric pressure corresponding to the barometer, and is expressed in pounds per square inch (kiloPascals).

Absolute temperature Temperature measured from absolute zero. A point of temperature theoretically equal to -459.72°F (-273.18°C). The hypothetical point at which a substance would have no molecular motion and no heat.

Absolute zero Zero point on the absolute temperature scale. A point at which there is a total absence of heat, equivalent to -459.72°F (-273.18°C).

Absorption Immersion in a fluid for a definite period of time, usually expressed as a percent of the weight of the dry pipe.

Access door Hinged panel mounted in a frame with a lock, normally in a wall or ceiling, to provide access to concealed valves or equipment that require frequent attention.

Accessible 1. a) (When applied to a fixture, connection, appliance, or piece of equipment) Having access thereto, though access may necessitate the removal of an access panel, door, or similar obstruction; b) (readily accessible) having direct access to without the necessity of removing or moving any panel, door, or similar obstruction. 2. (re: the physically challenged) Term used to describe a site, building, facility, or portion thereof, or a plumbing fixture that can be approached, entered, and/or used by physically challenged individuals.

Accumulator A container in which fluid or gas is stored under pressure as a source of power.

Acid vent A pipe venting an acid-waste system.

Acid waste A pipe that conveys liquid waste matter containing a pH of less than 7.0.

Acme thread A screw thread, the thread section of which is between the square and V threads, used extensively for feed screws. The included angle of space is 29°, compared to 60° of the National Coarse of U.S. Thread.

Acrylonitrile-butadiene-styrene A thermoplastic compound from which fittings, pipe, and tubing are made.

Active sludge Sewage sediment, rich in destructive bacteria, that can be used to break down fresh sewage more quickly.

Adapter fitting 1. Any of various fittings designed to mate, or fit to each other, two pipes or fittings that are different in design, when the connection would otherwise be impossible. 2. A fitting that serves to connect two different tubes or pipes to each other, such as copper tube to iron pipe.

Administrative authority The individual official, board, department, or agency established and authorized by a state, county, city, or other political subdivision created by law to administer and enforce the provisions of the plumbing code. *Also known as* AUTHORITY HAVING JURISDICTION.

Aeration An artificial method of bringing water and air into direct contact with each other. One purpose is to release certain dissolved gases that often cause water to have obnoxious odors or disagreeable tastes. Also used to furnish oxygen to waters that are oxygen deficient. The process may be accomplished by spraying the liquid in the air, bubbling air through the liquid, or agitating the liquid to promote surface absorption of the air.

Aerobic (re: bacteria) Living or active only in the presence of free oxygen.

AGA Abbreviation for American Gas Association.

Air break A physical separation in which a drain from a fixture, appliance, or device indirectly discharges into a fixture, receptacle, or interceptor at a point below the flood level rim of the receptacle to prevent backflow or back-siphonage. *Also known as* AIR GAP.

Air chamber A continuation of the water piping beyond the branch to fixtures that are finished with a cap designed to eliminate shock or vibration (water hammer) of the piping when the faucet is closed suddenly.

Air, compressed Air at any pressure greater than atmospheric pressure.

Air, free Air that is not contained and subject only to atmospheric conditions.

Air gap The unobstructed vertical distance, through the free atmosphere, between the lowest opening from a pipe or faucet conveying water or waste to a tank, plumbing-fixture receptor, or other device and the flood-level rim of the receptacle. (Usually required to be a minimum of twice the diameter of the inlet.)

Air, standard Air having a temperature of 70°F (21.1°C) at standard density of 0.0075 lb/ft (0.11 kg/m) and under pressure of 14.70 psia (101.4 kPa).

The gas industry usually considers 60°F (15.6°C) the temperature of standard air.

Air test A test using compressed air or nitrogen applied to a plumbing system upon its completion but before the building is sheetrocked.

Alarm (FP) 1. Any audible or visible signal indicating existence of a fire or emergency requiring evacuation of occupants and response and emergency action on the part of the firefighting service. 2. The alarm device(s) by which fire and emergency signals are received.

Alarm check valve (FP) A check valve, equipped with a signaling device, that will annunciate a remote alarm when a sprinkler head(s) is discharging.

Alloy A substance composed of two or more metals or a metal and nonmetal intimately united, usually fused together and dissolving in each other when molten.

Alloy pipe A steel pipe with one or more elements, other than carbon, that give it greater resistance to corrosion and more strength than carbon steel pipe.

Ambient temperature The prevailing temperature in the immediate vicinity of or the temperature of the medium surrounding an object.

American standard pipe thread A type of screw thread commonly used on pipe and fittings.

Anaerobic (re: bacteria) Living or active in the absence of free oxygen.

Anchor A device used to fasten or secure pipes to the building or structure.

Angle of bend In a pipe, the angle between radial lines from the beginning and end of the bend to the center.

Angle stop Common term for right-angle valves used to control water supplies to plumbing fixtures.

Angle valve A device, usually of the globe type, in which the inlet and outlet are at right angles.

ANSI Abbreviation for American National Standards Institute.

Approved Accepted or acceptable under an applicable specification or standard stated or cited for the proposed use under the procedures and authority of the administrative authority.

Approved testing agency An organization established for purposes of testing to approved standards and acceptable to the administrative authority.

Area drain A receptacle designed to collect surface or rainwater from a determined or calculated open area.

Arterial vent A vent serving the building drain and the public sewer.

ASHRAE Abbreviation for American Society of Heating, Refrigerating and Air Conditioning Engineers.

ASME Abbreviation for American Society of Mechanical Engineers.

ASPE Abbreviation for American Society of Plumbing Engineers.

ASPERF Abbreviation for American Society of Plumbing Engineers Research Foundation.

Aspirator A fitting or device supplied with water or other fluid under positive pressure that passes through an integral orifice or "constriction," causing a vacuum.

ASSE Abbreviation for American Society of Sanitary Engineering or American Society of Safety Engineers.

ASTM Abbreviation for American Society for Testing and Materials.

Atmospheric vacuum breaker A mechanical device consisting of a check valve that opens to the atmosphere when the pressure in the piping drops to atmospheric.

Authority having jurisdiction (FP) The organization, office, or individual responsible for approving equipment, materials, installation, or procedure.

AWWA Abbreviation for American Water Works Association.

Backfill Material used to cover piping laid in an earthen trench.

Backflow The flow of water or other liquids, mixtures, or substances from any source(s) other than the one(s) intended into the distributing pipes of a potable supply of water. *See* BACK-SIPHONAGE.

Backflow connection A connection in any arrangement whereby backflow can occur.

Backflow preventer A device or means to prevent backflow into the potable water system.

Backing ring A metal strip used to prevent melted metal, from the welding process, from entering a pipe in the process of making a butt-welded joint.

Back-siphonage The flowing back of used, contaminated, or polluted water from a plumbing fixture or vessel into the potable water supply pipe due to a negative pressure in the pipe. *See* BACKFLOW.

Backup A condition where the waste water may flow back into another fixture or compartment but not backflow into the potable water system.

Backwater valve A device that permits drainage in one direction but has a check valve that closes against back pressure. Sometimes used conjunctively with gate valves designed for sewage.

Baffle plate A tray or partition placed in process equipment or tanks to direct or change the direction of flow.

Ball check valve A device used to stop the flow of media in one direction while allowing flow in an opposite direction. The closure member used is spherical or ball-shaped.

Ball valve A spherical gate valve providing very tight shut-off; a quick-closing (quarter-turn) valve.

Barrier free *See* ACCESSIBLE, def. 2.

Base The lowest portion or lowest point of a stack of vertical pipe.

Battery of fixtures Any group of two or more similar, adjacent fixtures that discharge into a common horizontal waste or soil branch.

Bell That portion of a pipe that, for a short distance, is sufficiently enlarged to receive the end of another pipe of the same diameter for the purpose of making a joint.

Bell-and-spigot joint A commonly used joint in cast-iron soil pipe. Each piece is made with an enlarged diameter or bell at one end into which the plain or spigot end of another piece is inserted. The joint is then made tight by cement, oakum, lead, or rubber caulked into the bell around the spigot. *See also* HUB-AND-SPIGOT.

Black pipe Steel pipe that has not been galvanized.

Blank flange A solid plate flange used to seal off flow in a pipe.

Boiler blow-off An outlet on a boiler to permit emptying or discharge of sediment.

Boiler blow-off tank A vessel designed to receive the discharge from a boiler blow-off outlet and cool the discharge to a temperature that permits its safe discharge to the drainage system.

Bonnet That part of a valve that connects the valve actuator to the valve body; in some valves, it may also contain the stem packing.

Branch Any part of a piping system other than a main, riser, or stack.

Branch interval A length of soil or waste stack corresponding, in general, to a story height, but in no case less than 8 feet (2.4 m), within which the horizontal branches from one floor or story of a building are connected to the stack.

Branch tee A tee having one side branch.

Branch vent A vent connecting one or more individual vents with a vent stack or stack vent.

Brazing ends The ends of a valve or fitting that are prepared for silver brazing.

Bronze trim or bronze-mounted An indication that certain internal (water contact) parts of the valves known as trim materials (stem, disc, seat rings, etc.) are made of copper alloy.

Btu Abbreviation for “British thermal unit.” The amount of heat required to raise the temperature of 1 pound (0.45 kg) of water 1 degree Fahrenheit (0.565°C).

Btu/h Abbreviation for “British thermal units per hour.”

Bubble tight The condition of a valve seat that prohibits the leakage of visible bubbles when the valve is closed.

Building (house) A structure built, erected, and framed of component structural parts designed for the housing, shelter, enclosure, or support of persons, animals, or property of any kind.

Building (house) drain That part of the lowest piping of a drainage system that receives the discharge from soil, waste, and other drainage pipes inside the walls of the building (house) and conveys it to the building (house) sewer, which begins outside the building (house) walls.

Building (house) drain, combined A building (house) drain that conveys both sewage and storm water or other drainage.

Building (house) drain, sanitary A building (house) drain that conveys only sewage.

Building (house) drain, storm A building (house) drain that conveys storm water or other drainage but no sewage.

Building (house) sewer That part of the horizontal piping of a drainage system that extends from the end of the building (house) drain and receives the discharge from the building (house) drain and conveys it to a public sewer, private sewer, individual sewage-disposal system, or other approved point of disposal.

Building (house) subdrain That portion of a drainage system below the building (house) sewer that cannot drain by gravity in the building (house) sewer.

Building (house) trap A device, fitting, or assembly of fittings installed in the building (house) drain to prevent circulation of air between the drainage of the building (house) and the building (house) sewer. It is usually installed as a running trap.

Bull head tee A tee in which the branch is larger than the run.

Burst pressure That pressure that can slowly be applied to a valve at room temperature for 30 seconds without causing rupture.

Bushing A pipe fitting for connecting a pipe with a female fitting of a larger size. It is a hollow plug with internal and external threads. Used in lieu of a reducer/increaser.

Butterfly valve A device deriving its name from the wing-like action of the disc, which operates at right angles to the flow. The disc impinges against the resilient liner with low-operating torque.

Butt weld joint A welded pipe joint made with the ends of the two pipes butting each other, the weld being around the periphery.

Butt weld pipe Pipe welded along a seam butted edge to edge and not scarfed or lapped.

Bypass An auxiliary loop in a pipeline intended for diverting flow around a valve or other piece of equipment.

Bypass valve A device used to divert the flow past the part of the system through which it normally passes.

Capacity 1. The maximum or minimum flow obtainable under given conditions of media, temperature, pressure, velocity, etc. 2. The volume of media that may be stored in a container or receptacle.

Capillary The action by which the surface of a liquid, where it is in contact with a solid, is elevated or depressed, depending on the relative attraction of the molecules of the liquid for each other and for those of the solid.

Cathodic protection 1. The control of the electrolytic corrosion of an underground or underwater metallic structure by the application of an electric current in such a way that the structure is made to act as the cathode instead of the anode of an electrolytic cell. 2. The use of materials and liquid to cause electricity to flow to avoid corrosion.

Caulking The method of rendering a joint tight against water or gas by means of applying plastic substances such as lead and oakum; a method of sealing between fixtures and adjacent surfaces.

Cavitation A localized gaseous condition (usually involving air) that is found within a liquid stream.

CDA Abbreviation for Copper Development Association.

Cement joint The union of two fittings by the insertion of material. Sometimes this joint is accomplished mechanically, sometimes chemically.

Cesspool A lined excavation in the ground that receives the discharge of a drainage system, or part thereof, and is so designed to retain the organic matter and solids discharged therein but permit the liquids to seep through the bottom and sides.

Chainwheel-operated valve A device operated by a chain-driven wheel that opens and closes the valve seats. Usually required for larger valves.

Channel That trough through which any media may flow.

Chase A recess in a wall or a space between two walls in which pipes can be run.

Check valve A device designed to allow a fluid to pass through in one direction only.

Chemical waste system Piping that conveys corrosive or harmful industrial, chemical, or processed wastes to the drainage system.

Circuit The directed route taken by a flow of media from one point to another.

Circuit vent A branch vent that serves two or more traps and extends from in front of the last fixture connection of a horizontal branch to the vent stack.

CISPI Abbreviation for Cast Iron Soil Pipe Institute.

Clamp gate valve A gate valve whose body and bonnet are held together by a U-bolt clamp.

Cleanout A plug or cover (joined to an opening in a pipe) that can be removed for the purpose of cleaning or examining the interior of the pipe.

Clear-water waste Cooling water and condensate drainage from refrigeration and air-conditioning equipment; cooled condensate from steam-heating systems; cooled boiler blowdown water; waste-water drainage from equipment rooms and other areas where water is used without an appreciable addition of oil, gasoline, solvent, acid, etc.; and treated effluent in which impurities have been reduced below a minimum concentration considered harmful.

Close nipple A nipple with a length twice the length of a standard pipe thread.

Cock An original form of valve having a hole in a tapered plug that is rotated to provide passageway for fluid.

Code Those regulations, subsequent amendments thereto, and any emergency rule or regulation that the department having jurisdiction may lawfully adopt.

Coefficient of expansion The increase in unit length, area of volume for a 1-degree rise in temperature.

Coliform group of bacteria All organisms considered in the coli aerogenes group as set forth by the American Water Works Association.

Combination fixture A fixture that combines one sink and tray or a two- or three-compartment sink and/or tray in one unit.

Combined waste and vent system A specially designed system of waste piping, embodying the horizontal wet venting of one or more sinks, floor sinks, or floor drains by means of a common waste and vent pipe, adequately sized to provide free movement of air above the flow line of the drain.

Combustion efficiency The rated efficiency of a water heater or boiler determined by the equipment's ability to completely burn fuel, leaving no products of combustion in the flue gas.

Common vent A vent that connects at the junction of two fixture drains and serves as a vent for both fixtures. *Also known as a* DUAL VENT.

Companion flange A pipe flange to connect with another flange or with a flanged valve or fitting. It is attached to the pipe by threads, welding, or another method and differs from a flange that is an integral part of a pipe or fitting.

Compression joint A multi-piece joint with cup-shaped, threaded nuts that, when tightened, compress tapered sleeves so they form a tight joint on the periphery of the tubing they connect.

Compressor A mechanical device for increasing the pressure of air or gas.

Condensate Water that has liquefied (cooled) from steam.

Conductor The piping from the roof to the building storm drain, combined building sewer, or other approved means of disposal; it is located inside the building.

Conduit A pipe or channel for conveying media.

Confluent vent A vent serving more than one fixture vent or stack vent.

Contaminator A medium or condition that spoils the nature or quality of another medium.

Continuous vent A vent that is a continuation of the drain to which it connects.

Continuous waste A drain from two or three fixtures connected to a single trap.

Control A device used to regulate the function of a component or system.

Controller (FP) The cabinet containing motor starter(s), circuit breaker(s), disconnect switch(s), and other control devices for the control of electric motors and internal-combustion-engine-driven fire pumps.

Corporation cock A stopcock screwed into the street water main to supply the house service connection.

Coupling A pipe fitting with female threads used only to connect two pipes in a straight line.

CPVC Abbreviation for "chlorinated polyvinylchloride."

Critical level The point on a backflow-prevention device or vacuum breaker that determines the minimum elevation above the flood level rim of the fixture or receptacle served at which the device may be installed; the point conforms to approved standards and is established by the recognized (approved) testing laboratory (usually stamped or marked CL or C/L on the device by the manufacturer). When a backflow-prevention device does not bear critical-level marking, the bottom of the vacuum breaker or combination valve or the bottom of any such approved device shall constitute the critical level.

Cross A pipe fitting with four branches in pairs, each pair on one axis, and the axis at right angles.

Cross-connection Any physical connection or arrangement between two otherwise separated piping systems—one of which contains potable water and the other of which contains water or another substance of unknown or questionable safety—whereby flow may occur from one system to the other, the direction of flow depending on the pressure differential between the two systems. *See* BACKFLOW and BACK-SIPHONAGE.

Crossover A pipe fitting with a double offset, or shaped like the letter "U" with the ends turned out, used to pass the flow of one pipe past another when the pipes are in the same plane.

Cross valve A valve fitted on a transverse pipe so as to open communication between two parallel pipes.

Crown That part of a trap in which the direction of flow is changed from upward to horizontal.

Crown vent A vent pipe connected at the topmost point in the crown of a trap.

CS Abbreviation for Commercial Standards.

Curb box A device at the curb that contains a valve is used to shut off a supply line, usually of gas or water.

Dampen 1. To check or reduce. 2. To deaden vibration.

Dead end A branch leading from a soil, waste, or vent pipe; building (house) drain; or building (house) sewer that is terminated at a developed distance of 2 feet (0.6 m) or more by means of a plug or other closed fitting.

Department having jurisdiction The administrative authority—and any other law enforcement agency—affected by any provision of a code, whether such agency is specifically named or not.

Detector, smoke (FP) Listed device for sensing visible or invisible products of combustion.

Developed length The length along the center line of the pipe and fittings.

Dewpoint The temperature of a gas or liquid at which condensation or evaporation occurs.

Diameter Unless specifically stated otherwise, the nominal diameter as designated commercially.

Diaphragm A flexible disc that is used to separate the control medium from the controlled medium and actuates the valve stem.

Diaphragm-control valve A control valve having a spring-diaphragm actuator.

Dielectric fitting A fitting having insulating parts or material that prohibits the flow of electric current. Used to separate dissimilar metals.

Differential The variance between two target values, one of which is the high value of conditions, the other of which is the low value of conditions.

Digestion That portion of the sewage treatment process where biochemical decomposition of organic matter takes place, resulting in the formation of simple organic and mineral substances.

Disc That part of a valve that actually closes off the flow.

Dishwasher An appliance for washing dishes, glassware, flatware, and some utensils.

Displacement The volume or weight of a fluid, such as water, displaced by a floating body.

Disposer A motor-driven appliance for reducing food and other waste by grinding so that it can flow through the drainage system.

Domestic sewage The liquid and waterborne wastes derived from ordinary living processes that are free of industrial wastes and of such a character as to permit satisfactory disposal, without special treatment, into the public sewer or by means of a private sewage disposal system.

Dosing tank A watertight tank in a septic system placed between the septic tank and the distribution box and equipped with a pump or automatic siphon designed to discharge sewage intermittently to a disposal field. This is done so that rest periods may be provided between discharges.

Double disc A two-piece disc used in the gate valve. The wedges between the disc faces, upon contact with the seating faces in the valve, force them against the body seats to shut off the flow.

Double offset Two changes of direction installed in succession, or series, in continuous pipe.

Double-ported valve A valve having two ports to overcome line-pressure imbalance.

Double-sweep tee A tee made with easy (lon-radius) curves between body and branch.

Double wedge A device used in gate valves that is similar to a double disc, in that the last downward turn of the stem spreads the split wedges, and each seals independently.

Down Term referring to piping running through the floor to a lower level.

Downspout The rainleader from the roof to the building storm drain, combined building sewer, or other means of disposal; it is located outside of the building.

Downstream Term referring to a location in the direction of flow after passing a referenced point.

Drain Any pipe that carries waste water or waterborne wastes in a building drainage system.

Drain field The area of a piping system arranged in troughs for the purpose of disposing unwanted liquid waste.

Drainage fitting A type of fitting used for draining fluid from pipes. The fitting makes possible a smooth and continuous interior surface for the piping system.

Drainage system The drainage piping within public or private premises (usually to 5 feet outside building walls) that conveys sewage, rainwater, or other liquid wastes to an approved point of disposal but does not include the mains of a public sewer system or a private or public sewage-treatment or disposal plant.

Drift The sustained deviation in a corresponding controller resulting from the predetermined relation between values and the controlled variable and positions of the final control element. *Also known as* WANDER.

Droop The amount by which the controlled variable pressure, temperature, liquid level, or differential pressure deviates from the set value at minimum controllable flow to the rated capacity.

Drop Term referring to piping running to a lower elevation within the same floor level.

Drop elbow A small elbow having wings cast on each side, the wings having countersunk holes so they may be fastened by wood screws to a ceiling, wall, or framing timbers.

Drop tee A tee having wings of the same type as the drop elbow.

Dross 1. The solid scum that forms on the surface of a metal, as lead or antimony, when it is molten or melting, largely as a result of oxidation but sometimes because of the rising of dirt and impurities to the surface. 2. Waste or foreign matter mixed with a substance or left as a residue after that substance has been used or processed.

Dry-bulb temperature The temperature of air as measured by an ordinary thermometer.

Dry-pipe valve (FP) A valve used with a dry-pipe sprinkler system where water is on one side of the valve and air is on the other side. When a sprinkler head's fusible link melts, releasing air from the system, this valve opens, allowing water to flow to the sprinkler head.

Dry-weather flow Sewage collected during the summer that contains little or no ground water by infiltration and no storm water at the time of collection.

Dry well *See* LEACHING WELL.

Dual vent *See* COMMON VENT.

Durham system A term used to describe soil or waste systems where all piping is of threaded pipe, tubing or, other such material of rigid construction, and where recessed draining fittings corresponding to the type of piping are used.

Durion A high-silicon alloy that is resistant to practically all corrosive wastes. The silicon content is approximately 14.5 percent, and the acid resistance is in the entire thickness of the metal.

Dwelling A one-family unit with or without accessory buildings.

DWV Abbreviation for "drainage, waste, and vent." A name for copper or plastic tubing used for drain, waste, or venting pipe.

Eccentric fittings Fittings where the openings are offset, allowing liquid to flow freely.

Effective opening The minimum cross-sectional area at the point of water-supply discharge, measured or expressed in terms of the diameter of a circle or, if the opening is not circular, the diameter of a circle of equivalent cross-sectional area. (This is applicable to an AIR GAP.)

Effluent Sewage, treated or partially treated, flowing out of sewage-treatment equipment.

Elastic limit The greatest stress that a material can withstand without permanent deformation after the release of the stress.

Elbow (Ell) A fitting that makes an angle between adjacent pipes. The angle is 90°, unless another angle is specified.

Electrolysis The process of producing chemical changes by passage of an electric current through an electrolyte (as in a cell), the ions present carrying the current by migrating to the electrodes where they may form new substances (as in the deposition of metals or the liberation of gases).

Elutriation A process of sludge conditioning in which certain constituents are removed by successive decontaminations with fresh water or plant effluent, thereby reducing the demand for conditioning chemicals.

End connection A reference to the method of connecting the parts of a piping system, e.g., threaded, flanged, butt-weld, socket-weld.

Engineered plumbing system Plumbing system designed by use of scientific engineering design criteria other than design criteria normally given in plumbing codes.

Erosion The gradual destruction of metal or other material by the abrasive action of liquids, gases, solids, or mixtures of these materials.

Evapotranspiration Loss of water from the soil by both evaporation and transpiration from the plants growing thereon.

Existing work A plumbing system, or any part thereof, that was installed prior to the effective date of an applicable code.

Expansion joint A joint whose primary purpose is to absorb longitudinal thermal expansion in the pipe line due to heat.

Expansion loop A large radius bend in a pipe line to absorb longitudinal thermal expansion in the line due to heat.

Extra heavy Description of piping material, usually cast-iron, indicating piping that is thicker than standard pipe.

Face-to-face dimensions The dimensions from the face of the inlet port to the face of the outlet port of a valve or fitting.

Female thread Internal thread in pipe fittings, valves, etc., for making screwed connections.

Filter A device through which fluid is passed to separate contaminants from it.

Filter element or media A porous device that performs the process of filtration or filtering.

Fire alarm system (FP) A functionally related group of devices that, when automatically or manually activated, will sound audio or visual warning devices on or off the protected premises, signaling a fire.

Fire department connection (FP) A piping connection for fire department use to supplement in supplying water for standpipes and sprinkler systems. *See* STANDPIPE SYSTEM.

Fire hazard (FP) Any thing or act that increases, or will cause an increase of, the hazard or menace of fire to a degree greater than what is customarily recognized as normal by persons in the public service regularly engaged in preventing, suppressing, or extinguishing fire; or that will obstruct, delay, hinder, or interfere with the operations of the fire department or the egress of occupants in the event of fire.

Fire hydrant valve (FP) A valve that, when closed, drains at an underground level to prevent freezing.

Fire line (FP) A system of pipes and equipment used exclusively to supply water for extinguishing fires.

Fire pump types

Can pump (FP) A vertical-shaft, turbine-type pump in a can (suction vessel) for installation in a pipeline to raise water pressure.

Centrifugal pump (FP) A pump in which the pressure is developed principally by the action of centrifugal force.

End-suction pump (FP) A single-suction pump having its suction nozzle on the opposite side of the casing from the stuffing box and having the face of the suction nozzle perpendicular to the longitudinal axis of the shaft.

Excess pressure pump (FP) UL-listed and/or FM-approved, low-flow, high-head pump for sprinkler systems not being supplied from a fire pump. The pump pressurizes the sprinkler system so that the loss of water-supply pressure will not cause a false alarm.

Fire pump (FP) UL-listed and/or FM-approved pump with driver, controls, and accessories used for fire protection service. Fire pumps are of the centrifugal or turbine type and usually have an electric-motor or diesel-engine driver.

Horizontal pump (FP) A pump with the shaft normally in a horizontal position.

Horizontal split-case pump (FP) A centrifugal pump characterized by a housing that is split parallel to the shaft.

In-line pump (FP) A centrifugal pump in which the drive unit is supported by the pump, having its suction and discharge flanges on approximately the same center line.

Pressure maintenance (jockey) pump (FP) Pump with controls and accessories used to maintain pressure in a fire protection system without the operation of the fire pump. Does not have to be a listed pump.

Vertical shaft turbine pump (FP) A centrifugal pump with one or more impellers discharging into one or more bowls and a vertical educator or column pipe used to connect the bowl(s) to the discharge head on which the pump driver is mounted.

Fitting The connector or closure for fluid lines and passages.

Fitting, compression A fitting designed to join pipe or tubing by means of pressure or friction.

Fitting, flange A fitting that utilizes a radially extending collar for sealing and connection.

Fitting, welded A fitting attached by welding.

Fixture branch A pipe connecting several fixtures.

Fixture carrier A metal unit designed to support an off-the-floor plumbing fixture.

Fixture carrier fittings Special fittings for wall-mounted fixture carriers. Fittings have a sanitary drainage waterway with a minimum angle of 30 – 45 degrees so that there are no fouling areas.

Fixture drain The drain from the trap of a fixture to the junction of that drain with any other drain pipe.

Fixture, plumbing *See* PLUMBING FIXTURE.

Fixture supply A water supply pipe connecting the fixture to the fixture branch or directly to a main water supply pipe.

Fixture unit, drainage (dfu) A measure of probable discharge into the drainage system by various types of plumbing fixtures. The drainage fixture unit value for a particular fixture depends on its volume rate of drainage discharge, on the time duration of a single drainage operation, and on the average time between successive operations. Laboratory tests have shown that the rate of discharge of an ordinary lavatory with a nominal 1.2-inches (31.8-mm) outlet, trap, and waste is about 7.5 gpm (0.5 L/s). This figure is so near to 1 ft^3/min (0.5 L/s) that "1 ft^3/min" (0.5 L/s) has become the accepted flow rate of one fixture unit.

Fixture unit, supply (sfu) A measure of the probable hydraulic demand on the water supply by various types of plumbing fixtures. The supply fixture unit value for a particular fixture depends on its volume rate of supply, the time duration of a single supply operation, and the average time between successive operations.

Flange In pipe work, a ring-shaped plate on the end of a pipe at right angles to the end of the pipe and provided with holes for bolts to allow fastening the pipe to a similarly equipped adjoining pipe. The resulting joint is a flanged joint.

Flange bonnet A valve bonnet having a flange through which bolts connect it to a matching flange on the valve body.

Flange ends A valve or fitting having flanges for joining to other piping elements. Flange ends can be plain-faced, raised-face, large male-and-female, large tongue-and-groove, small tongue-and-groove, or ring-joint.

Flange faces Pipe flanges that have the entire surface of the flange faced straight across and use either a full-face or ring gasket.

Flap valve A non-return valve in the form of a hinged disc or flap, sometimes having leather or rubber faces.

Flash point The temperature at which a fluid first gives off sufficient flammable vapor to ignite when approached with a flame or spark.

Float valve A valve that is operated by means of a bulb or ball floating on the surface of a liquid within a tank. The rising and falling action operates a lever, which opens and closes the valve.

Flooded The condition when liquid rises to the flood level rim of a fixture.

Flood level rim The top edge of a receptacle or fixture from which water overflows.

Flow pressure The pressure in the water supply pipe near the water outlet while the faucet or water outlet is fully open and flowing.

Flue An enclosed passage, primarily vertical, for removal of gaseous products of combustion to the outer air.

Flush valve A device located at the bottom of a tank for the purpose of flushing water closets and similar fixtures.

Flushing-type floor drain A floor drain that is equipped with an integral water supply, enabling flushing of the drain receptor and trap.

Flushometer valve A device that discharges a predetermined quantity of water to fixtures for flushing purposes and is actuated by direct water pressure.

Footing The part of a foundation wall or column resting on the bearing soil, rock, or piling that transmits the superimposed load to the bearing material.

Foot valve A check valve installed at the base of a pump-suction pipe. Its purpose is to maintain pump prime by preventing pumped liquid from draining away from the pump.

French drain A drain consisting of an underground passage made by filling a trench with loose stones and covering with earth. *Also known as* RUBBLE DRAIN.

Fresh-air inlet A vent line connected with the building drain just inside the house trap and extending to the outer air. It provides fresh air at the lowest point of the plumbing system, and with the vent stacks, provides a ventilated system. A fresh-air inlet is not required where a septic-tank system of sewage disposal is employed.

Frostproof closet A hopper that has no water in the bowl and has the trap and control valve for its water supply installed below the frost line.

FS Abbreviation for "federal specifications."

Galvanic action When two dissimilar metals are immersed in the same electrolytic solution and connected electrically, there is an interchange of atoms carrying an electric charge between them. The anode metal with the higher electrode potential corrodes; the cathode is protected. Thus magnesium will protect iron; iron will protect copper. *See also* ELECTROLYSIS.

Galvanizing A process where the surface of iron or steel piping or plate is covered with a layer of zinc.

Generally accepted standard A document referred to in a code that covers a particular subject and is accepted by the administrative authority.

Grade The slope or fall of a line of pipe in reference to a horizontal plane. In drainage, it is expressed as the fall in a fraction of an inch or percentage slope per foot (mm/m) length of pipe.

Grease interceptor An automatic or manual device used to separate and retain grease, with a capacity greater than 50 gal (227.3 L), and generally located outside a building.

Grease trap An automatic or manual device used to separate and retain grease, with a capacity of 50 gallons (227.3 L) or less, and generally located inside a building.

Grinder pump A special class of solids-handling pump that grinds sewage solids to a fine slurry, rather than passing through entire spherical solids.

Halon 1301 (FP) Halon 1301 (bromtrifluoromethane CBrF3) is a colorless, odorless, electrically non-conductive gas that is an effective medium for extinguishing fires.

Halon system types (FP) There are two types of systems recognized in this standard: "Total flooding systems" and "local application systems."

Total flooding system Consists of a supply of Halon 1301 arranged to discharged into, and fill to the proper concentration, an enclosed space or enclosure around the hazard.

Local application system Consists of a supply of Halon 1301 arranged to discharge directly on the burning material.

Hangers *See* SUPPORTS.

Hub-and-spigot Piping made with an enlarged diameter or hub at one end and being plain or having a spigot at the other end. The joint is made tight by oakum and lead or by use of a neoprene gasket caulked or inserted in the hub around the spigot.

Hubless Soil piping with plain ends. The joint is made tight with a stainless steel or cast-iron clamp and neoprene gasket assembly.

Indirect waste pipe A pipe that does not connect directly with the drainage system but conveys liquid waste by discharging into a plumbing fixture or receptacle directly connected to the drainage system.

Individual vent A pipe that is installed to vent a fixture trap and connects with the vent system above the fixture served or terminates in the open air.

Induced siphonage Loss of liquid from a fixture trap due to pressure differential between the inlet and outlet of a trap, often caused by the discharge of another fixture.

Industrial waste All liquid or waterborne waste from industrial or commercial processes except domestic sewage.

Insanitary A condition that is contrary to sanitary principles or injurious to health.

Interceptor A device designed and installed so as to separate and retain deleterious, hazardous, or undesirable matter from normal wastes and to permit normal sewage or liquid wastes to discharge into the disposal terminal by gravity.

Invert Term referring to the lowest point on the interior of a horizontal pipe.

Labeled Term describing equipment or materials bearing a label of a listing agency.

Lateral sewer A sewer that does not receive sewage from any other common sewer except house connections.

Leaching well A pit or receptacle having porous walls that permit the contents to seep into the ground. *Also known as* DRY WELL.

Leader The water conductor from the roof to the building (house) storm drain. *Also known as* DOWNSPOUT.

Liquid waste The discharge from any fixture, appliance, or appurtenance in connection with a plumbing system that does not receive fecal matter.

Listed Term describing equipment and materials included in a list published by an organization acceptable to the authority having jurisdiction and concerned (a listing agency).

Listing agency An agency accepted by the administrative authority that lists or labels certain models of a product and maintains a periodic inspection program on the current production of listed models. It makes available a published report of its listing, including information indicating that the products have been tested, comply with generally accepted standards, and are found safe for use in a specified manner.

Load factor The percentage of the total connected fixture unit flow that is likely to occur at any point in the drainage system. The load factor represents the ratio of the probable load to the potential load and is determined by the average rates of flow of the various kinds of fixtures, the average frequency of use, the duration of flow during one use, and the number of fixtures installed.

Loop vent *See* VENT, LOOP.

Main The principal artery of a system of continuous piping to which branches may be connected.

Main vent A vent header to which vent stacks are connected.

Malleable Capable of being extended or shaped by beating with a hammer, or by the pressure of rollers. Most metals are malleable. The term “malleable iron” also has the older meaning (still universal in Great Britain) of “wrought iron,” abbreviated “Mall.”

Master plumber An individual who is licensed and authorized to install and assume responsibility for contractual agreements pertaining to plumbing and to secure any required permits. The journeyman plumber is allowed to install plumbing only under the responsibility of a master plumber.

MSS Abbreviation for Manufacturers Standardization Society of the Valve and Fittings Industry, Inc.

NFPA Abbreviation for National Fire Protection Association.

NSF Abbreviation for National Sanitation Foundation Testing Laboratory.

Offset A combination of pipe(s) and/or fittings that join two approximately parallel sections of a line of pipe.

Outfall sewers Sewers receiving the sewage from a collection system and carrying it to the point of final discharge or treatment. They are usually the largest sewers of an entire system.

Oxidized sewage Sewage in which the organic matter has been combined with oxygen and become stable in nature.

PB Abbreviation for "polybutylene."

PDI Abbreviation for Plumbing and Drainage Institute.

PE Abbreviation for "polyethylene."

Percolation The flow or trickling of a liquid downward through a contact or filtering medium; the liquid may or may not fill the pores of the medium.

Pitch The amount of slope or grade given to horizontal piping and expressed in inches or vertically projected drop per foot (mm/m) on a horizontally projected run of pipe.

Plumbing The practice, materials, and fixtures used in the installation, maintenance, extension, and alteration of all piping, fixtures, appliances, and appurtenances in connection with any of the following: Sanitary drainage or storm drainage facilities; venting systems and public or private water-supply systems, within or adjacent to any building, structure, or conveyance; water supply systems and/or the storm water, liquid waste, or sewage system of any premises to their connection with any point of public disposal or other acceptable terminal.

Plumbing appliance A plumbing fixture that is intended to perform a special plumbing function. Its operation and/or control may be dependent upon one or more energized components, such as a motor, control, heating element, or pressure or temperature-sensing element. Such fixtures may operate automatically through one or more of the following actions: A time cycle, a temperature range, a pressure range, a measured volume, or weight; or the fixture may be manually adjusted or controlled by the user or operator.

Plumbing appurtenances A manufactured device, prefabricated assembly, or on-the-job assembly of component parts that is an adjunct to the basic piping system and plumbing fixtures. An appurtenance demands no additional water supply, nor does it add any discharge load to a fixture or the drainage system. It is presumed perform some useful function in the operation, maintenance, servicing, economy, or safety of the plumbing system.

Plumbing engineering The application of scientific principles to the design, installation, and operation of efficient, economical, ecological, and energy-conserving systems for the transport and distribution of liquids and gases.

Plumbing fixtures Installed receptacles, devices, or appliances are supplied with water or that receive liquid or liquid-borne wastes and discharge such wastes into the drainage system to which they may be directly or indirectly connected. Industrial or commercial tanks, vats, and similar processing equipment are not plumbing fixtures but may be connected to or discharged into approved traps or plumbing fixtures.

Plumbing inspector Any person who, under the supervision of the department having jurisdiction, is authorized to inspect plumbing and drainage systems as defined in the code for the municipality and complying with the laws of licensing and/or registration of the state, city, or county.

Plumbing system All potable water supply and distribution piping, plumbing fixtures and traps, drainage and vent pipe, and building (house) drains; including their respective joints, connections, devices, receptacles, and appurtenances within the property lines of the premises. Additional components in the system include: Potable water-treating or water-using equipment, fuel gas piping, water heaters, and vents for same.

Polymer A chemical compound or mixture of compounds formed by polymerization and consisting essentially of repeating structural units.

Pool A water receptacle used for swimming or as a plunge or other bath, designed to accommodate more than one bather at a time.

Potable water Water that is satisfactory for drinking, culinary, and domestic purposes and meets the requirements of the health authority having jurisdiction.

Precipitation The total measurable supply of water received directly from the clouds as snow, rain, hail, and sleet. It is expressed in inches (mm) per day, month, or year.

Private sewage disposal system A septic tank with the effluent discharging into a subsurface disposal field, one or more seepage pits, or a combination of subsurface disposal field and seepage pit, or of such other facilities as may be permitted under the procedures set forth in a code.

Private sewer A sewer that is privately owned and not directly operated by public authority.

Private use Applies to plumbing fixtures in residences and apartments, private bathrooms in hotels and hospitals, and rest rooms in commercial establishments containing restricted-use single fixtures or groups of single fixtures and similar installations, where the fixtures are intended for the use of a family or an individual.

Public sewer A common sewer directly operated by public authority.

Public use Applies to toilet rooms and bathrooms used by employees, occupants, visitors, or patrons, in or about any premises, and locked toilet rooms or bathrooms to which several occupants or employees on the premises possess keys and have access.

Putrefaction Biological decomposition of organic matter with the production of ill-smelling products; usually takes place when there is a deficiency of oxygen.

PVC Abbreviation for "polyvinyl chloride."

PVDF Abbreviation for "polyvinyl-fluoridine."

Raw sewage Untreated sewage.

Receptor A plumbing fixture or device of such material, shape, and capacity that it will adequately receive the discharge from indirect waste pipes and, so constructed and located, that it can be readily cleaned.

Reduced size vent Dry vents that are smaller than those allowed by model plumbing codes.

Reducer 1. A pipe fitting with inside threads that is larger at one end than at the other. 2. A fitting so shaped at one end that it can receive a larger size pipe in the direction of flow.

Reflecting pool A water receptacle used for decorative purposes.

Relief vent A vent designed to provide circulation of air between drainage and vent systems or to act as an auxiliary vent.

Residual pressure (FP) Pressure less than static that varies with the flow discharged from outlets.

Return offset A double offset installed to return the pipe to its original alignment.

Revent pipe That part of a vent pipe line that connects directly with an individual waste pipe or group of waste pipes, underneath or at the back of the fixture, and extends either to the main or branch vent pipe. *Also known as* INDIVIDUAL VENT.

Rim An unobstructed open edge of a fixture.

Riser 1. A water supply pipe that extends vertically one full story or more to convey water to branches or fixtures. 2. (FP) A vertical pipe used to carry water for fire protection to elevations above or below grade, such as a standpipe riser, sprinkler riser, etc.

Roof drain A drain installed to remove water collecting on the surface of a roof and discharge it into the leader (downspout).

Roughing in The installation of all parts of a plumbing system that can be completed prior to the installation of fixtures. This includes drainage, water supply and vent piping, and the necessary fixture supports.

Sand filter A water-treatment device for removing solid or colloidal material with sand as the filter medium.

Sanitary sewer A conduit or pipe carrying sanitary sewage. It may include storm water and infiltrated ground water.

Seepage pit A lined excavation in the ground that receives the discharge of a septic tank that is designed to permit effluent from the tank to seep through its bottom and sides.

Septic tank A watertight receptacle that receives the discharge of a drainage system, or part thereof, and is designed and constructed to separate solids from liquids and digest organic matter over a period of detention.

Sewage Any liquid waste containing animal, vegetable, or chemical wastes in suspension or solution.

Sewage ejector A mechanical device or pump for lifting sewage.

Siamese (FP) A hose fitting for combining the flow from two or more lines into a single stream. *See* FIRE DEPARTMENT CONNECTION.

Side vent A vent connected to the drain pipe through a fitting at an angle not greater than 45 degrees to the vertical.

Sludge The accumulated, suspended solids of sewage deposited in tanks, beds, or basins, mixed with water to form a semiliquid mass.

Soil pipe Any pipe that conveys the discharge of water closets, urinals, or fixtures having similar functions, with or without the discharge from other fixtures, to the building (house) drain or building (house) sewer.

Special wastes Wastes that require some special method of handling, such as the use of indirect waste piping and receptors; corrosion-resistant piping; sand, oil, or grease interceptors; condensers; or other pretreatment facilities.

Sprinkler system (FP) An integrated system of underground and overhead piping designed in accordance with fire-protection engineering standards. The installation includes one or more automatic water supplies. The portion of the sprinkler system above ground is a network of specially sized or hydraulically designed piping installed in a building, structure, or area, generally overhead, and to which sprinklers are attached in a systematic pattern. The valve controlling each system riser is located in the system riser or its supply piping. Each sprinkler system riser includes a device for actuating an alarm when the system is in operation. The system is activated by heat from a fire and discharges water over the fire area.

Sprinkler system classification

Automatic sprinkler system types *(FP)*

1. Wet-pipe systems.
2. Dry-pipe systems.
3. Pre-action systems.
4. Deluge systems.
5. Combined dry-pipe and pre-action systems.

Sprinkler systems–special types Special-purpose systems employing departures from the requirements of standards, such as special water supplies and reduced pipe sizing, shall be installed in accordance with their listings.

Occupancy classification Relates to sprinkler installations and their water supplies only, not intended to be a general classification of occupancy hazards.

1. Extra hazard occupancies Occupancies or portions of other occupancies where quantity and combustibility of contents is very high, and flammable and combustible liquids, dust, lint, or other materials are present, introducing the probability of rapidly developing fires with high rates of heat release. Extra hazard occupancies involve a wide range of variables that may produce severe fires. The following shall be used to evaluate the severity of extra hazard occupancies:
   A. Extra hazard group 1 Includes occupancies with little or no flammable or combustible liquids.
   B. Extra hazard group 2 Includes occupancies with moderate to substantial amounts of flammable or combustible liquids or where shielding of combustibles is extensive.
2. Ordinary hazard occupancies
   A. Ordinary hazard group 1 Occupancies or portions of other occupancies where combustibility is low, quantity of combustibles does not exceed 8 feet (2.4 m), and fires with moderate rates of heat release are expected.
   B. Ordinary hazard group 2 Occupancies or portions of other occupancies where quantity and combustibility of contents is moderate, stockpiles do not exceed 12 feet (3.7 m), and fires with moderate rates of heat release are expected.
   C. Ordinary hazard group 3 Occupancies or portions of other occupancies where quantity and/or combustibility of contents is high and fires of high rates of heat release are expected.
3. Light hazard occupancies Occupancies or portions of other occupancies where the quantity and/or combustibility of contents is low and fires with relatively low rates of heat release are expected.

Sprinkler types (FP)

Concealed sprinklers Recessed sprinklers with cover plates.

Corrosion-resistant sprinklers Sprinklers with special coatings or platings to be used in an atmosphere that would corrode an uncoated sprinkler.

Dry, pendent sprinklers Sprinklers for use in a pendent position in a dry-pipe or wet-pipe system with the seal in a heated area.

Dry, upright sprinklers Sprinklers designed to be installed in an upright position, on a wet-pipe system, to extend into an unheated area with a seal in a heated area.

Extended-coverage sidewall sprinklers Sprinklers with special extended, directional, discharge patterns.

Flush sprinklers Sprinklers in which all or part of the body, including the shank thread, is mounted above the lower plane of the ceiling.

Intermediate-level sprinklers Sprinklers equipped with integral shields to protect their operating elements from the discharge of sprinklers installed at high elevations.

Large-drop sprinklers Listed sprinklers that are characterized by a K factor between 11.0 and 11.5 and a proven ability to meet the prescribed penetration, cooling, and distribution criteria prescribed in the large-drop sprinkler examination requirements. The deflector/discharge characteristics of the large-drop sprinkler generate large drops of such size and velocity as to enable effective penetration of a high-velocity fire plume.

Nozzles Devices for use in applications requiring special discharge patterns, directional spray, fine spray, or other unusual discharge characteristics.

Open sprinklers Sprinklers from which the actuating elements (fusible links) have been removed.

Ornamental sprinklers Sprinklers that have been painted or plated by the manufacturer.

Pendant sprinklers Sprinklers designed to be installed in such a way that the water stream is directed downward against the deflector.

Quick-response sprinklers A type of sprinkler that is both a fast-response and a spray sprinkler.

Recessed sprinklers Sprinklers in which all or a part of the body, other than the shank thread, is mounted within a recessed housing.

Residential sprinklers Sprinklers that have been specifically listed for use in residential occupancies.

Sidewall sprinklers Sprinklers having special deflectors that are designed to discharge most of the water away from a nearby wall in a pattern resembling a quarter of a sphere, with a small portion of the discharge directed at the wall behind the sprinkler.

Special sprinklers Sprinklers that have been tested and listed as having special limitations.

Upright sprinklers Sprinklers designed to be installed in such a way that the water spray is directed upward against the deflector.

Stack The vertical main of a system of soil, waste, or vent piping extending through one or more stories.

Stack group The location of fixtures in relation to the stack so that, by means of proper fittings, vents may be reduced to a minimum.

Stack vent The extension of a soil waste stack above the highest horizontal drain connected to the stack. *Also known as* WASTE or SOIL VENT.

Stack venting A method of venting a fixture or fixtures through the soil or waste stack.

Stale sewage Sewage that contains little or no oxygen and is free from putrefaction.

Standpipe A vertical pipe generally used for the storage and distribution of water for fire extinguishing.

Standpipe system (FP) An arrangement of piping, valves, hose connections, and allied equipment installed in a building or structure with the hose connections located in such a manner that water can be discharged in streams or spray patterns through attached hose and nozzles, for the purpose of extinguishing a fire and so protecting a building or structure and its contents as well as its occupants. This is accomplished by connections to water supply systems or by pumps, tanks, and other equipment necessary to provide an adequate supply of water to the hose connections.

Standpipe system class of service (FP)

Class I For use by fire departments and those trained in handling heavy fire streams (2½-inch hose).

Class II For use primarily by the building occupants until the arrival of the fire department (1½-inch hose).

Class III For use either by fire departments and those trained in handling heavy hose streams (2½-inch hose) or by the building occupants (1½-inch hose).

Standpipe system types (FP)

Dry standpipe A system having no permanent water supply, maybe so arranged through the use of approved devices as to admit water to the system automatically by the opening of a hose valve.

Wet standpipe A system having the supply valve open and water pressure maintained in the system at all times.

Stop valve A valve used for the control of water supply, usually to a single fixture. Can be a straight or angle configuration.

Storm sewer A sewer used for conveying rainwater, surface water, condensate, cooling water, or similar liquid wastes, exclusive of sewage and industrial waste.

Strain Change of the shape or size of a body produced by the action of stress.

Stress Reactions within a body resisting external forces acting on it.

Subsoil drain A drain that receives only subsurface or seepage water and conveys it to an approved place of disposal.

Submain sewer A sewer into which the sewage from two or more lateral sewers is discharged. *Also known as* BRANCH SEWER.

Sump A tank or pit that receives sewage or liquid waste, is located below the normal grade of the gravity system, and must be emptied by mechanical means.

Sump pump A mechanical device for removing liquid waste from a sump.

Supervisory (tamper) switch (FP) A device attached to the handle of a valve that, when the valve is closed, annunciates a trouble signal at a remote location.

Supports Devices for supporting and securing pipe and fixtures to walls, ceilings, floors, or structural members.

Swimming pool A structure, basin, or tank containing water for swimming, diving, or recreation.

Tempered water Water ranging in temperature from 85 to 110°F (29 to 43°C) thermal efficiency.

Thermal efficiency The ratio of the energy output from the system to energy input to the system.

Trailer park sewer That part of the horizontal piping of a drainage system that begins 2 feet (0.6 m) downstream from the last trailer site connection, receives the discharge of the trailer site, and conveys it to a public sewer, private sewer, individual sewage disposal system, or other approved point of disposal.

Trap A fitting or device designed and constructed to provide, when properly vented, a liquid seal that will prevent the back passage of air without significantly affecting the flow of sewage or waste water through it.

Trap primer A device or system of piping to maintain a water seal in a trap.

Trap seal The maximum vertical depth of liquid that a trap will retain, measured between the crown weir and the top of the dip of the trap.

Turbulence Any deviation from parallel flow in a pipe due to rough inner wall surfaces, obstructions, or directional changes.

Underground piping Piping in contact with the earth below grade.

Upstream Term referring to a location in the direction of flow before reaching a referenced point.

Vacuum Any pressure less than that exerted by the atmosphere. *Also known as* NEGATIVE PRESSURE.

Vacuum breaker *See* BACKFLOW PREVENTER.

Vacuum relief valve A device to prevent excessive vacuum in a pressure vessel.

Velocity Time rate of motion in a given direction and sense.

Vent, loop Any vent connecting a horizontal branch or fixture drain with the stack vent of the originating waste or soil stack.

Vent stack A vertical vent pipe installed primarily for the purpose of providing circulation of air to and from any part of the drainage system.

Vertical pipe Any pipe or fitting installed in a vertical position or that makes an angle of not more than 45 degrees with the vertical.

Vitrified sewer pipe Conduit made of fired and glazed earthenware installed to receive waste or sewage or sewerage.

Waste The discharge from any fixture, appliance, area, or appurtenance that does not contain fecal matter.

Waste pipe The discharge pipe from any fixture, appliance, or appurtenance in connection with the plumbing system that does not contain fecal matter.

Water-conditioning or treating device A device that conditions or treats a water supply to change its chemical content or remove suspended solids by filtration.

Water-distributing pipe A pipe that conveys potable water from the building supply pipe to the plumbing fixtures and other water outlets in the building.

Water hammer The forces, pounding noises, and vibration that develop in a piping system when a column of noncompressible liquid flowing through a pipeline at a given pressure and velocity is stopped abruptly.

Water hammer arrester A device, other than an air chamber, designed to provide protection against excessive surge pressure.

Water main The water supply pipe for public or community use. Normally under the jurisdiction of the municipality or water company.

Water riser A water supply pipe that extends vertically one full story or more to convey water to branches or fixtures.

Water-service pipe The pipe from the water main or other source of water supply to the building served.

Water supply system The building supply pipe, the water distributing pipes, and the necessary connecting pipes, fittings, control valves, and all appurtenances carrying or supplying potable water in, or adjacent to, the building or premises.

Wet vent A vent that also serves as a drain.

Yoke vent A pipe connecting upward from a soil or waste stack to a vent stack for the purpose of preventing pressure changes in the stacks.

RECOMMENDED PRACTICE FOR CONVERSION TO THE INTERNATIONAL SYSTEM OF UNITS

The International System of Units was developed by the General Conference of Weights and Measures, an international treaty organization, and has been officially abbreviated "SI" from the French term, "Systeme International and d'Unites." The SI system of units is a preferred international measurement system that evolved from earlier decimal metric systems.

When President Ford signed the Metric Conversion Act (Public Law 94-168) on December 23, 1975, a metric system in the United States was declared and a United States Metric Board was established to coordinate the national voluntary conversion effort to the metric system. The Metric Conversion Act specifically defines the metric system of measurement to be used as the International System of Units (SI), established by the General Conference of Weights and Measures and as interpreted and modified by the Secretary of Commerce.

The "recommended practice" section that follows outlines a selection of SI units, including multiples and submultiples, for use in plumbing design and related fields of science and engineering. It is intended to provide the technical basis for a comprehensive and authoritative standard guide for SI units to be used in plumbing design and related fields of science and engineering.

The section also is intended to provide the basic concepts and practices for the conversion of units given in several systems of measurement to the SI system. Rules and recommendations are detailed for the presentation of SI units and their corresponding symbols and numerical values used in conjunction with the SI system.

A selection of conversion factors to SI units for use in plumbing design and related fields of science and engineering is also given. It should be noted that the SI units, rules, and recommendations listed herein comply with those provisions set forth in the American National Standard Metric Practice, ANSI Z210.1 (ASTM E380).

Terminology and Abbreviations

For uniformity in the interpretation of the provisions set forth in this recommended practice section, the following definitions and abbreviations will apply:

Accuracy The degree of conformity of a measured or calculated value to some recognized standard or specified value.

Approximate value A quantity that is nearly, but not exactly, correct or accurate.

CGPM Abbreviation for the General Conference on Weights and Measures, from the French term, "Conference Generale de Poids et Measures."

Coherent unit system A system in which relations between units contain as numerical factor only the number 1 (or unity). All derived units have a unity relationship to the constituent base or supplementary units.

Deviation The variation from a specified dimension or design requirement, defining the upper and lower limits.

Digit One of the ten arabic numerals (0 to 9).

Dimension A geometric element in a design or the magnitude of such a quantity.

Feature An individual characteristic of a component or part.

Nominal value A value assigned for the purpose of convenient designation, existing in name only.

Precision The degree of mutual agreement between individual measurements, namely, repeatability and reproducibility.

Significant digit Any digit necessary to define a value or quantity.

Tolerance The total range of variation permitted; the upper and lower limits between which a dimension must be maintained.

Unit The reference value of a given quantity as defined by CGPM.

Types of Conversion

Exact These conversions denote the precise (or direct) conversion to the SI unit value, accurate to a number of decimal places.

Soft These conversions denote the conversion to the SI unit value in the software only. The materials and products remain unchanged and minimal rounding off to the nearest integer is usually applied.

Hard These conversions denote that the product or material characteristics are physically changed from existing values to preferred SI unit values.

SI Units and Symbols[5]

The International System of Units has three types of units, as follows:

Base units These units are used for independent quantities. There are seven base units:

Quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Current (electric)	ampere	A
Temperature (thermodynamic)	kelvin	K
Substance (amount)	mole	mol
Intensity (luminous)	candela	cd

Supplementary units These units are used to denote angles. There are two supplementary units:

Quantity	Unit	Symbol
Plane angle	radian	rad
Solid angle	steradian	sr

Derived units These units are defined in terms of their derivation from base and supplementary units. Derived units are classified in two categories: (1) derived units with special names and symbols and (2) derived units with generic or complex names, expressed in terms of a base unit, two or more base units, base units and/or derived units with special names, or supplementary units and base and/or derived units.

Quantity	Unit	Symbol
Frequency	hertz	Hz
Force	newton	N
Pressure, stress	pascal	Pa
Energy, work, heat (quantity)	joule	J
Power	watt	W
Electricity (quantity)	coulomb	C
Electric potential, electromotive force	volt	V
Electric capacitance	farad	F
Electric resistance	ohm	Ω
Magnetic flux	weber	Wb
Illuminance	lux	lx
Electric inductance	henry	H
Conductance	siemens	S
Magnetic flux density	tesla	T
Luminous flux	lumen	lm

The following are classified as derived units with generic or complex names, expressed in various terms:

Quantity	Unit	Symbol
Linear acceleration	meter per second sq.	m/s^2
Angular acceleration	radian per second sq.	rad/s^2
Area	meter squared	m^2
Density	kilogram per cubic meter	kg/m^3
Electric charge density	coulomb per cubic meter	C/m^3
Electric permittivity	farad per meter	F/m
Electric permeability	henry per meter	H/m
Electric resistivity	ohm-meter	Ω·m
Entropy	joule per kelvin	J/K
Luminance	candela per meter sq.	cd/m^2
Magnetic field strength	ampere per meter	A/m
Mass per unit length	kilogram per meter	kg/m
Mass per unit area	kilogram per meter sq.	kg/m^2
Mass flow rate	kilogram per second	kg/s
Moment of inertia	kilogram-meter sq.	$kg \cdot m^2$
Momentum	kilogram-meter per sec.	kg·m/s
Torque	newton-meter	N·m
Specific heat	joule per kg per kelvin	J/kg·K
Thermal conductivity	watt per meter per kelvin	W/m·K
Linear velocity	meter per second	m/s
Angular velocity	radian per second	rad/s
Dynamic viscosity	pascal-second	Pa·s
Kinematic viscosity	meter squared per second	m^2/s
Volume, capacity	cubic meter	m^3
Volume flow rate	cubic meter per second	m^3/s
Specific volume	cubic meter per kilogram	m^3/kg

Non-SI Units and Symbols for Use with the SI System

There are several (non-SI) units that are traditional and acceptable for use in the SI system of units due to their significance in specific and general applications. These units are as follows:

Quantity	Unit	Symbol
Area	hectare	ha
Energy	kilowatt-hour	kW·h
Mass	metric ton	t
Temperature	degree celsius	C
Time	minute, hour, year	min, h, y (respectively)
Velocity	kilometer per hour	km/h
Volume	liter	L

SI Unit Prefixes and Symbols

The SI unit system is based on multiples and submultiples. The following prefixes and corresponding symbols are accepted for use with SI units.

Factor	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto[a]	h
10^{1}	deka[a]	da
10^{-1}	deci[a]	d
10^{-2}	centi[a]	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

[a]Use of these prefixes should be avoided whenever possible.

SI Units Style and Use

1. Multiples and submultiples of SI units are to be formed by adding the appropriate SI prefixes to such units.
2. Except for the kilogram, SI prefixes are not to be used in the denominator of compound numbers.
3. Double prefixes are not to be used.
4. Except for exa (E), peta (P), teca (T), giga (G), and mega (M), SI prefixes are not capitalized.
5. The use of units from other systems of measurement is to be avoided.
6. Except when the SI unit is derived from a proper name, the symbol for SI units is not capitalized.
7. SI unit symbols are always denoted in singular form.
8. Except at the end of a sentence, periods are not used after SI unit symbols.
9. Digits are placed in groups of three numbers, separated by a space to the left and to the right of the decimal point. In the case of four digits, spacing is optional.
10. A center dot indicates multiplication, and a slash indicates division (to the left of the slash is the numerator and to the right of the slash is the denominator).
11. When equations are used, such equations are to be restated using SI terms.
12. All units are to be denoted by either their symbols or their names written in full. Mixed use of symbols and names is not allowed.

SI UNIT CONVERSION FACTORS

To convert from other systems of measurement to SI values, the following conversion factors are to be used. (*Note*: For additional conversion equivalents not shown herein, refer to ANSI Z210.1–also issued as ASTM E380).

Acceleration, linear

foot per second squared = 0.3048 m/s^2	m/s^2 = 3.28 ft/s^2
inch per second squared = 0.0254 m/s^2	m/s^2 = 39.37 in/s^2

Area

acre = 4046.9 m^2	m^2 = 0.0000247 acre
foot squared = 0.0929 m^2	m^2 = 10.76 ft^2
inch squared = 0.000645 m^2 = 645.16 mm^2	m^2 = 1550.39 in^2
mile squared = 2 589 988 m^2 = 1.59	km^2 = 0.39 mi^2
yard squared = 0.836 m^2	m^2 = 1.2 yd^2

Bending movement (torque)

pound-force-inch = 0.113 N·m	N·m = 8.85 lb_f-in
pound-force-foot = 1.356 N·m	N·m = 0.74 lb_f-ft

Bending movement (torque) per unit length

pound-force-inch per inch = 4.448 N·m/m	N·m/m = 0.225 lb_f-in/in
pound-force-foot per inch = 53.379 N·m/m	N·m/m = 0.019 lb_f-ft/in

Electricity and magnetism

ampere = 1A
ampere-hour = 3600C
coulomb = 1C
farad = 1F
henry = 1H
ohm = 1Ω
volt = 1V

Energy (work)

British thermal unit (Btu) = 1055 J	J = 0.000948 Btu
foot-pound-force = 1.356 J	J = 0.74 ft-lb_f
kilowatt-hour = 3 600 000 J	J = 0.000000278 kW-h

Energy per unit area per unit time

Btu per foot squared-second = 11 349 W/m^2	W/m^2 = 0.000088 Btu/ft^2-s

Force

ounce-force = 0.287 N	N = 3.48 oz_f
pound-force = 4.448 N	N = 0.23 lb_f
kilogram-force = 9.807 N	N = 0.1 kg_f

Force per unit length

pound-force per inch = 175.1 N/m	N/m = 0.0057 lb_f/in
pound-force per foot = 14.594 N/m	N/m = 0.069 lb_f/ft

Heat

Btu-inch per second-foot squared-F = 519.2 W/m·K — W/m·K = 0.002 Btu-in/s-ft²F

Btu-inch per second-foot squared-F = 519.2 W/m·K	W/m·K = 0.002 Btu-in/s-ft^2F
Btu-inch per hour-foot squared-F = 0.144 W/m·K	W/m·K = 6.94 Btu-in/h-ft^2F
Btu per foot squared = 11 357 J/m^2	J/m^2 = 0.000088 Btu/ft^2
Btu per hour-foot squared-F = 5.678 W/m^2·K	W/m^2·K = 0.176 Btu/h-ft^2F
Btu per pound-mass = 2326 J/kg	J/kg = 0.00043 Btu/lb_m
Btu per pound-mass-F = 4186.8 J/kg·K	J/kg·K = 0.000239 Btu/lb_m F
F-hour-foot squared per Btu = 0.176 K·m^2/W	K·m^2/W = 5.68 F-h-ft^2/Btu

Length

inch = 0.0254 m	m = 39.37 in
foot = 0.3048 m	m = 3.28 ft
yard = 0.914 m	m = 1.1 yd
mile = 1609.3 m	m = 0.000621 mi

Light (illuminance)

footcandle = 10.764 lx	lx = 0.093 ftcd

Mass

ounce-mass = 0.028 kg	kg = 35.7 oz_m
pound-mass = 0.454 kg	kg = 2.2 lb_m

Mass per unit area

pound-mass per foot squared = 4.882 kg/m^2	kg/m^2 = 0.205 lb_m/ft^2

Mass per unit length

pound-mass per foot = 1.488 kg/m	kg/m = 0.67 lb_m/ft

Mass per unit time (flow)

pound-mass per hour = 0.0076 kg/s	kg/s = 131.58 lb_m/h

Mass per unit volume (density)

pound-mass per cubic foot = 16.019 kg/m^3	kg/m^3 = 0.062 lb_m/ft^3
pound-mass per cubic inch = 27 680 kg/m^3	kg/m^3 = 0.000036 lb_m/in^3
pound-mass per gallon = 119.8 kg/m^3	kg/m^3 = 0.008347 lb_m/gal

Moment of inertia

pound-foot squared = 0.042 kg·m^2	kg·m^2 = 23.8 lb-ft^2

Plane angle

degree = 17.453 mrad	mrad = 0.057 deg
minute = 290.89 µrad	µrad = 0.00344 min
second = 4.848 µrad	µrad = 0.206 s

Power

Btu per hour = 0.293 W	W = 3.41 Btu/h
foot-pound-force per hour = 0.38 mW	mW = 2.63 ft-lb_f/h
horsepower = 745.7 W	W = 0.00134 hp

Pressure (stress), force per unit area

inches water column = 25.4 mm water	mm water = 0.0394 in. wc
atmosphere = 101.325 kPa	kPa = 0.009869 atm
inch of mercury (at 60°F) = 3.3769 kPa	kPa = 0.296 in. Hg
inch of water (at 60°F) = 248.8 Pa	Pa = 0.004 in. H_2O
pound-force per foot squared = 47.88 Pa	Pa = 0.02 lb_f/ft^2
pound-force per inch squared = 6.8948 kPa	kPa = 0.145 lb_f/in^2 (psi)

pounds per square inch = 0.0703 kg/cm^3 | kg/cm^3 = 14.22 psi
pounds per square inch = 0.069 bars | bars = 14.50 psi

Temperature equivalent

$t_k = (t_f + 459.67)/1.8$ | $t_f = 1.8\ t_k - 459.67$
$t_c = (t_f - 32)/1.8$ | $t_f = 1.8\ t_c + 32$

Velocity (length per unit time)

foot per hour = 0.085 mm/s | mm/s = 11.76 ft/h
foot per minute = 5.08 mm/s | mm/s = 0.197 ft/min
foot per second = 0.3048 m/s | m/s = 3.28 ft/s
inch per second = 0.0254 m/s | m/s = 39.37 in./s
mile per hour = 0.447 m/s | m/s = 2.24 mi/h

Volume

cubic foot = 0.028 m^3 = 28.317 L | m^3 = 35.71 ft^3
cubic inch = 16 378 mL | mL = 0.061 in^3
gallon = 3.785 L | L = 0.264 gal
ounce = 29.574 mL | mL = 0.034 oz
pint = 473.18 mL | mL = 0.002 pt
quart = 946.35 mL | mL = 0.001 qt
acre-foot = 1233.49 m^3 | m^3 = 0.00081 acre-ft

Volume per unit time (flow)

cubic foot per minute = 0.472 L/s | L/s = 2.12 ft^3/min
cubic inch per minute = 0.273 mL/s | mL/s = 3.66 $in.^3$/min
gallon per minute = 0.063 L/s | L/s = 15.87 gal/min
cubic feet per hour = 0.0283 m^3/h | m^3/h = 35.31 ft^3/h (cfh)
cubic feet per hour = 0.007866 L/s | L/s = 127.13 cfh

Table 1-4 Temperature Conversion Chart, °F – °C

The numbers in the center column refer to the known temperature, in either °F or °C, to be converted to the other scale. If converting from °F to °C, the number in the center column represents the known temperature, in °F, and its equivalent temperature, in °C, will be found in the left column. If converting from °C to °F, the number in the center represents the known temperature, in °C, and its equivalent temperature, in °F, will be found in the right column.

	Known Temp.	
°C	(°F or °C)	°F
–59	–74	–101
–58	–73	–99
–58	–72	–98
–57	–71	–96
–57	–70	–94
–56	–69	–92
–56	–68	–90
–55	–67	–89
–54	–66	–87
–54	–65	–85
–53	–64	–83
–53	–63	–81
–52	–62	–80
–52	–61	–78
–51	–60	–76
–51	–59	–74
–50	–58	–72
–49	–57	–71
–49	–56	–69
–48	–55	–67
–48	–54	–65
–47	–53	–63
–47	–52	–62
–46	–51	–60
–45.6	–50	–58.0
–45.0	–49	–56.2
–44.4	–48	–54.4
–43.9	–47	–52.6
–43.3	–46	–50.8
–42.8	–45	–49.0
–42.2	–44	–47.2
–41.7	–43	–45.4
–41.1	–42	–43.6
–40.6	–41	–41.8
–40.0	–40	–40.0
–39.4	–39	–38.2
–38.9	–38	–36.4
–38.3	–37	–34.6
–37.8	–36	–32.8
–37.2	–35	–31.0
–36.7	–34	–29.2
–36.1	–33	–27.4
–35.5	–32	–25.6
–35.0	–31	–23.8
–34.4	–30	–22.0
–33.9	–29	–20.2
–33.3	–28	–18.4
–32.8	–27	–16.6
–32.2	–26	–14.8
–31.6	–25	–13.0
–31.1	–24	–11.2
–30.5	–23	–9.4
–30.0	–22	–7.6
–29.4	–21	–5.8

	Known Temp.	
°C	(°F or °C)	°F
–28.9	–20	–4.0
–28.3	–19	–2.2
–27.7	–18	–0.4
–27.2	–17	1.4
–26.6	–16	3.2
–26.1	–15	5.0
–25.5	–14	6.8
–25.0	–13	8.6
–24.4	–12	10.4
–23.8	–11	12.2
–23.3	–10	14.0
–22.7	–9	15.8
–22.2	–8	17.6
–21.6	–7	19.4
–21.1	–6	21.2
–20.5	–5	23.0
–20.0	–4	24.8
–19.4	–3	26.6
–18.8	–2	28.4
–18.3	–1	30.2
–17.8	0	32.0
–17.2	1	33.8
–16.7	2	35.6
–16.1	3	37.4
–15.6	4	39.2
–15.0	5	41.0
–14.4	6	42.8
–13.9	7	44.6
–13.3	8	46.4
–12.8	9	48.2
–12.2	10	50.0
–11.7	11	51.8
–11.1	12	53.6
–10.6	13	55.4
–10.0	14	57.2
–9.4	15	59.0
–8.9	16	60.8
–8.3	17	62.6
–7.8	18	64.4
–7.2	19	66.2
–6.7	20	68.0
–6.1	21	69.8
–5.6	22	71.6
–5.0	23	73.4
–4.4	24	75.2
–3.9	25	77.0
–3.3	26	78.8
–2.8	27	80.6
–2.2	28	82.4
–1.7	29	84.2
–1.1	30	86.0
–0.6	31	87.8
0	32	89.6
0.6	33	91.4

	Known Temp.	
°C	(°F or °C)	°F
1.1	34	93.2
1.7	35	95.0
2.2	36	96.8
2.8	37	98.6
3.3	38	100.4
3.9	39	102.2
4.4	40	104.0
5.0	41	105.8
5.6	42	107.6
6.1	43	109.4
6.7	44	111.2
7.2	45	113.0
7.8	46	114.8
8.3	47	116.6
8.9	48	118.4
9.4	49	120.2
10.0	50	122.0
10.6	51	123.8
11.1	52	125.6
11.7	53	127.4
12.2	54	129.2
12.8	55	131.0
13.3	56	132.8
13.9	57	134.6
14.4	58	136.4
15.0	59	138.2
15.6	60	140.0
16.1	61	141.8
16.7	62	143.6
17.2	63	145.4
17.8	64	147.2
18.3	65	149.0
18.9	66	150.8
19.4	67	152.6
20.0	68	154.4
20.6	69	156.2
21.1	70	158.0
21.7	71	159.8
22.2	72	161.6
22.8	73	163.4
23.3	74	165.2
23.9	75	167.0
24.4	76	168.8
25.0	77	170.6
25.6	78	172.4
26.1	79	174.2
26.7	80	176.0
27.2	81	177.8
27.8	82	179.6
28.3	83	181.4
28.9	84	183.2
29.4	85	185.0
30.0	86	186.8
30.6	87	188.6

	Known Temp.	
°C	(°F or °C)	°F
31.1	88	190.4
31.7	89	192.2
32.2	90	194.0
32.8	91	195.8
33.3	92	197.6
33.9	93	199.4
34.4	94	201.2
35.0	95	203.0
35.6	96	204.8
36.1	97	206.6
36.7	98	208.4
37.2	99	210.2
37.8	100	212.0
43	110	230
49	120	248
54	130	266
60	140	284
66	150	302
71	160	320
77	170	338
82	180	356
88	190	374
93	200	392
99	210	410
100	212	414
104	220	428
110	230	446
116	240	464
121	250	482
127	260	500
132	270	518
138	280	536
143	290	554
149	300	572
154	310	590
160	320	608
166	330	626
171	340	644
177	350	662
182	360	680
188	370	698
193	380	716
199	390	734
204	400	752
210	410	770
216	420	788
221	430	806
227	440	824
232	450	842
238	460	860
243	470	878
249	480	896
254	490	914
260	500	932

Table 1-5 Conversion to SI Units

Multiply	By	To Obtain
acre	0.4047	ha
atmosphere (standard)	101.325[a]	kPa
bar	100[a]	kPa
barrel (42 US gal, petroleum)	159 0.159	L m^3
Btu (International Table)	1.055	kJ
Btu/ft^2	11.36	kJ/m^2
Btu/ft^3	37.3	kJ/m^3
Btu/gal	279	kJ/m^3
Btu · ft/h · ft^2 · °F	1.731	W/(m · K)
Btu · in/h · ft^2 · °F (thermal conductivity, *k*)	0.1442	W/(m · K)
Btu/h	0.2931	W
Btu/h · ft^2	3.155	W/m^2
Btu/h · ft^2 · °F (overall heat transfer coefficient, *U*)	5.678	W/(m^2 · K)
Btu/lb$_m$	2.326[a]	kJ/kg
Btu/lb$_m$ · °F (specific heat, c_p)	4.186	kJ/(kg · K)
bushel	0.03524	m^3
calorie, gram	4.1868	J
calorie, kilogram (kilocalorie)	4.1868	kJ
centipoise (dynamic viscosity, μ)	1.00[a]	mPa · s
centistokes (kinematic viscosity, v)	1.00[a]	mm^2/s
clo	0.155	m^2 · K/W
dyne/cm^2	0.100[a]	Pa
EDR hot water (150 Btu/h)	44.0	W
EDR steam (240 Btu/h)	70.3	W
EER	0.293	COP
ft	0.3048[a] 304.8[a]	m mm
ft/min, fpm	0.00508[a]	m/s
ft/s, fps	0.3048[a]	m/s
ft of water	2.99	kPa
ft of water per 100 ft pipe	0.0981	kPa/m
ft^2	0.09290	m^2
ft^2 · h · °F/Btu (thermal resistance, *R*)	0.176	m^2 · K/W
ft^2/s (kinematic viscosity, v)	92.900	mm^2/s
ft^3	28.32 0.02832	L m^3
ft^3/min, cfm	0.4719	L/s
ft^3/s, cfs	28.32	L/s
To Obtain	**By**	**Divide**

Multiply	By	To Obtain
ft · lb$_f$ (torque or moment)	1.356	N · m
ft · lb$_f$ (work)	1.356	J
ft · lb$_f$/lb (specific energy)	2.99	J/kg
ft · lb$_f$/min (power)	0.0226	W
footcandle	10.76	lx
gallon (US, 231 in^3)	3.7854[a]	L
gph	1.05	mL/s
gpm	0.0631	L/s
gpm/ ft^2	0.6791	L/(s · m^2)
gpm/ton refrigeration	0.0179	mL/J
grain (1/7000 lb)	0.0648	g
gr/gal	17.1	g/m^3
gr/lb	0.143	g/kg
horsepower (boiler) (33,470 Btu/h)	9.81	kW
horsepower (550 ft · lb$_f$/s)	0.746	kW
inch	25.4[a]	mm
in of mercury (60°F)	3.377	kPa
in of water (60°F)	249	Pa
in/100 ft, thermal expansion	0.833	mm/m
in · lb$_f$ (torque or moment)	113	mN · m
in^2	645	mm^2
in^3 (volume)	16.4	mL
in^3/min (SCIM)	0.273	mL/s
in^3 (section modulus)	16,400	mm^3
in^4 (section moment)	416,200	mm^4
km/h	0.278	m/s
kWh	3.60[a]	MJ
kW/1000 cfm	2.12	kJ/m^3
kilopond (kg force)	9.81	N
kip (1000 lb$_f$)	4.45	kN
kip/in^2 (ksi)	6.895	MPa
litre	0.001[a]	m^3
met	58.15	W/m^2
micron (μm) of mercury (60°F)	133	mPa
mile	1.609	km
mile, nautical	1.852[a]	km
mph	1.609 0.447	km/h m/s
millibar	0.100[a]	kPa
mm of mercury (60°F)	0.133	kPa
mm of water (60°F)	9.80	Pa
To Obtain	**By**	**Divide**

(CONTINUED)

Table 1-5 Conversion to SI Units (continued)

Multiply	By	To Obtain
ounce (mass, avoirdupois)	28.35	g
ounce (force, thrust)	0.278	N
ounce (liquid, US)	29.6	mL
ounce inch (torque, moment)	7.06	mN · m
ounce (avoirdupois) per gallon	7.49	kg/m³
perm (permeance)	57.45	ng/(s · m² · Pa)
perm inch (permeability)	1.46	ng/(s · m · Pa)
pint (liquid, US)	473	mL
pound		
lb_m (mass)	0.4536 453.6	kg g
lb_f (force, thrust)	4.45	N
lb_m/ft (uniform load)	1.49	kg/m
lb_m/ft · h (dynamic viscosity, μ)	0.413	mPa · s
lb_m/ft · s (dynamic viscosity, μ)	1490	mPa · s
lb_f · s/ft² (dynamic viscosity, μ)	47.88	Pa · s
lb/h	0.126	g/s
lb/min	0.00756	kg/s
lb/h [steam at 212°F (100°C)]	0.284	kW
lb_f/ ft²	47.9	Pa
lb_m/ ft²	4.88	kg/m²
lb_m/ft³ (density, ρ)	16.0	kg/m³
lb_m/gallon	120	kg/m³
ppm (by mass)	1.00[a]	mg/kg
psi	6.895	kPa
quad (10^{15} Btu)	1.055	EJ
quart (liquid, US)	0.946	L
square (100 ft²)	9.29	m²
tablespoon (approx.)	15	mL
teaspoon (approx.)	5	mL
therm (US)	105.5	MJ
ton, long (2240 lb)	1.016	Mg
ton, short (2000 lb)	0.907	Mg; t (tonne)
ton, refrigeration (12,000 Btu/h)	3.517	kW
ton (1 mm Hg at 0°C)	133	Pa
watt per square foot	10.76	W/m²
yd	0.9144[a]	m
yd²	0.836	m²
yd³	0.7646	m³
To Obtain	**By**	**Divide**

Notes: 1. Units are US values unless noted otherwise. 2. Litre is a special name for the cubic decimetre. 1 L = dm³ and 1 mL = 1 cm³.

[a]Conversion factor is exact.

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3. Chan, Wen-Yung W., and Milton Meckler. 1983. "Pumps and Pump Systems." Sherman Oaks, Calif.: American Society of Plumbing Engineers.
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2 Standards for Plumbing Materials and Equipment

A plumbing engineer's life is surrounded by codes and standards. This chapter lists the majority of codes and standards used and referenced by the profession.

Codes and standards often cross paths to the point that it is difficult to understand the difference between a code and a standard. A code typically regulates a broad part of construction, whereas a standard regulates a very specific area. Codes often include installation, material, and approval requirements. Codes rely on standards and normally reference standards for specific materials or installation requirements. State and local jurisdictions adopt codes to regulate construction. The standard only becomes a legally enforceable document when it is referenced in the adopted code.

Sometimes a standard crosses the line and becomes a code. A good example is the National Fuel Gas Code. As the name implies, the document is a code that regulates the installation of fuel gas systems. However, the National Fuel Gas Code is an NFPA standard, NFPA 54. Another document that regulates fuel gas systems is the International Fuel Gas Code. This document is a code and does not have a standard designation.

Codes and standards are continually updated. As a result, as soon as this Data Book is published, the list of standards is out-of-date. To identify the specific edition of a standard, the date is located in the numerical designation of the standard. Whenever using a standard, it is appropriate to check with the standard-promulgating organization in order to identify the latest edition of that standard.

This chapter is separated into three sections: Standards Listed By Code and Standards Listed by Category (Table 2-1), Complete List of Standards By Standard Writing Organizations, and Organization Abbreviation, Address, and Phone Number Listing (Table 2-3). The first section identifies codes and standards based on their category. For example, the heading of water distribution piping aboveground lists the standards for each given material approved for such use. In this first section, only the standard acronym and number are identified. Not every standard is listed in this section. The more complete listing of standards appears in the second portion of the chapter. The third section provides information to contact the organizations.

In the second section, the standard designation, date, and full title of the standard appear. The standards are listed in alphabetical numerical order for each standard-promulgating agency. It should be noted that the American National Standards Institute (ANSI) accredits many standards as American National Standards. ANSI is the organization in the United States that oversees the development of national consensus standards. ANSI does not develop standards; they regulate (as an oversight organization) the agencies that promulgate standards, such as ASME.

ANSI identifies the standard by the acronym of the standard-promulgating agency. For example, the vitreous china fixture standard may be written as ANSI/ASME A112.19.2; however, both ANSI and ASME will also identify the same standard as ASME A112.19.2. For ease of identification, the ANSI has not been included in the table for the ANSI-accredited standards. The only listings of ANSI standards are the few remaining standards that do not have another acronym from a promulgating agency identifying the standard. A typical example is ANSI LC-1, which regulates corrugated stainless steel tubing.

Most standards are developed through a consensus process. This would include all ANSI, ASTM, and CSA standards. A consensus process requires the standards committee to be balanced between the various interest groups. For example, material standards will have manufacturers (producers), users (engineers), and general-interest representatives on the committee. The consensus process also requires all negative comments to be resolved. As a result of the consensus process, the standards are of a higher caliber, developed through a fair and open process.

Table 2-1 Codes and Standards Listed by Category

CODES LISTED BY CATEGORY	
Boiler Code	ASME BPVC, IAPMO UMC, ICC IMC
Building Code	ICC IBC, NFPA 5000
Energy Code	ASHRAE 90.1, ASHRAE 90.2, ICC IECC
Fuel Gas Code	IAPMO UPC, ICC IFGC, NFPA 54, NFPA 58
Mechanical Code	IAPMO UMC, ICC IMC
Plumbing Code	IAPMO UPC, ICC IPC, PHCC-NA NSPC
STANDARDS LISTED BY CATEGORY	
Aboveground Sanitary (or Storm) Drainage and Vent Pipe	
Acrylonitrile butadiene styrene (ABS) plastic pipe	ASTM D 2661; ASTM F 628; CSA B181.1
Brass pipe	ASTM B 43
Cast-iron pipe	ASTM A 74; ASTM A 888; CISPI 301
Coextruded composite ABS or PVC DWV pipe	ASTM F 1488
Copper or copper-alloy pipe	ASTM B 42; ASTM B 302
Copper or copper-alloy tubing	ASTM B 75; ASTM B 88; ASTM B 251; ASTM B 306
Galvanized steel pipe	ASTM A 53
Glass pipe	ASTM C 1053
Polyolefin pipe	CAN/CSA-B181.2
Polyvinyl chloride (PVC) plastic pipe (Type DWV)	ASTM D 2665; ASTM D 2949; ASTM F 891; CAN/CSA-B181.2; ASTM F 1488
Stainless steel drainage systems, types 304 and 316L	ASME/ANSI A112.3.
Backflow Preventers	
Air gap	ASME A112.1.2, ASME A112.1.3
Backflow preventer w/intermediate atmospheric vents	ASSE 1012, CAN/CSA-B64.3
Ballcock	ASSE 1002
Carbonated beverage dispensers backflow preventer	ASSE 1022
Double check backflow prevention assembly	ASSE 1015, ASSE 1048, AWWA C510
Dual-check-valve-type backflow preventer	ASSE 1024
Faucet and fixture fitting backflow devices	ASME A112.18.3
Hose connection backflow preventer	ASSE 1052
Hose-connection vacuum breaker	ASSE 1011, ASSE 1019, CAN/CSA-B64.2.2
Laboratory faucet backflow preventer	ASSE 1035, CSA B64.7
Pipe-applied atmospheric-type vacuum breaker	ASSE 1001, CAN/CSA-B64.1.1
Pressure vacuum breaker assembly	ASSE 1020, ASSE 1056
Reduced pressure principle backflow preventer	ASSE 1013, ASSE 1047, AWWA C511, CAN/CSA-B64.4
Building Storm Sewer Pipe	
Acrylonitrile butadiene styrene (ABS) plastic pipe	ASTM D 2661; ASTM D 2751; ASTM F 628
Asbestos-cement pipe	ASTM C 428
Cast-iron pipe	ASTM A 74; ASTM A 888; CISPI 301
Concrete pipe	ASTM C 14; ASTM C 76; CSA A257.1; CSA CAN/CSA A257.2
Copper or copper-alloy tubing	ASTM B 75; ASTM B 88; ASTM B 251; ASTM B 306
Polyvinyl chloride (PVC) plastic pipe	ASTM D 2665; ASTM D 3034; ASTM F 891; CSA B182.2; CAN/CSA B182.4
Stainless steel drainage systems, Type 316L	ASME/ANSI A112.3.1
Vitrified clay pipe	ASTM C 4; ASTM C 700
Fire Protection	
Combustibility test	ASTM E 136
Fire pumps	NFPA 20
Fire resistance rating test	ASTM E 119
Flame spread and smoke developed	ASTM E 84
One- and two-family dwelling sprinkler design	NFPA 13D
Residential sprinkler design	NFPA 13R

(CONTINUED)

Table 2-1 Codes and Standards Listed by Category (continued)

Sprinkler design	NFPA 13
Standpipe systems	NFPA 14
Through penetration fire test	ASTM E 814
Gas Piping	
Aluminum	ASTM B 210; ASTM B 211; ASTM B 241
Copper and copper-alloy tubing	ASTM B 88; ASTM B 280
Corrugated stainless steel tubing	ANSI LC1
Plastic pipe (underground only)	ASTM D 2513
Steel pipe	ASTM A 53; ASTM A 106
Joints and Connections	
ABS solvent cement	ASTM D 2235; CSA B181.1
Brazed filler metal	AWS A5.8
Cast iron hubless coupling	ASTM C1277; CISPI 310
CPVC solvent cement	ASTM F 493
Elastomeric Seal	ASTM C 425; ASTM C 443; ASTM C 477; ASTM C 564; ASTM C 1440; ASTM D 1869; CAN/CSA A257.3; CAN/CSA B602
Pipe thread	ASME B 1.20.1
PVC solvent cement	ASTM D 2564; CSA B137.3; CSA B181.2
PVC primer	ASTM F 656
Solder filler metal	ASTM B 32
Solder flux	ASTM B 813
Miscellaneous	
Air admittance valves	ASSE 1050, ASSE 1051
Backwater valves	ASME A112.14.1, CSA B181.1, CSA B181.2
Category II, III, IV vent systems	UL 1738
Disinfecting methods	AWWA 651, AWWA 652
Drinking water material protection	NSF 61
Factory built chimneys	UL 103
Grease traps and interceptors	ASME A112.14.3, ASME A112.14.4, PDI G101
Pipe hangers	MSS SP-58, MSS SP-69
Plastic pipe quality control	NSF 14
Type B vents	UL 441
Type L vents	UL 641
Water hammer arresters	ASSE 1010, PDI WH 201
Water heaters	ANSI Z21.10.1, ANSI Z21.10.3, UL 732, UL 1261
Pipe Nipples	
Steel	ASTM A 733
Brass-, copper-, chromium-plated	ASTM B 687
Plumbing Fixtures	
Bathtubs	ASME A112.19.1, ASME A112.19.4, ASME A112.19.7, ASME A112.19.9, ANSI Z124.1, CSA B45.2, CSA B45.3, CSA B45.5
Bidet	ASME A112.19.2, ASME A112.19.9, CSA B45.1
Dishwashing machines	ASSE 1004, ASSE 1006, NSF 3
Drinking fountains	ASME A112.19.1, ASME A112.19.2, ASME A112.19.9, ARI 1010
Emergency shower and eyewash stations	ISEA Z358.1
Faucets and fixture fittings	ASME A112.18.1, CSA B125
Fixture waste fittings	ASME A112.18.2
Floor drains	ASME A112.3.1, ASME A112.6.3, CSA B79
Food waste grinders	ASSE 1008, ASSE 1009

(CONTINUED)

Table 2-1 Codes and Standards Listed by Category (continued)

Lavatories	ASME A112.19.1, ASME A112.19.2, ASME A112.19.3, ASME A112.19.4, ASME A112.19.9, ANSI Z124.3, CSA B45.1, CSA B45.2, CSA B45.3, CSA B45.4
Pressure balancing valves	ASSE 1016, ASSE 1066
Roof drains	ASME A112.3.1, ASME A112.6.4
Showers	ASME A112.19.9, ANSI Z124.2, CSA B45.5
Sinks	ASME A112.19.1, ASME A112.19.2, ASME A112.19.3, ASME A112.19.4, ASME A112.19.9, ANSI Z124.6, CSA B45.1, CSA B45.2, CSA B45.3, CSA B45.4
Thermostatic mixing valves	ASSE 1016, ASSE 1017
Urinals	ASME A112.19.2, ANSI Z124.4, CSA B45.1, CSA B45.5
Wall carriers	ASME A112.6.1, ASME A112.6.2
Water closets	ASME A112.19.2, ANSI Z124.4, CSA B45.1, CSA B45.4, CSA B45.5
Sanitary Drainage Pipe Fittings	
Acrylonitrile butadiene styrene (ABS) plastic	ASTM D 2661; ASTM D 3311; CSA B181.1
Cast iron	ASME B16.4; ASME B16.12; ASTM A 74; ASTM A 888; CISPI 301
Copper or copper alloy	ASME B16.15; ASME B16.18; ASME B16.22; ASME B16.23; ASME B16.26; ASME B16.29; ASME B16.32
Glass	ASTM C 1053
Gray iron and ductile iron	AWWA C110
Malleable iron	ASME B16.3
Polyvinyl chloride (PVC) plastic	ASTM D 3311; ASTM D 2665
Stainless steel drainage systems	ASME/ANSI A112.3.1
Steel	ASME B16.9; ASME B16.11; ASME B16.28
Sanitary Sewer Pipe	
Acrylonitrile butadiene styrene (ABS) plastic pipe	ASTM D 2661; ASTM D 2751; ASTM F 628
Asbestos-cement pipe	ASTM C 428
Cast-iron pipe	ASTM A 74; ASTM A 888; CISPI 301
Coextruded composite ABS or PVC DWV pipe	ASTM F 1488
Concrete pipe	ASTM C 14; ASTM C 76; CSA A257.1; CAN/CSA A257.2
Copper or copper-alloy tubing	ASTM B 75; ASTM B 88; ASTM B 251
Polyvinyl chloride (PVC) plastic pipe	ASTM D 2665; ASTM D 2949; ASTM D 3034; ASTM F 891; CSA B182.2; CAN/CSA-B182.4
Stainless steel drainage systems, Type 316L	ASME/ANSI A112.3.1
Vitrified clay pipe	ASTM C 4; ASTM C 700
Subsoil Drainage Pipe	
Asbestos-cement pipe	ASTM C 508
Cast-iron pipe	ASTM A 74; ASTM A 888; CISPI 301
Polyethylene (PE) plastic pipe	ASTM F 405
Polyvinyl chloride (PVC) plastic pipe	ASTM D 2729; ASTM F 891; CSA-B182.2; CSA CAN/CSA-B182.4
Stainless steel drainage systems, Type 316L	ASME/ANSI A112.3.1
Vitrified clay pipe	ASTM C 4; ASTM C 700
Underground Building Sanitary (or Storm) Drainage and Vent Pipe	
Acrylonitrile butadiene styrene (ABS) plastic pipe	ASTM D 2661; ASTM F 628; CSA B181.1
Asbestos-cement pipe	ASTM C 428
Cast-iron pipe	ASTM A 74; ASTM A 888; CISPI 301
Coextruded composite ABS or PVC DWV pipe	ASTM F 1488

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Table 2-1 Codes and Standards Listed by Category (continued)

Copper or copper-alloy tubing	ASTM B 75; ASTM B 88; ASTM B 251; ASTM B 306
Polyolefin pipe	CAN/CSA-B181.2
Polyvinyl chloride (PVC) plastic pipe (Type DWV)	ASTM D 2665; ASTM D 2949; ASTM F 891; CAN/CSA-B181.2
Stainless steel drainage systems, Type 316L	ASME/ANSI A112.3.1
Water Distribution Piping (Aboveground)	
Brass pipe	ASTM B 43
Chlorinated polyvinyl chloride (CPVC) plastic pipe and tubing	ASTM D 2846; ASTM F 441; ASTM F 442; CSA B137.6
Copper or copper-alloy pipe	ASTM B 42; ASTM B 302
Copper or copper-alloy tubing	ASTM B 75; ASTM B 88; ASTM B 251; ASTM B 447
Cross-linked polyethylene (PEX) plastic tubing	ASTM F 877; CAN/CSA B137.5
Cross-linked polyethylene/aluminum/cross-linked polyethylene (PEX-AL-PEX) pipe	ASTM F 1281; CAN/CSA B137.10
Galvanized steel pipe	ASTM A 53
Polybutylene (PB) plastic pipe and tubing	ASTM D 3309; CSA CAN3-B137.8
Water Pipe Fittings	
Acrylonitrile butadiene styrene (ABS) plastic	ASTM D 2468
Cast iron	ASME B16.4; ASME B16.12
Chlorinated polyvinyl chloride (CPVC) plastic	ASTM F 437; ASTM F 438; ASTM F 439
Copper or copper alloy	ASME B16.18; ASME B16.22; ASME B16.23; ASME B16.26; ASME B16.29; ASME B16.32
Gray iron and ductile iron	AWWA C110; AWWA C153
Malleable iron	ASME B16.3
(PEX) Tubing	ASTM F 1807
Polyethylene (PE) plastic	ASTM D 2609
Polyvinyl chloride (PVC) plastic	ASTM D 2464; ASTM D 2466; ASTM D 2467; CAN/CSA-B137.2
Steel	ASME B16.9; ASME B16.11; ASME B16.28
Water Service Piping (Underground)	
Acrylonitrile butadiene styrene (ABS) plastic pipe	ASTM D 1527; ASTM D 2282
Asbestos-cement pipe	ASTM C 296
Brass pipe	ASTM B 43
Copper or copper-alloy pipe	ASTM B 42; ASTM B 302
Copper or copper-alloy tubing	ASTM B 75; ASTM B 88; ASTM B 251; ASTM B 447
Chlorinated polyvinyl chloride (CPVC) plastic pipe	ASTM D 2846; ASTM F 441; ASTM F 442; CSA B137.6
Cross-linked polyethylene (PEX) plastic tubing	ASTM F 876; ASTM F 877; CSA CAN/CSA-B137.5
Cross-linked polyethylene/ aluminum/cross-linked polyethylene (PEX-AL-PEX) pipe	ASTM F 1281; CAN/CSA B137.10
Ductile iron water pipe	AWWA C115; AWWA C151
Galvanized steel pipe	ASTM A 53
Polybutylene (PB) plastic pipe and tubing	ASTM D 2662; ASTM D 2666; ASTM D 3309; CSA B137.8
Polyethylene (PE) plastic pipe	ASTM D 2239; CAN/CSA-B137.1
Polyethylene (PE) plastic tubing	ASTM D 2737; CSA B137.1
Polyethylene/aluminum/polyethylene (PE-AL-PE) pipe	ASTM F 1282; CAN/CSA-B137.9
Polyvinyl chloride (PVC) plastic pipe	ASTM D 1785; ASTM D 2241; ASTM D 2672; CAN/CSA-B137.3

Table 2-2 Complete List of Standards By Standard-Writing Organization

ANSI

American National Standards Institute
25 West 43rd Street, Fourth Floor
New York, NY 10036

www.ansi.org
(212) 642-4900
(212) 398-0023 facsimile

LC1-97 (R2001)	Interior Gas Piping Systems Using Corrugated Stainless Steel Tubing
Z4.3-95	Minimum Requirements for Nonsewered Waste-Disposal Systems
Z21.8-94 (R2000)	Installation of Domestic Gas Conversion Burners
Z21.10.1-01	Gas Water Heaters – Volume I, Storage Water Heaters with Input Ratings of 75,000 Btu per Hour or Less
Z21.10.3-98	Gas Water Heaters – Volume III, Storage Water Heaters with Input Ratings Above 75,000 Btu per hour, Circulating and Instantaneous Water Heaters—with Z21.10.3a-99 Addendum
Z21.13-99	Gas-Fired Low-Pressure Steam and Hot Water Boilers— with Addenda Z21.13a-1993 and Z21.13b-1994
Z21.15-97	Manually Operated Gas Valves for Appliances, Appliance Connector Valves, and Hose End Valves
Z21.19-90	Refrigerators Using Gas (R1999) Fuel—with Addenda Z721.19a-1992 (R1999) and Z21.19b-1995 (R1999)
Z21.22-99	Relief Valves for Hot Water Supply Systems
Z21.40.1-96	Gas-Fired Heat Activated Air Conditioning and Heat Pump Appliances—with Z21.40.1a-98 Addendum
Z21.40.2-96	Gas-Fired Work Activated Air Conditioning and Heat Pump Appliances (Internal Combustion)—with Z21.40.2a-97 Addendum
Z21.42-93	Gas-Fired Illuminating Appliances
Z21.50-98	Vented Decorative Gas Appliances
Z21.56-98	Gas-Fired Pool Heaters—with Z21.56a-99 Addendum
Z21.61-83 (R1996)	Toilets, Gas-Fired
Z21.69-97	Connectors for Movable Gas Appliances
Z21.83-98	Fuel Cell Power Plants
Z21.84-99	Manually Lighted, Natural Gas Decorative Gas Appliances for Installation in Solid Fuel Burning Fireplaces
Z21.88-99	Vented Gas Fireplace Heaters
Z83.11-00	Gas Food Service Equipment (Ranges and Unit Broilers), Baking and Roasting Ovens, Fat Fryers, Counter Appliances and Kettles, Steam Cookers, and Steam Generators
Z124.1-95	Plastic Bathtub Units
Z124.2-95	Plastic Shower Receptors and Shower Stalls
Z124.3-95	Plastic Lavatories
Z124.4-96	Plastic Water Closet Bowls and Tanks
Z124.5-97	Plastic Toilet (Water Closet) Seats
Z124.6-97	Plastic Sinks
Z124.7-97	Prefabricated Plastic Spa Shells
Z124.9-94	Plastic Urinal Fixtures

ARI

Air-Conditioning & Refrigeration Institute
4100 North Fairfax Drive, Suite 200
Arlington, VA 22203

www.ari.org
(703) 524-8800
(703) 528-3816 facsimile

700-99	Specifications for Fluorocarbon and Other Refrigerants
1010-02	Self-Contained, Mechanically Refrigerated Drinking-Water Coolers

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continuted)

ASHRAE

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
1791 Tullie Circle, NE
Atlanta, GA 30329-2305

www.ashrae.org
(404) 636-8400
(404) 321-5478 facsimile

15-2001	Safety Standard for Refrigeration Systems
34-2001	Designation and Safety Classification of Refrigerants
90.1-2001	Energy Standards for Buildings Except for Low Rise Residential Buildings
90.2-2001	Energy Efficient Design for Low Rise Residential Buildings
100-1995	Energy Conservation in Existing Buildings
118.1-2003	Method of Testing for Rating Commercial Gas, Electric, and Oil Service Water Heating Equipment
118.2-1993	Method of Testing for Rating Residential Water Heaters
124-1991	Method of Testing for Rating Combination Space Heating and Water Heating Appliances
137-1995	Method of Testing for Efficiency of Space Conditioning/Water Heating Appliances that Include a Desuperheater Water Heater
146-1998	Method of Testing and Rating Pool Heaters

ASME

American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016-5990

www.asme.org
800-THE-ASME (843-2763)
(973) 882-1717 facsimile (Inquiries)
(212) 591-7674 facsimile (NY)

A112.1.2-1991 (R2002)	Air Gaps in Plumbing Systems
A112.1.3-2000	Air Gap Fittings for Use with Plumbing Fixtures, Appliances and Appurtenances
A112.3.1-1993	Performance Standard and Installation Procedures for Stainless Steel Drainage Systems or Sanitary, Storm and Chemical Applications, Above and Below Ground
A112.3.4-2000	Macerating Toilet Systems and Related Components
A112.4.1-1993 (R2002)	Water Heater Relief Valve Drain Tubes
A112.4.3-1999	Plastic Fittings for Connecting Water Closets to the Sanitary Drainage System
A112.4.7-2002	Point of Use and Branch Water Submetering Systems
A112.6.1M-1997 (R2002)	Floor-Affixed Supports for Off-the-Floor Plumbing Fixtures for Public Use
A112.6.2-2000	Framing-Affixed Supports for Off-the-Floor Water Closets with Concealed Tanks
A112.6.3-2001	Floor and Trench Drains
A112.6.4-2003	Roof, Deck, and Balcony Drains
A112.6.7-2001	Enameled and Epoxy-Coated Cast-Iron and PVC Plastic Sanitary Floor Sinks.
A112.14.1-1975 (R1998)	Backwater Valves.
A112.14.3-2000	Grease Interceptors
A112.14.4-2001	Grease Removal Devices
A112.18.1-2003	Plumbing Fixture Fittings
A112.18.2-2002	Plumbing Fixture Waste Fittings
A112.18.3M-2003	Performance Requirements for Backflow Protection Devices and Systems in Plumbing Fixture Fittings
A112.18.6-1999	Flexible Water Connectors
A112.18.7-99-2000	Deck mounted Bath/Shower Transfer Valves with Internal Backflow Protection
A112.19.1M-1994 (R1999)	Enameled Cast Iron Plumbing Fixtures
A112.19.2M-1998	Vitreous China Plumbing Fixtures
A112.19.3-2001	Stainless Steel Plumbing Fixtures (Designed for Residential Use)
A112.19.4M-1994 (R1999)	Porcelain Enameled Formed Steel Plumbing Fixtures
A112.19.5-1999	Trim for Water-Closet Bowls, Tanks, and Urinals

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continuted)

A112.19.6-1995	Hydraulic Performance Requirements for Water Closets and Urinals
A112.19.7M-1995	Whirlpool Bathtub Appliances
A112.19.8M-1987 (R1996)	Suction Fittings for Use in Swimming Pools, Wading Pools, Spas, Hot Tubs, and Whirlpool Bathtub Appliances
A112.19.9M-1991 (R1998)	Non-Vitreous Ceramic Plumbing Fixtures
A112.19.12-2000	Wall Mounted and Pedestal Mounted, Adjustable and Pivoting Lavatory and Sink Carrier Systems
A112.19.13-2001-2002	Electrohydraulic Water Closets
A112.19.14-2001	Six-Liter Water Closets Equipped With a Dual Flushing Device
A112.19.15-2001	Bathtub/Whirlpool Bathtubs with Pressure Sealed Doors
A112.19.17-2002	Manufacturers Safety Vacuum Release Systems (SVRS) for Residential and Commercial Swimming Pool, Spa, Hot Tub, and Wading Pool Suction Systems
A112.21.1M-1991 (R1998)	Floor Drains
A112.36.2M-1991 (R2002)	Cleanouts
B1.20.1-1983 (R2001)	Pipe Threads, General Purpose (inch)
B16.1-1998	Cast Iron Pipe Flanges and Flanged Fittings, Class 25, 125 and 250
B16.3-1998	Malleable Iron Threaded Fittings Classes 150 and 300
B16.4-1998	Gray Iron Threaded Fittings Classes 125 and 250
B16.5-1996	Pipe Flanges and Flanged Fittings NPS ½ through NPS 24—with B16.5a-1998 Addendum
B16.9-2001	Factory-Made Wrought Steel Buttwelding Fittings
B16.11-2001	Forged Fittings, Socket-Welding and Threaded
B16.12-1998	Cast-Iron Threaded Drainage Fittings
B16.15-1985(R1994)	Cast Bronze Threaded Fittings, Classes 125 and 250
B16.18-2002	Cast Copper Alloy Solder Joint Pressure Fittings
B16.20-1998	Metallic Gaskets for Pipe Flanges Ring-Joint, Spiral-Wound, and Jacketed—with B16.20a-2000 Addendum
B16.22-2002	Wrought Copper and Copper Alloy Solder Joint Pressure Fittings
B16.23-2002	Cast Copper Alloy Solder Joint Drainage Fittings DWV
B16.24-2002	Cast Copper Alloy Pipe Flanges and Flanged Fittings: Class 150, 300, 400, 600, 900, 1500 and 2500
B16.26-1988	Cast Copper Alloy Fittings for Flared Copper Tubes
B16.28-1994	Wrought Steel Buttwelding Short Radius Elbows and Returns
B16.29-2001	Wrought Copper and Wrought Copper Alloy Solder Joint Drainage Fittings—DWV
B16.33-1990	Manually Operated Metallic Gas Valves for Use in Gas Piping Systems up to 125 psig (Sizes ½ through 2)
B16.50-2001-2002	Wrought Copper and Copper Alloy Braze-Joint Pressure Fittings
B31.3-2002	Process Piping
B36.10M-2001	Welded and Seamless Wrought-Steel Pipe
BPVC-2001	Boiler & Pressure Vessel Code (Sections I, II, IV, V & VI)
CSD-1-1998	Control and Safety Devices for Automatically Fired Boilers with the ASME CSD-1a-1999 Addendum

ASSE

American Society of Sanitary Engineering
901 Canterbury Road, Suite A
Westlake, OH 44145

www.asse-plumbing.org
(440) 835-3040
(440) 835-3488 facsimile

1001 – 2002	Atmospheric Type Vacuum Breakers
1002 – 1999	Water Closet Flush Tank Ball Cocks
1003 – 2001	Water Pressure Reducing Valves for Domestic Water Supply Systems
1004 – 1990	Backflow Prevention for Commercial Dishwashing Machines
1005 – 1999	Water Heater Drain Valves
1006 – 1986	Residential Use Dishwashers
1007 – 1992	Home Laundry Equipment

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continuted)

1008 – 1986	Household Food Waste Disposer Units
1009 – 1990	Commercial Food Waste Grinder Units
1010 – 1998	Water Hammer Arresters
1011 – 1995	Hose Connection Vacuum Breakers
1012 – 2002	Backflow Preventer with Intermediate Atmospheric Vent
1013 – 1999	Reduced Pressure Principle Backflow Preventers and Reduced Pressure Principle Fire Protection Backflow Preventers
1014 – 1989	Handheld Showers
1015 – 1999	Double Check Backflow Prevention Assemblies and Double Check Fire Protection Backflow Prevention Assemblies
1016 – 1996	Individual Thermostatic, Pressure Balancing and Combination Pressure Balancing and Thermostatic Control Valves for Individual Fixture Fittings
1017 – 2003	Temperature Actuated Mixing Valves for Hot Water Distribution Systems
1019 – 1997	Vacuum Breaker Wall Hydrants, Freeze Resistant, Automatic Draining Type
1020 – 1998	Vacuum Breakers, Anti-siphon, Pressure Type
1021 – 2001	Drain Air Gaps for Domestic Dishwashers
1022 – 2003	Backflow Preventer for Carbonated Beverage Dispensing Equipment
1023 – 1979	Plumbing Requirements for Hot Water Dispensers, Household Storage Type, Electrical
1024 – 2003	Dual Check Valve Type Backflow Preventers—Revised 1994
1025 – 1978	Diverters for Plumbing Faucets with Hose Spray, Anti-Siphon Type, Residential Applications
1032 – 1980	Dual Check Valve Type Backflow Preventer for Carbonated Beverage Dispensers –Post Mix Type
1035 – 2002	Laboratory Faucet Backflow Preventers
1037 – 1990	Pressurized Flushing Devices for Plumbing Fixtures
1043 – 1992	Cast Iron Sovent Sanitary Drainage Systems
1044 – 2002	Trap Seal Primer Devices—Drainage Types and Electric Design Types
1047 – 1999	Reduced Pressure Detector Fire Protection Backflow Prevention Assemblies
1048 – 1999	Double Check Detector Fire Protection Backflow Prevention Assemblies
1050 – 2002	Air Admittance Valves for DWV Systems, Stack Type Device
1051 – 2002	Air Admittance Valves for Plumbing Drainage Systems
1052 – 1994	Hose Connection Backflow Preventers
1055 – 1997	Chemical Dispensing Systems
1056 – 2001	Spill Resistant Vacuum Breakers
1057 – 2001	Freeze Resistant Sanitary Yard Hydrants with Backflow Protection
1060 – 1996	Outdoor Enclosures for Backflow Prevention Assemblies
1062 – 1997	Temperature Actuated, Flow Reduction (TAFR) Valves for Individual Fixture Fittings
1064 – 2002	Backflow Prevention Assembly Field Test Kits
1066 – 1997	Individual Pressure Balancing in-Line Valves for Individual Fixture Fittings

ASTM

ASTM International
100 Barr Harbor Drive
P.O. Box C700
West Conshohocken, PA 19428-2959

www.astm.org
(610) 832-9585
(610) 832-9555 facsimile

A 53/A 53M-02	Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless
A 74-03b	Specification for Cast Iron Soil Pipe and Fittings
A 106-02a	Specification for Seamless Carbon Steel Pipe for High-Temperature Service
A 126-01	Specification for Gray Iron Castings for Valves, Flanges, and Pipe Fittings
A 254-97(2002)	Specification for Copper-Brazed Steel Tubing
A 312/A 312M-03	Specification for Seamless and Welded Austenitic Stainless Steel Pipes
A 420/A 420M-03	Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service
A 539-99	Specification for Electric-Resistance-Welded Coiled Steel Tubing for Gas and Fuel Oil Lines

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continuted)

A 733-03	Specification for Welded and Seamless Carbon Steel and Austenitic Stainless Steel Pipe Nipples
A 778-01	Specification for Welded, Unannealed Austenitic Stainless Steel Tubular Products
A 888-03	Specification for Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste and Vent Piping Applications
B 32-03	Specification for Solder Metal
B 42-02e1	Specification for Seamless Copper Pipe, Standard Sizes
B 43-98e1	Specification for Seamless Red Brass Pipe, Standard Sizes
B 68-02	Specification for Seamless Copper Tube, Bright Annealed
B 75-02	Specification for Seamless Copper Tube
B 88-03	Specification for Seamless Copper Water Tube
B 135-02	Specification for Seamless Brass Tube
B 152/B 152M-00	Specification for Copper Sheet, Strip, Plate and Rolled Bar
B 210-02	Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes
B 211-03	Specification for Aluminum and Aluminum-Alloy Bar, Rod and Wire
B 241/B 241M-02	Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube
B 251-02e1	Specification for General Requirements for Wrought Seamless Copper and Copper-Alloy Tube
B 280-03	Specification for Seamless Copper Tube for Air Conditioning and Refrigeration Field Service
B 302-02	Specification for Threadless Copper Pipe, Standard Sizes
B 306-02	Specification for Copper Drainage Tube (DWV)
B 447-02	Specification for Welded Copper Tube
B 687-99	Specification for Brass, Copper, and Chromium-Plated Pipe Nipples
B 813-00e01	Specification for Liquid and Paste Fluxes for Soldering of Copper and Copper Alloy Tube
B 828-02	Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings
C 4-03	Specification for Clay Drain Tile and Perforated Clay Drain Tile
C 14-03	Specification for Concrete Sewer, Storm Drain, and Culvert Pipe
C 76-03	Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe
C 296-00	Specification for Asbestos-Cement Pressure Pipe
C 411-97	Test Method for Hot-Surface Performance of High-Temperature Thermal Insulation
C 425-02	Specification for Compression Joints for Vitrified Clay Pipe and Fittings
C 428-97(2002)	Specification for Asbestos-Cement Nonpressure Sewer Pipe
C 443-02a	Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets
C 508-00	Specification for Asbestos-Cement Underdrain Pipe
C 564-03	Specification for Rubber Gaskets for Cast Iron Soil Pipe and Fittings
C 700-02	Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated
C 913-98	Specification for Precast Concrete Water and Waste Water Structures
C 1053-00	Specification for Borosilicate Glass Pipe and Fittings for Drain, Waste, and Vent (DWV) Applications
C 1173-02	Specification for Flexible Transition Couplings for Underground Piping Systems
C 1277-03	Specification for Shielded Coupling Joining Hubless Cast Iron Soil Pipe and Fittings
C 1440-99e1	Specification for Thermoplastic Elastomeric (TPE) Gasket Materials for Drain, Waste, and Vent (DWV), Sewer, Sanitary and Storm Plumbing Systems
C 1460-00	Specification for Shielded Transition Couplings for Use with Dissimilar DWV Pipe and Fittings Above Ground
C 1461-02	Specification for Mechanical Couplings Using Thermoplastic Elastomeric (TPE) Gaskets for Joining Drain, Waste, and Vent (DWV) Sewer, Sanitary and Storm Plumbing Systems for Above and Below Ground Use
D 1527-99	Specification for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe, Schedules 40 and 80
D 1785-99	Specification for Poly (Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80 and 120
D 1869-95(2000)	Specification for Rubber Rings for Asbestos-Cement Pipe
D 2235-01	Specification for Solvent Cement for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe and Fittings
D 2239-03	Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter
D 2241-00	Specification for Poly (Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR-Series)
D 2282-99	Specification for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (SDR-PR)

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continuted)

D 2447-03	Specification for Polyethylene (PE) Plastic Pipe, Schedules 40 and 80, Based on Outside Diameter
D 2464-99	Specification for Threaded Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80
D 2466-02	Specification for Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 40
D 2467-02	Specification for Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80
D 2468-96a	Specification for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe Fittings, Schedule 40
D 2513-01A	Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings
D 2564-02	Specification for Solvent Cements for Poly (Vinyl Chloride) (PVC) Plastic Piping Systems
D 2609-02	Specification for Plastic Insert Fittings for Polyethylene (PE) Plastic Pipe
D 2657-03	Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings
D 2661-02	Specification for Acrylonitrile-Butadiene-Styrene (ABS) Schedule 40 Plastic Drain, Waste, and Vent Pipe and Fittings
D 2662-96a	Specification for Polybutylene (PB) Plastic Pipe (SDR-PR) Based on Controlled Inside Diameter
D 2665-02ae1	Specification for Poly (Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings
D 2666-96a(2003)	Specification for Polybutylene (PB) Plastic Tubing
D 2672-96a(2003)	Specification for Joints for IPS PVC Pipe Using Solvent Cement
D 2683-98	Specification for Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing
D 2729-96a	Specification for Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings
D 2737-03	Specification for Polyethylene (PE) Plastic Tubing
D 2751-96a	Specification for Acrylonitrile-Butadiene-Styrene (ABS) Sewer Pipe and Fittings
D 2846/D 2846M-99	Specification for Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Hot and Cold Water Distribution Systems
D 2855-96(2002)	Standard Practice for Making Solvent-Cemented Joints with Poly (Vinyl Chloride) (PVC) Pipe and Fittings
D 2949-01a	Specification for 3.25-In Outside Diameter Poly (Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings
D 2996-01	Specification for Filament-Wound "Fiberglass" (Glass Fiber Reinforced Thermosetting-Resin) Pipe
D 3034-00	Specification for Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings
D 3035-01	Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter
D 3139-98	Specification for Joints for Plastic Pressure Pipes Using Flexible Elastomeric Seals
D 3212-96a(2003)	Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
D 3309-96a(2002)	Specification for Polybutylene (PB) Plastic Hot and Cold Water Distribution Systems
D 3311-02	Specification for Drain, Waste and Vent (DWV) Plastic Fittings Patterns
D 3350-02a	Specification for Polyethylene Plastics Pipe and Fittings Materials
D 4068-01	Specification for Chlorinated Polyethylene (CPE) Sheeting for Concealed Water-Containment Membrane
D 4551-96(2001)	Specification for Poly (Vinyl Chloride) (PVC) Plastic Flexible Concealed Water-Containment Membrane
E 84-03b	Test Method for Surface Burning Characteristics of Building Materials
E 119-00a	Test Method for Fire Tests of Building Construction and Materials
E 136-99e01	Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C
E 814-02	Test Method for Fire Tests of Through-Penetration Fire Stops
F 405-97	Specification for Corrugated Polyethylene (PE) Tubing and Fittings
F 409-02	Specification for Thermoplastic Accessible and Replaceable Plastic Tube and Tubular Fittings
F 437-99	Specification for Threaded Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80
F 438-02e1	Specification for Socket-Type Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 40
F 439-02e1	Specification for Socket-Type Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80
F 441/F 441M-02	Specification for Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe, Schedules 40 and 80
F 442/F 442M-99	Specification for Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe (SDR-PR)
F 477-02e1	Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continuted)

F 493-97	Specification for Solvent Cements for Chlorinated Poly (Vinyl Chloride) (CPVC) Plastic Pipe and Fittings
F 628-01	Specification for Acrylonitrile-Butadiene-Styrene (ABS) Schedule 40 Plastic Drain, Waste, and Vent Pipe with a Cellular Core
F 656-02	Specification for Primers for Use in Solvent Cement Joints of Poly (Vinyl Chloride) (PVC) Plastic Pipe and Fittings
F 714-03	Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
F 876-03a	Specification for Cross-Linked Polyethylene (PEX) Tubing
F 877-02e	Specification for Cross-Linked Polyethylene (PEX) Plastic Hot and Cold Water Distribution Systems
F 891-00e1	Specification for Coextruded Poly (Vinyl Chloride) (PVC) Plastic Pipe with a Cellular Core
F 1055-98e1	Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing
F 1281-03	Specification for Cross-Linked Polyethylene/Aluminum/Cross-linked Polyethylene (PEX-AL-PEX) Pressure Pipe
F 1282-03	Specification for Polyethylene/Aluminum/Polyethylene (PE-AL-PE) Composite Pressure Pipe
F 1488-03	Specification for Coextruded Composite Pipe
F 1807-03	Specification for Metal Insert Fittings Utilizing a Copper Crimp Ring for SDR9 Cross-Linked Polyethylene (PEX) Tubing
F 1866-98	Specification for Poly (Vinyl Chloride) (PVC) Plastic Schedule 40 Drainage and DWV Fabricated Fittings
F 1960-03	Specification for Cold Expansion Fittings with PEX Reinforcing Rings for use with Cross-Linked Polyethylene (PEX) Tubing
F 1974-02	Specification for Metal Insert Fittings for Polyethylene/Aluminum/Polyethylene and Cross-Linked Polyethylene/Aluminum/Cross-Linked Polyethylene Composite Pressure Pipe
F 2080-02	Specifications for Cold-Expansion Fittings with Metal Compression-Sleeves for Cross-Linked Polyethylene (PEX) Pipe

AWS

American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

www.aws.org
(800) 443-9353
(305) 443-5951 facsimile

A5.8-92	Specifications for Filler Metals for Brazing and Braze Welding

AWWA

American Water Works Association
6666 West Quincy Avenue
Denver, CO 80235

www.awwa.org
(800) 926-7337
(303) 347-0804 facsimile

C104-95	Standard for Cement-Mortar Lining for Ductile-Iron Pipe and Fittings for Water
C110-98	Standard for Ductile-Iron and Gray-Iron Fittings, 3 Inches Through 48 Inches, for Water
C111-00	Standard for Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings
C115-99	Standard for Flanged Ductile-Iron Pipe with Ductile-Iron or Gray-Iron Threaded Flanges
C151/A21.51-902	Standard for Ductile-Iron Pipe, Centrifugally Cast for Water
C153-00	Standard for Ductile-Iron Compact Fittings, 3 in. Through 24 in. and 54 in. Through 64 in. for Water Service
C510-97	Double Check Valve Backflow Prevention Assembly
C511-97	Reduced-Pressure Principle Backflow Prevention Assembly
C651-99	Disinfecting Water Mains
C652-02	Disinfection of Water-Storage Facilities

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continted)

CISPI

Cast Iron Soil Pipe Institute
5959 Shallowford Road, Suite 419
Chattanooga, TN 37421

www.cispi.org
(423) 892-0137
(423) 892-0817 facsimile

301-00	Specification for Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste and Vent Piping Applications
310-97	Specification for Coupling for Use in Connection with Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste and Vent Piping Applications

CGA

Compressed Gas Association
4221 Walney Rd., 5th Floor
Chantilly, VA 20151-2923

www.cganet.com
(703) 788-2700
(703) 961-1831 facsimile

S-1.1-(1994)	Pressure Relief Device Standards-Part 1-Cylinders for Compressed Gases
S-1.2-(1995)	Pressure Relief Device Standards-Part 2-Cargo and Portable Tanks for Compressed Gases
S-1.3-(1995)	Pressure Relief Device Standards-Part 3-Stationary Storage Containers for Compressed Gases

CSA

Canadian Standards Association
178 Rexdale Blvd.
Toronto, Ontario, Canada M9W 1R3

www.csa-international.org
(416) 747-4000 or 866-797-4272
(416) 747-4149 facsimile

B45.1-02	Ceramic Plumbing Fixtures
B45.2-02	Enameled Cast-Iron Plumbing Fixtures
B45.3-02	Porcelain Enameled Steel Plumbing Fixtures
B45.4-02	Stainless-Steel Plumbing Fixtures
B45.5-02	Plastic Plumbing Fixtures
B45.9-02	Macerating Systems and Related Components
B45.10-01	Hydromassage Bathtubs
B64.7-01	Vacuum Breakers, Laboratory Faucet Type (LFVB)
B79-94(2000)	Floor, Area and Shower Drains, and Cleanouts for Residential Construction
B125-01	Plumbing Fittings
B137.1-02	Polyethylene Pipe, Tubing and Fittings for Cold Water Pressure Services
B137.2-02	PVC Injection-Moulded Gasketed Fittings for Pressure Applications
B137.3-02	Rigid Poly (Vinyl Chloride) (PVC) Pipe for Pressure Applications
B137.5-02	Cross-Linked Polyethylene (PEX) Tubing Systems for Pressure Applications—with Revisions Through September 1992
B137.6-02	CPVC Pipe, Tubing and Fittings for Hot and Cold Water Distribution Systems—with Revisions Through May 1986
B137.8-99	Polybutylene (PB) Piping for Pressure Applications
B181.1-99	ABS Drain, Waste, and Vent Pipe and Pipe Fittings
B181.2-99	PVC Drain, Waste, and Vent Pipe and Pipe Fittings—with Revisions Through December 1993
B182.1-02	Plastic Drain and Sewer Pipe and Pipe Fittings
B182.2-02	PVC Sewer Pipe and Fittings (PSM Type)
CAN3-B137.8M-99	Polybutylene (PB) Piping for Pressure Applications—with Revisions through July 1992
CAN/CSA-A257.1M-92	Circular Concrete Culvert, Storm Drain, Sewer Pipe and Fittings
CAN/CSA-A257.2M-92	Reinforced Circular Concrete Culvert, Storm Drain, Sewer Pipe and Fittings

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continuted)

CAN/CSA-A257.3M0-92	Joints for Circular Concrete Sewer and Culvert Pipe, Manhole Sections, and Fittings Using Rubber Gaskets
CAN/CSA-B64.1.1-01	Vacuum Breakers, Atmospheric Type (AVB)
CAN/CSA-B64.2-01	Vacuum Breakers, Hose Connection Type (HCVB) 608.13.6
CAN/CSA-B64.2.2-01	Vacuum Breakers, Hose Connection Type (HCVB) with Automatic Draining Feature
CAN/CSA-B64.3-01	Backflow Preventers, Dual Check Valve Type with Atmospheric Port (DCAP)
CAN/CSA-B64.4-01	Backflow Preventers, Reduced Pressure Principle Type (RP)
CAN/CSA-B64.10-01	Manual for the Selection, Installation, Maintenance and Field Testing of Backflow Prevention Devices
CAN/CSA-B137.1-99	Polyethylene Piping (PE), Tubing, and Fittings for Cold-Water Pressure Services
CAN/CSA-B137.3-99	Rigid Polyvinyl Chloride (PVC) Pipe for Pressure Applications
CAN/CSA-B137.5-99	Cross-Linked Polyethylene (PEX) Tubing Systems for Pressure Applications
CAN/CSA-B137.9-02	Polyethylene/Aluminum/Polyethylene Composite Pressure Pipe Systems
CAN/CSA-B137.10M-02	Cross-linked Polyethylene/Aluminum/Polyethylene Composite Pressure Pipe Systems
CAN/CSA-B181.2-99	PVC Drain, Waste, and Vent Pipe and Pipe Fittings
CAN/CSA-B181.3-02	Polyolefin Laboratory Drainage Systems
CAN/CSA-B182.4-02	Profile PVC Sewer Pipe and Fittings
CAN/CSA-B602-02	Mechanical Couplings for Drain, Waste, and Vent Pipe and Sewer Pipe

DOTn

Department of Transportation
400 Seventh St. SW
Washington, DC 20590

www.dot.gov
(202) 366-4000

49 CFR	Parts 192.281(e) & 192.283 (b) Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards Parts 100-180 Hazardous Materials Regulations

FS*

Federal Specification
1941 Jefferson Davis Highway, Suite 104
Arlington, VA 22202

* Standards are available from the Supt. of Documents, U.S. Government Printing Office, Washington, DC 20402-9325

TT-P-1536A(1975)	Federal Specification for Plumbing Fixture Setting Compound
WW-P-325B (1976)	Pipe, Bends, Traps, Caps and Plugs; Lead (for Industrial Pressure and Soil and Waste Applications)

IAPMO

International Association of Plumbing and Mechanical Officials
5001 E. Philadelphia St.
Ontario, CA 91761-2816

www.iapmo.org
909-472-4100
909-472-4150 facsimile

UMC-03	Uniform Mechanical Code
UPC-03	Uniform Plumbing Code
USEC-00	Uniform Solar Energy Code
USPC-00	Uniform Swimming Pool, Spa and Hot Tub Code

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continuted)

ICC	**International Code Council** 5203 Leesburg Pike, Suite 600 Falls Church, VA 22041 www.iccsafe.org 703-931-4533 703-379-1546 facsimile
IBC-03	International Building Code
ICC EC-03	ICC Electrical Code
IEBC-03	International Existing Building Code
IECC-03	International Energy Conservation Code
IFC-03	International Fire Code
IFGC-03	International Fuel Gas Code
IMC-03	International Mechanical Code
IPC-03	International Plumbing Code
IPSDC-03	International Private Sewage Disposal Code
IRC-03	International Residential Code
ISEA	**Industry Safety Equipment Association** 1901 N. Moore Street, Suite 808 Arlington, VA 22209-1762 www.safetyequipment.org (703) 525-1695 (703) 528-2148 facsimile
Z358.1-2004	Emergency Eyewash and Shower Equipment
MSS	**Manufacturers Standardization Society of the Valve & Fittings Industry, Inc.** 127 Park Street, N.E. Vienna, VA 22180 www.mss-hq.com (703) 281-6613 (703) 281-6671 facsimile
SP-6-2001	Standard Finishes for Contact Faces of Pipe Flanges and Connecting-End Flanges of Valves and Fittings
SP-58-2002	Pipe Hangers and Supports—Materials, Design and Manufacture
SP-69-2002	Pipe Hangers and Supports-Selection and Application
SP-70-1998	Cast Iron Gate Valves, Flanged and Threaded Ends
SP-72-1999	Ball Valves with Flanged or Butt-Welding Ends for General Service
SP-80-2003	Bronze Gate, Globe, Angle and Check Valves
NFPA	**National Fire Protection Association** 1 Batterymarch Park Quincy, MA 02269 www.nfpa.org (617) 770-3000 (617) 770-0700 facsimile
1-03 Uniform Fire Code	
13-02	Installation of Sprinkler Systems
13D-02	Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes
13R-02	Installation of Sprinkler Systems in Residential Occupancies up to and Including 4 Stories in Height
14-03	Installation of Standpipe, Private Hydrants and Hose Systems
20-99	Installation of Stationary Pumps for Fire Protection

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continuted)

24-02	Installation of Private Fire Service Mains and Their Appurtenances
25-02	Inspection, Testing and Maintenance of Water-Based Fire Protection Systems
30-03	Flammable and Combustible Liquids Code
31-01	Installation of Oil-Burning Equipment
37-02	Stationary Combustion Engines and Gas Turbines
45-00	Fire Protection for Laboratories Using Chemicals
50-01	Bulk Oxygen Systems at Consumer Sites
50A-99	Gaseous Hydrogen Systems at Consumer Sites
51-02	Design and Installation of Oxygen-Fuel Gas Systems for Welding, Cutting, and Allied Processes
54-02	National Fuel Gas Code
58-01	Liquefied Petroleum Gas Code
69-02	Explosion Prevention Systems
70-02	National Electrical Code
72-02	National Fire Alarm Code
85-01	Boiler and Construction Systems Hazards Code
88B-97	Repair Garages
96-01	Ventilation Control and Fire Protection of Commercial Cooking Operations
99-02	Standard for Health Care Facilities
101-03	Life Safety Code
211-03	Chimneys, Fireplaces, Vents, and Solid Fuel-Burning Appliances
704-01	Identification of the Hazards of Materials for Emergency Response
853-00	Installation of Stationary Fuel Cell Power Plants
5000-03	Building Construction and Safety Code
8501-01	Single Burner Boiler Operation
8502-99	Prevention of Furnace Explosions/Implosions in Multiple Burner Boiler-Furnaces
8504-96	Atmospheric Fluidized-Bed Boiler Operation

NSF

National Sanitation Foundation
789 N. Dixboro Road
P.O. Box 130140
Ann Arbor, MI 48113-0140

www.nsf.org
800-NSF-Mark
(734) 769-0109 facsimile

3-2003	Commercial Warewashing Equipment
14-2003	Plastic Piping System Components and Related Materials
18-1996	Manual Food and Beverage Dispensing Equipment
40-2000	Residential Wastewater Treatment Systems
41-1999	Non-Liquid Saturated Treatment Systems (Composting Toilets)
42-2002	Drinking Water Treatment Units—Aesthetic Effects
44-2002	Residential Cation Exchange Water Softeners
53-2002	Drinking Water Treatment Units—Health Effects
58-2002	Reverse Osmosis Drinking Water Treatment Systems
61-2002	Drinking Water System Components—Health Effects
62-2002	Drinking Water Distillation Systems

PDI

Plumbing and Drainage Institute
800 Turnpike Street, Suite 300
North Andover, MA 01845

www.pdionline.org
(978) 557-0720
(978) 557-0721 facsimile

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Table 2-2 Complete List of Standards By Standard-Writing Organization (continuted)

G101-2003	Testing and Rating Procedure for Grease Interceptors with Appendix of Sizing and Installation Data
WH201-1994	Water Hammer Arresters

PHCC-NA

Plumbing Heating and Cooling Contractors National Association
180 S. Washington St.
P.O. Box 6808
Falls Church, VA 22040

www.phccweb.org
(800) 533-7694
(703) 237-7442 facsimile

NSPC-03	National Standard Plumbing Code

UL

Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062-2096

www.ul.com
(847) 272-8800
(847) 272-8129 facsimile

17-94	Vent or Chimney Connector Dampers for Oil-Fired Appliances—with Revisions Through September 1998
70-96	Septic Tanks, Bituminous Coated Metal
103-98	Factory-Built Chimneys, Residential Type and Building Heating Appliance—with Revisions Through March 1999
127-96	Factory-Built Fireplaces—with Revisions Through November 1999
174-98	Household Electric Storage Tank Water Heaters—with Revisions Through October 1999
343-97	Pumps for Oil-Burning Appliances--with Revisions Through December 22, 1999
391-95	Solid-Fuel and Combination-Fuel Central and Supplementary Furnaces—with Revisions Through May 1999
441-96	Gas Vents – With Revisions Through April 1999
536-97	Flexible metallic Hose—with Revisions Through October 2000
641-95	Type L Low-Temperature Venting Systems—with Revisions Through April 1999
710-95	Exhaust Hoods for Commercial Cooking Equipment— with Revisions Through April 1999
726-95	Oil-Fired Boiler Assemblies—with Revisions Through January 1999
727-94	Oil-Fired Central Furnaces—with Revisions Through January 1999
729-98	Oil-Fired Floor Furnaces—with Revisions Through January 1999
730-98	Oil-Fired Wall Furnaces—with Revisions Through January 1999
731-95	Oil-Fired Unit Heaters—with Revisions Through January 1999
732-95	Oil-Fired Storage Tank Water Heaters—With Revisions Through January 1999
834-98	Heating, Water Supply and Power Boilers Electric—with Revisions Through November 1998
896-93	Oil-Burning Stoves—with Revisions Through November 1999
959-01	Medium Heat Appliance Factory-Built Chimneys
1261-96	Electric Water Heaters for Pools and Tubs—with Revisions Through November 25, 1998
1453-95	Electronic Booster and Commercial Storage Tank Water Heaters—with Revisions Through September 1998
1738-93	Venting Systems for Gas Burning Appliances, Categories II, III and IV—with Revisions Through December 2000
1820-97	Fire Test of Pneumatic Tubing for Flame and Smoke Characteristics—with Revisions Through March 1999
1887-96	Fire Tests of Plastic Sprinkler Pipe for Visible Flame and Smoke Characteristics—with Revisions through June 1999

(CONTINUED)

Table 2-3 Organization Abbreviation, Address, and Phone Number Listing

ANSI
American National Standards Institute
25 West 43rd Street, Fourth Floor
New York, NY 10036
www.ansi.org
(212) 642-4900
(212) 398-0023 facsimile

ARI
Air-Conditioning & Refrigeration Institute
4100 North Fairfax Drive, Suite 200
Arlington, VA 22203
www.ari.org
(703) 524-8800
(703) 528-3816 facsimile

ASHRAE
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
1791 Tullie Circle, NE
Atlanta, GA 30329-2305
www.ashrae.org
(404) 636-8400
(404) 321-5478 facsimile

ASME
American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016-5990
www.asme.org
800-THE-ASME (843-2763)
(973) 882-1717 facsimile (Inquiries)
(212) 591-7674 facsimile (NY)

ASSE
American Society of Sanitary Engineering
901 Canterbury Road, Suite A
Westlake, OH 44145
www.asse-plumbing.org
(440) 835-3040
(440) 835-3488 facsimile

ASTM
ASTM International
100 Barr Harbor Drive
P.O. Box C700
West Conshohocken, PA 19428-2959
www.astm.org
(610) 832-9585
(610) 832-9555 facsimile

AWS
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126
www.aws.org
(800) 443-9353
(305) 443-5951 facsimile

AWWA
American Water Works Association
6666 West Quincy Avenue
Denver, CO 80235
www.awwa.org
(800) 926-7337
(303) 347-0804 facsimile

CISPI
Cast Iron Soil Pipe Institute
5959 Shallowford Road, Suite 419
Chattanooga, TN 37421
www.cispi.org
(423) 892-0137
(423) 892-0817 facsimile

CGA
Compressed Gas Association
4221 Walney Rd., 5th Floor
Chantilly, VA 20151-2923
www.cganet.com
(703) 788-2700
(703) 961-1831 facsimile

CSA
Canadian Standards Association
178 Rexdale Blvd.
Toronto, Ontario, Canada M9W 1R3
www.csa-international.org
(416) 747-4000 or 866-797-4272
(416) 747-4149 facsimile

DOTn
Department of Transportation
400 Seventh St. SW
Washington, DC 20590
www.dot.gov
(202) 366-4000

FS*
Federal Specification
1941 Jefferson Davis Highway, Suite 104
Arlington, VA 22202
* Standards are available from the Supt. of Documents, U.S. Government Printing Office, Washington, DC 20402-9325

IAPMO
International Association of Plumbing and Mechanical Officials
5001 E. Philadelphia St.
Ontario, CA 91761-2816
www.iapmo.org
909-472-4100
909-472-4150 facsimile

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ICC
International Code Council
5203 Leesburg Pike, Suite 600
Falls Church, VA 22041
www.iccsafe.org
703-931-4533
703-379-1546 facsimile

ISEA
Industry Safety Equipment Association
1901 N. Moore Street, Suite 808
Arlington, VA 22209-1762
www.safetyequipment.org
(703) 525-1695
(703) 528-2148 facsimile

MSS
Manufacturers Standardization
Society of the Valve & Fittings Industry, Inc.
127 Park Street, N.E.
Vienna, VA 22180
www.mss-hq.com
(703) 281-6613
(703) 281-6671 facsimile

NFPA
National Fire Protection Association
1 Batterymarch Park
Quincy, MA 02269
www.nfpa.org
(617) 770-3000
(617) 770-0700 facsimile

NSF
National Sanitation Foundation
789 N. Dixboro Road
P.O. Box 130140
Ann Arbor, MI 48113-0140
www.nsf.org
800-NSF-Mark
(734) 769-0109 facsimile

PDI
Plumbing and Drainage Institute
800 Turnpike Street, Suite 300
North Andover, MA 01845
www.pdionline.org
(978) 557-0720
(978) 557-0721 facsimile

PHCC-NA
Plumbing Heating and Cooling
Contractors National Association
180 S. Washington St.
P.O. Box 6808
Falls Church, VA 22040
www.phccweb.org
(800) 533-7694
(703) 237-7442 facsimile

UL
Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062-2096
www.ul.com
(847) 272-8800
(847) 272-8129 facsimile

3 Specifications

INTRODUCTION

Plumbing drawings, plumbing specifications, general conditions, special conditions, and the addenda comprise the contract documents that make up the contract between the owner and the contractor. None of these items can stand alone: the drawings cannot serve as a contract without the specifications and vice versa. The plumbing designer must, therefore, be familiar with specification writing. If others prepare the specifications, then the plumbing designer must be able to coordinate the drawings with the project specifications.

When writing specifications, the plumbing designer must use clear, precise, and exact language in order to convey to the reader the information required. The essence of a well-written specification is clarity, brevity, correctness, and completeness.

Specification writers should follow established, uniform practices that will ensure good communication between the designer and all other segments of the construction industry. The result will be a set of documents that allow an engineer in one part of the country to converse with a supplier or contractor in another location, and the specifications contain the same language and meanings for all parties.

CONSTRUCTION CONTRACT DOCUMENTS

The Construction Specifications Institute (CSI) developed and implemented a set of documents known as the Manual of Practice that has been used nationwide for about 40 years.

This Manual is intended to provide an ordered, logical, simple, and flexible format for the specification writer to use in the preparation of specifications. One of the principles of this format, which is known as Masterformat, is to establish a standard location where only specific information is stated. This location lets the reader retrieve the information required in the least amount of time. It is essential that the plumbing specification writer be familiar with and understands all the components that constitute the Manual of Practice in order to write clear, concise specifications. The components discussed in this chapter are Uniformat, Masterformat, and Sectionformat.

DEFINITION OF TERMS

It is necessary to define some terms used in the construction contract documents so that one term, and only that one term, is used for any one part of the documents.

Bidder – The bidding and subsequent awarding of the contract.

Contractor – The successful bidder after the awarding of the contract.

Bidding documents – Construction documents issued to bidders before the owner/contractor agreement has been signed.

Bidding requirements – The explanation of procedures to follow when preparing and submitting the bid. This is also used to attract potential bidders.

Contract documents – Documents that are the legally enforceable requirements that become part of the contract when the agreement is signed.

Project manual – Bidding requirements combined with the other construction documents. These are not part of the contract documents.

Work – The performing of services, the furnishing of labor, and supplying and incorporating of materials and equipment into the construction.

Construction contract documents – The proposed construction which is referred to as the "*work.*" Many times these documents are referred to as the "*contract documents*" and erroneously, as the "plans and specifications." It should be noted that many times in these documents are neither plans nor specifications. Instead of the use of the term "plans" when referring to the graphic documents, the term "drawings" should be used. Many times the term "specifications" is expanded to generally refer to all written documents. The correct term when describing all of the documents, with the exception of the drawings, is "project manual."

PROJECT MANUAL

The project manual is an accurate and descriptive term to describe the collection of documents other than the drawings. This manual consists of the following documents:

1. *Pre-bid Information* advises those prospective bidders about the proposed project. Private work going out for bid is usually advertised to the bidders by mail or by telephone. The Architect, Engineer, or the Owner invites these bidders, and bidding is restricted to those bidders invited. This method is usually referred to as "*Bid by Invitation.*" Pre-bid information for public work is required by law to be advertised in all newspapers of general subscription in the immediate area where the work is to be bid. These public notices, which are governed by local ordinances, are published for a predetermined period of time.
2. *Instructions to Bidders* are written to inform the prospective bidders how to prepare their bid so that all bids are in the same format and can be easily and fairly compared after the bid opening.
3. *Bid Forms* are prepared by the Architect/Engineer to provide uniform bid submittals by the bidders and to facilitate the comparison and evaluation of the bids received.
4. *Bonds and Certificates* are the legal documents that bind a third party into the contract as a surety that the bidder and the owner will perform as agreed. This could also be used to insure that the contractor and subcontractors will perform as agreed. The types of bonds commonly used are:
   (a) *Bid Bond* – Assures that the bidder will enter into a contract with the owner or the contractor if the bidder is selected during the bidding phase;
   (b) *Performance Bond* – Assures that the work, once a contract has been signed, will be completed in compliance with the contract documents;
   (c) *Labor and Materials Payment Bond* – Assures that workers on this project will be paid in full, and that all suppliers that have provided materials for the project will be paid in full prior to the project closeout;
   (d) *Guaranty Bond* – Guarantees that the contractor will be paid in full for all work performed to construct the project;
   (e) *Certificates* – Certificates of insurance, or proof of insurance from the contractors and/or subcontractors, as well as certificates of compliance with applicable codes, laws, and regulations.
5. The *Agreement* is the written document signed by the owner and the contractor, or by the contractor and a subcontractor or a material supplier, that is the legal instrument binding these parties to the contract. The agreement defines the relationships as well as the obligations between the signing parties.
6. *General Conditions* are the general clauses that establish how the project is to be administered. These clauses contain provisions that are common practice in the United States. The American Institute of Architects, AIA, has developed Document A201, "*General Conditions of the Contract for Construction.*" A printed copy of which is usually included into the project manual and referenced by the other documents included in the manual. General conditions documents are available from other organizations such as the National Society of Professional Engineers (NSPE), the American Consulting Engineers Council (ACEC), the American Society of Civil Engineers (ASCE), and the Construction Specifications Institute (CSI).
7. *Supplementary Conditions* are the clauses that modify or supplement the general conditions, as needed, to provide for requirements specific to that project. They consist of modifications and/or substitutions such as insurance requirements, prevailing wage rates, etc. It is important to remember that these are not standardized documents like AIA A201 and must be prepared based on the requirements of the specific project.
8. *Specifications* verbally describe the required materials and equipment, the level of quality required for installation and equipment, and the methods by which the materials and equipment are assembled and installed, and how they interface within the project as a whole. The specifications also set the administrative requirements for the contract. All items pertaining to the work under contract should be included in the specifications. The plumbing drawings graphically illustrate the scope of the design, the equipment location, the routing of piping, the quantity of materials required, and the interface with the other trades involved.
9. *Addenda* are the written or graphic documents that are issued prior to the bid to clarify, revise, add to, or delete information in the original bidding documents or in previous addenda. It should be noted that while an addendum is typically issued prior to the bid opening, AIA document A201 allows for the issuance of an addendum any time up to the execution of the contract. This feature

allows for the negotiated adjustment of a selected bid after the bid opening. In contrast, the similar document by the Engineers Joint Contract Documents Committee (EJCDC) restricts the issuance of addenda pre-bid opening.

10. *Modifications* are the written or graphic documents that are issued after the construction agreement has been signed to allow for additions to, deletions from, or modifications of the work to be performed. These changes are accomplished by the use of *change orders*, *construction change directives*, *work change directives*, *field orders*, *architect's supplemental Instructions (ASI)*, and *written amendments* to the construction agreement. These changes or modifications can be issued anytime during the contract period.

Each of the above listed documents is a separate document, but when grouped together, they are collectively referred to as the "*Front End Documents.*" Although the specifications document usually comprises the bulk of the project manual, it is only one of the required documents. If the project is primarily plumbing, then the plumbing engineer/designer may be responsible for the preparation of the entire project manual.

SPECIFICATIONS

Originally all documentation for a given project was placed upon the drawings, but as the amount of information increased to where it would not fit the drawing, another way was needed to present this information. The designers simply started compiling all the notes that would not fit onto the drawings and over time designers have added additional information, product requirements, contractual provisions, as well as construction methods and systems to create a written document. The specification is used to define the qualitative requirements for products, materials and workmanship that will be used to construct a given project.

As the popularity of the specification grew among design professionals, so did the problems this new idea created. Among these problems, there were no "universal" guidelines to insure a uniform document. Each designer wrote specifications using their own style according to what they thought was important. Even the specifications that came from large firms were lacking in consistency between documents. Materials, methods or items that were related were not grouped together in a logical manner but were scattered throughout the document in a seemingly random manner. This practice caused great difficulty when the contractor tried to prepare a specific bid, making it very easy to overlook important and costly items. Also, coordination between the various trades and the contractor would be difficult at best. Last-minute changes were extremely difficult to accomplish.

Specifications can be generated in as many ways. They may be produced by the designer as part of the design process or by a specific individual within the firm who is employed full time to writing project specifications. Large firms may even have a full-time specifications department.

The first thing the designer must have is as much information as possible that pertains to the section to be written. This includes any reference materials that describe products and methods of construction to be described within the specification section. The project information would include the drawing set as prepared by the designer, the project notebook, the project scope of work and any applicable laws and/or building codes. Information for the products can be obtained through a variety of sources, which include: (1) previous project specifications; (2) manufacturer's information; (3) handbooks, pamphlets, etc for the various trade associations; (4) information from the manufacturer's representatives; (5) reference standards from national standards organizations, governmental agencies, and trade associations; (6) technical and professional societies; (7) commercially prepared guide specifications; (8) information obtained from the trades, contractors, etc.; and (9) personal experience.

Never edit previous specifications for use in the new project, as they may not contain required language, the standards cited may have changed, the products specified may not be available any more, or the codes and/or laws may have changed since those specifications were first written.

Once the information that will be needed has been gathered the designer must now decide what type of format will be used as the basis of the specifications to be written.

Depending on the size of the project or the project phase that the specification is being prepared for, the designer may choose a short abbreviated format such as Uniformat developed by the CSI. For the larger, more complex projects the designer may choose the full format as is found in the Masterformat developed by the CSI. Both Uniformat and Masterformat were developed in the early 1970s and 1960s, respectively.

In addition to the Uniformat and Masterformat specification format listed above, there are also specifications developed by the Engineer's Joint Contract Documents Committee (EJCDC), American Institute of Architects (AIA), National Society of Professional Engineers (NSPE), as well as various governmental agencies such as the Corps of Engineers (USACOE), the armed services, NASA, etc.

The designer needs to become knowledgeable of the different specifications that are available so they can decide which specification is best suited for the phase of the project being designed.

UNIFORMAT

Uniformat is the specification system that was developed during the early 1970s and is a system-based format. This format is used primarily during the schematic phase as well as the preliminary or "budgetary" cost estimates. The Construction Specifications Institute (CSI) and the Construction Specifications Canada (CSC) recommend the organization of project data during the preliminary project phases.

Uniformat is divided into eight broad categories or sections: (A) substructure;

(B) shell; (C) interiors; (D) services; (E) equipment and furnishings; (F) other building construction; (G) sitework; and (Z) general. For more information and the subcategories found within each of the eight categories of this format, refer to Appendix 3-A1. Additional information on Uniformat may be obtained from CSI's publication Manual of Practice.

One of the best features of Uniformat is that each category or sub-category can be easily expanded as more information is accumulated during the ongoing design process. As more information is added to the Uniformat, provides the estimator with valuable information to prepare an informed preliminary cost estimate.

Once the project progresses from the preliminary or schematic phase (where the Uniformat provides the necessary information) to the design development or "DD" phase, more detailed information is required that Uniformat is not designed to handle. At this stage of the project, outline specifications are usually introduced to organize the required information. In some projects, the use of the outline specification may be required as part of the agreement between the owner and the architect/engineer (A/E). Refer to AIA document B141 and ESCDC document 1910-1 for additional information.

Drawings that are prepared during the design development phase contain more detail, both general and specific, than the schematic phase drawings.

MASTERFORMAT

Some designers organize their outline specifications at this point around CSI's Masterformat because this format can be used from the design development phase through to the construction documents (CD).

Masterformat is a master list of the divisions numbers and titles that was developed during the Washington, D.C., conferences in 1962 and 1963 and later became the industry standard in both the United States and Canada. The core of this system is the five-digit numbers and titles that arrange construction/project data into an organized order of sequence. By having this universal standardized system, the placement and retrieval of information is greatly facilitated, and communication throughout the entire construction phase also is greatly improved. Under this format, group numbers and titles are organized under these headings: (1) introductory information; (2) bidding requirements; (3) contracting requirements; (4) facilities and spaces; (5) systems and assemblies; and (6) construction products and activities (divisions 1-16). The first five groups, while they are not specifications, are usually included in the project manual. The last group forms the construction specifications.

Under the heading (6) construction products and activities, there are four levels of detail for each division. Level One consists of the titles for the 16 divisions (see Appendix 3-A2). The Level Two titles (or sections) are referred to as "broad scope" because they provide the widest scope in describing the work to be performed or the products to be utilized (see Appendix 3-A3). Level Three titles are sometimes referred to as "medium scope" since they cover work that is more limited in scope than under the level two titles. Level Three takes the titles listed under Level Two and further divides them in order to add a more definitive scope (see Appendix 3-A4). The titles found under Level Four are the most limited in scope and are often referred to as "narrow scope". These titles cover elements of the work that are very specific (see Appendix 3-A5).

In the progression from Level One to Level Four, the titles (or sections) become more narrow or specialized. For example, using the spec for nitrogen piping, at Level One it would be 15000-Mechanical. Then, at Level Two the title is further defined to 15200-Process piping. At Level Three, this section is defined as 15210-Process Air and Gas Piping. Finally, at Level Four, the title is further defined to 15215-Nitrogen Piping.

MASTERFORMAT 2004—AN OVERVIEW

Since last being updated in 1995, CSI's MasterFormat has been the staple of the architectural and engineering community. This document, while it was good, began to show some problems with respect to supporting the entire construction industry and it had very limited room for any future expansion. In 2001 a seventeen-member task force known as the MasterFormat expansion task team (MFETT) was formed by CSI to address problems of the document currently in use. Three years and many drafts later, the revised document known as MasterFormat 2004 is now ready and will be available in late autumn 2004 through CSI at their website (www.CSINet.org) .

Significant changes have been made in the organization of this document. The first significant change to be made in the organization of the MasterFormat 95 is the reduction of the six groups to only two groups (Procurement and Contracting Requirements Group and Specifications Group). The Procurement and Contracting Requirements Group known, by the more familiar name front end documents, contains the bidding information, project forms, contract conditions, etc. Essentially this is the same material, just with a new name and different location. The Specifications Group contains the administrative and technical requirements that govern a project. This group is divided into five subgroups, which are further divided into a total of forty-nine divisions. The five subgroups comprising the Specifications Group are: (1) General Requirements (Division 01), (2) Facility Construction (Divisions 02-19), (3) Facility Services (Divisions 20-29), (4) Site and Infrastructure (Divisions 30-39), and (5) Process Equipment (Divisions 40-49). Appendix 3-B1 contains a complete list of subgroups and divisions and a short description of any changes.

The original numbering system consisted of a five-digit number (began in 1978) that organized the information throughout the sixteen divisions. The new system utilizes a six-digit number that consists of three pairs of two digit numbers. For example, 03200 found in MasterFormat 95 was replaced by 03 20 00 (the new number for Concrete Reinforcement). Level four numbers have been removed. However, recommendations for their use have been included in the supporting documents should the specifier wish to include level four. It should be noted that each level has two digits and this alone allows ten times as many subjects as was possible under the old five digit format.

Site construction was located in Division 2 under the old system and is now listed as Division 02-Existing Conditions and all site construction subjects have been relocated to the Civil and Infrastructure Subgroup. Division 02 now contains subjects dealing with items and conditions on the job site at the start of the project including selected demolition, subsurface and site investigation, surveying, site decontamination and site remediation, etc.,

Beginning with this edition, there will be sections included to classify information for facility operations and maintenance, repairs and commissioning. This information will be located in **each** division instead of being placed in its own division.

Another change is the relocation of certain items from one Division to other Divisions. Division 15 has now been reserved for future expansion. Plumbing items have been relocated to Division 22-Plumbing and HVAC items have been moved to Division 23-Heating, Ventilation and Air Conditioning. Fire Suppression items that were located to Division 13 have been relocated to Division 21-Fire Suppression. Refer to Appendix 3-B2 for a listing of sections found in Division 21-Fire Suppression. For a more detailed breakdown of subjects listed in this Division refer to Appendix 3-B3. Appendix 3-B4 contains a listing of the sections found in Division 22-Plumbing, while Appendix 3-B5 contains a more detailed breakdown of the sections and subjects.

In conclusion, the changes discussed above and any others made to MasterFormat 2004 were made to facilitate use in the Architectural and Engineering fields for years to come. As when anything changes, there will be those who love, hate, use or ignore the new. However, MasterFormat 2004 deserves a chance.

While Masterformat provides standardization as well as the titles to be used in the project manual, it does not address the way in which information will be organized. This need for standardization within a section prompted the development of Sectionformat. This format or outline produces organization, appearance, and completeness that is consistent from one section to the next. It may be used as a checklist to gather information for each section.

A good specification section will provide the answer to the following three questions: (1) How does the work defined in the section relate to the work defined for the rest of the project? (2) What materials and/or products are to be used to complete the work under this section? (3) How are these materials and/or products to be incorporated into the work under this section and the project as a whole? The answers to these questions are grouped into three parts to form the outline for a given section. These parts are: Part I—GENERAL, Part 2—PRODUCTS, and Part 3—EXECUTION. Refer to Appendix 3-C1 for the shell outline developed by the American Institute of Architects (AIA) that conforms to the manual of practice as prepared by the Construction Specifications Institute (CSI). The order in which these parts are used within a section is fixed in both name and order, providing a consistent format throughout all sections. This, in turn, simplifies the designer's job and makes the finding of information by the reader much easier.

Masterformat and Sectionformat, when used together, will produce specifications that are clear, complete, accurate, and coordinated. This allows the information to flow from the divisions to the sections to the parts and vice versa.

METHODS OF SPECIFICATION

Specifications are written using one of the following four methods of specifying products, materials, or workmanship. These four methods include: (1) descriptive specifications; (2) performance specifications; (3) reference standard specifications; and (4) proprietary specifications.

A *descriptive specification* consists of a detailed written description of the required properties of a product, material, or piece of equipment and the workmanship required for its proper installation. When writing this type of specification, it is important to remember that proprietary or brand names of manufactured products are not to be used and the specifier assumes the burden of performance. This method of specifying was once widely used, but as projects became more complex, its use has declined. Writing this type of specification is very tedious and time consuming. Descriptive specifications are used when the use of proprietary names are prohibited by law (such as with federally funded projects) or it is not possible to write a reference standard specification due to a lack of reference standards.

In order to write a descriptive specification, the specifier needs to adhere to certain basic steps. The specifier should: (1) Research available products that will be included in this section; (2) Research the critical features that will be required in this section, then analyze and compare these requirements with the products that are available; (3) Review the features that are required and determine which features are best described by the specification and which features would be best shown on the drawings; (4) Be sure to describe features considered to be critical and the minimum acceptable requirements; and (5) be certain requirements can be met by the products to be supplied. The designer should take care in selecting and specifying unique features from different products and manufacturers (picking features from one product and combining it with others, etc). This could create a descriptive specification of a particular product that does not exist. When this happens, the designer must spend additional time to rewrite the description. *Avoid any unnecessary features and minutely detailed requirements.*

A *performance specification* is a statement or statements of the results and criteria the specifier requires to verify compliance. It should not contain unnecessary limitations on the methods for achieving the required results. All desired end results the specifier wants must be spelled out completely. An incomplete performance specification will result in the designer losing control over the quantity of materials, equipment, and workmanship that will go into the project. Criteria for verifying compliance includes criteria for measurement, test evaluation, or other means as required by the designer to assure that the standards of performance have been met.

When using the performance specification, it should be remembered that only essential restrictions are to be placed upon the system while limitations on the means should be avoided. It also should be remembered that when performance specifications are the primary method of design and contracting procedure, specialized contract documents would be required. This is because the contract documents will be far more complex and often will involve a variety of participants in the contract proceedings.

The *reference standard specification* is the use of a nationally or internationally recognized standard to specify a product, materials, or workmanship instead of writing a detailed description. A standard is generally defined as a requirement defined by a recognized authority, custom, or general consensus. Trade associations, professional societies, standards organizations, or governmental and institutional organizations usually publish these standards. A committee of architects, engineers, scientists, technicians, manufacturers, and product users very knowledgeable about that particular subject area usually author a standard.

There are six types of reference-based standards that are commonly used when writing a specification. These include: (1) basic material standards; (2) product standards; (3) design standards; (4) workmanship standards; (5) test-method standards; and (6) codes. The materials are addressed for the system. Basic material standards, such as ASTM B88-03 "Standard Specification for Seamless Copper Water Tube," were written by the American Society of Testing Materials (ASTM) and cover one item — in this case, copper water tubing suitable for general plumbing or similar applications for conveying fluids and commonly used with solder, flared, or compression fittings. Products are to conform to items identified in a standard. Product standards, such as ASME B16.22-2002 "Wrought Copper and Copper Alloy, Solder Joint, Pressure Fittings," (written by the American Society of Mechanical Engineers (ASME)), establishes specifications for wrought copper and copper alloy, solder joint, seamless fittings designed for use with copper tube that conforms to ASTM B88-03.

Design requirements are set forth for the system. A design standard, such as ACI-318 "Building Code Requirements for Reinforced Concrete," is written by the American Concrete Institute (ACI) to cover the use of reinforced concrete in building assemblies. Workmanship standards describe the construction procedures that are necessary. Workmanship standards include items such as ASTM B828-02, "Standard Practice Making Capillary Joints by Soldering Copper and Copper Alloy Tubing and Fittings."

This standard describes the procedure for making capillary ("sweat") joints using solder, copper tube, and copper or copper alloy fittings.

Test method standards establish the minimum requirements of what is being tested and how to test systems for compliance to the standard. Test standards such as ASTM E53-02, "Standard Test Methods for Determination of Copper in Alloyed Copper by Gravimetry," describe the test procedures and protocols required to obtain a chemical analysis of copper having a minimal purity of 99.75% by gravimetric analysis. A code standard contains regulations that govern materials to be used, how they are to be installed, etc. Code standards, such as the National Standard Plumbing Code published by the National Association of Plumbing-Heating-Cooling Contractors is a body of code regulations adopted by local municipalities as their plumbing code.

When a designer wants to refer to or "cite" a standard, it is not necessary to include the entire text of the referenced standard into the body of the specification to be written. The desired standard can be included in the document by referring to its number, title, or other designation. The most common form is to cite it with the initials of the organization that sponsors it and the number of the standard, such as ASTM B88-03. The last digits separated by the hyphen are the date the standard was written or last revised. Sometimes the standard will be seen with a lower case "a" after the date. This indicates an amendment to the standard. These "cited" standards become part of the document just as surely as if the standard's entire text were included.

When using the reference standard, the designer needs to remember certain things. First, there are bad reference standards as well as good ones. Next, the indiscriminate use of these standards within the document can result in duplication, contradiction, and general chaos for designer, contractor, and the owner. Finally, some of the standards may contain hidden choices that the designer may not know even exists, and their inclusion into the document may cause a myriad of problems with the enforcement of the contract conditions. These standards often only meet the minimum requirements.

Before writing a reference based specification, the designers should thoroughly familiarize themselves with the standards they plan to use and how to incorporate these standards into the document correctly, as well as how to enforce the requirements of the standard once it has been included.

Due to possible conflicts between the language of the written standard and the general conditions of the contract, the designer should include a clause in the supplementary conditions of the contract that states the contract conditions shall govern over the requirements of the cited reference standards. Another clause should state that should a conflict or discrepancy arise between the reference standard and another cited reference and the specifications, the more stringent requirement shall apply. Once the standard has been specified, it becomes necessary for the designer to be able to enforce the requirements of that particular standard once the project begins. The most common means to ensure compliance of the standard is to check the shop drawings and other submittals (including manufacturer's literature, samples, and test reports) and make regular site visits to insure compliance of the workmanship standards.

The last method of specifying is the use of the *proprietary specification*. This method identifies the products to be used by manufacturer's name, brand name, the model number, type designation, or unique characteristics. A specification is considered proprietary if the product to be specified is available from a single source.

The use of this type of specification has both advantages and disadvantages. Advantages include: allowing for closer control in the selection of the product; having more detailed and complete drawings due to the more precise information from the product supplier; having shorter specifications which result in shorter production time; allowing for removal of product pricing as a major variable; and narrowing of the competition which will simplify the bidding process. Disadvantages to the use of this method include: the elimination or narrowing down of the competition (preferential treatment might be shown for one product over another and resentment might be directed back to the designer); forcing the contractor to do work with a product with which they have very little or no prior experience (this could result in poor performance by the contractor); and possibly specifying a product to be provided by a manufacturer that no longer exists.

There are two types of proprietary specifications: closed and open. The difference between them lies in how the subject of substitutions of the specified products is handled. Open specifications usually allow substitution of the products, while closed specifications usually do not allow any substitutions but restrict the selection to a limited number of choices.

The closed proprietary specification allows the design to be completed with higher-level detail while reducing the variables, thus promoting more accurate bids. It will not, however, provide protection against higher costs caused by a supplier of a specified product taking an unfair advantage of his proprietary position and increasing the price. The closed proprietary specification may either list one product or multiple products as the designer sees fit, and there are no substitutions allowed. The designer can control the product selection through the use of the instructions found in section 01630-("Product Substitution Procedures"), which provides requirements for the use of the product or products specified. Under a closed proprietary specification, when only a single product is specified, the substitution of another product is not allowed, and the bids submitted will be based upon this product only. When a product is specified by naming several manufacturers, the substitution of other products shall not be allowed, and the bids submitted will be based on the products specified. The successful bidder is usually required to submit a list of the product or products they intend to use; within a specified time following the bid for approval, but prior to purchase and installation. If there are at least three products named and competition is achieved in the bid process, it is up to the designer to make sure the products are equal and acceptable for the purpose to which they are being specified.

The open proprietary specification specifies or names products or materials in the same manner as the closed specification. The difference is that alternatives for the specified products or materials are also listed. The bidder must bid on those specified items and may also provide prices for the alternative items specified. These prices are usually included on the bid form in the spaces provided. To clarify bidding processes, the designer might include instructions to the bidder such as the following: "When the product is specified to only one manufacturer, substitution of products will not be allowed. If alternates to the base bid are requested, then the bidder may submit bids for the alternate items. These bid prices shall include the amount required to incorporate the alternate product into the project. Requests for additional monies for alternate products or materials shall not be considered after the agreement has been executed." The open proprietary specification removes the problem of overpricing, which is common in sole-source product or material bids. It also allows for the selection of alternate items and price quotations for those items.

The major problem with proprietary specifications is the attempts by some bidders to introduce products or materials inferior in quality to those that were specified originally. This problem is the greatest when the bidder is allowed to specify substitutions after the award of the contract. This leads to the practice known as "bid shopping." This is unfair to those who submitted bids originally and pressure is put on the designer to accept these inferior product substitutions.

In order to prevent this situation, the designer must maintain control over the bidding process by including requirements in the specifications similar to the following: (1) All substitution requests are to be in writing from the bidders, only and any requests from manufacturers and suppliers will not be considered. (2) The setting of a definite deadline for the submission of substitution requests by the bidder. This deadline should be a minimum of ten (10) days prior to the bid opening. (3) All requests for substitutions shall be submitted with the request for approval. Submissions without supporting documentation shall not be considered. (4) The designer shall review all submissions and issue notification of any accepted substitutions to all bidders by addendum. The time period between the deadline for requests and the addendum is at the discretion of the designer, but should not be less than three (3) days to allow proper examination of the submitted materials.

The federal government and other public authorities forbid the use of the proprietary or other exclusionary specifications except under special conditions.

CREATING THE SPECIFICATION SECTION

Having examined the methods by which products, materials, or workmanship are specified, we shall now look at how these methods are used to create a specification section for the project manual. Refer to Appendix 3-C1, *Section Shell Outline,* to help illustrate a specification section, in conformance with the Manual of Practice.

Beginning at the top, the first item to be completed is the section number. The section number is a five-digit number corresponding to MasterFormat. This number may refer to any level from Level Two to Level Four, depending on how specific this section will be. Following the section number is the section title. The designer should keep this to a maximum of one line, 6-8 words.

Under Sectionformat as discussed earlier, a specification section is divided into three parts. These are (1) PART 1—GENERAL; PART 2—PRODUCTS; PART 3—EXECUTION. The section number is usually either Level Two or Level Three. Level Four section numbers are not assigned. This provides the user with greater flexibility by allowing a location for the designer to add specifications if necessary.

PART 1—GENERAL includes: the scope of and, any necessary references to the related work, codes, and standards that are to be in force during the project; qualifications for both manufacturers and workmanship; required submittals, including the format required for submission of the submittals; any samples required for examination by the designer; required information on product manufacturing and shipping schedules; receiving and storage requirements; as well as any other information found to be necessary.

PART 2—PRODUCTS includes those products to be used on the project that are part of the work described by this specification section. These products should be described as accurately, completely, and, above all, briefly as possible to give the reader the facts needed in least amount of text. Any descriptions of these products shall be to describe the product to be used and present any pertinent data required for the use of that product. The designer should not include installation instructions and like information in this part, but should include it in PART 3—EXECUTION.

PART 3—EXECUTION contains the detailed instructions of how the products listed in PART 2 are to be used or installed in the work being performed. Each product listed in PART 2 should have information as to its use in this part. Also, included in this section: any testing that is to be performed (be sure to include instructions on who pays for the testing, as well as what tests and the number required); instructions for the coordination between the various trades; the acceptance of the substrate; and any required tolerances for installations.

PART 1

Section *1.1 Summary*

The first section of Part 1 is the summary. In this section, there is the description of the work to be performed, the listing of any products to be furnished but not installed, and products that are not furnished but are to be installed. This also is sometimes a clause referred to as "owner furnished, contractor installed." The next item found in PART 1 is the listing of the related sections. It is here that other sections in the specifications containing requirements related to this particular section are listed. Some designers choose to omit this part because during last-minute changes, this often fails to get updated resulting in a confusing, flawed document. Also found in the summary are allowances, unit prices, and alternates. An allowance is a predetermined monetary amount agreed to by both the designer and the owner to be inserted into the bid for certain items such as art work, furniture or even plumbing fixtures. A unit price is a fixed bid price amount for an item such as a water closet, lavatory, and per-foot price on a four-inch cast iron pipe, etc. An alternate is a defined portion of the work that is priced separately and provides the owner an option for to select for the final scope of the work. Alternates usually allow choices among the products to be used or to add or delete portions of the work from the project.

Section *1.2 References*

Another item found in the first section is the references. It is here that the reference standards that have been cited in this section are listed alphabetically. Standards are usually written in the following manner: (1) Standard number; (2) Standard title; (3) Standard society or agency; and (4) Date of the last revision. For example: ASME B16.22, Wrought Copper and Copper Alloy Solder Joint, Pressure Fittings, American Society of Mechanical Engineers (ASME), 2002. When there are multiple references by the same organization those references are arranged in ascending numerical order.

Section *1.3 Definition*

After the references, any special definitions required to explain the work or products used are listed alphabetically.

Section *1.4 System Description*

The system description is used by some designers and omitted by others. This is usually a brief but accurate description of how this spec section fits into the work.

Section *1.5 System Performance Criteria*

The system performance requirements give the performance criteria, if necessary, for this work. This section is usually omitted unless a performance specification is desired.

Section *1.6 Submittals*

The next portion of PART 1 is probably one of the most important ones because it governs the submittals. It tells what is required for all products used in the project. The designer must decide what information will be submitted for review and approval. On some government projects the submittal process will be under governmental control not the designer. The information required for the submittal can include: (1) Product data as prepared by the manufacturer or third-party organization; (2) Shop drawings from either the manufacturer or the contractor; (3) Coordination drawings; (4) Wiring or piping diagrams from the manufacturer or contractor; (5) Product certification from manufacturers that these products have been tested and are compliant with the appropriate standard cited by the manufacturer; (6) Test reports from an independent (or third party) test laboratory certifying those products; (7) Qualification data for manufacturers, firms, or individuals as required in Section 1.7 Quality Assurance; and (8) Maintenance data for the materials and products used for inclusion into the operation and maintenance (O&M) manuals for the owner (if required).

Section *1.7 Quality Assurance*

This is the quality control for the project. In this section the designer can include what he feels is needed to assure the project is completed correctly. Included in this section are manufacturer and installer qualifications. It is here the level of experience, usually a set number of years, is spelled out. The normal experience for a manufacturer is five years minimum; for an installer three years minimum is usual. Requirements for supervision and licensure can be included as well. For example, "all work required by this specification section shall be performed by licensed, experienced tradesmen working under the direct supervision of a licensed, experienced supervisor with a minimum of 10 years experience. No unsupervised work by unlicensed workers shall be allowed." Requirements for testing laboratories, welding and welder certifications, compliance with U. L. standards, compliance with NFPA 70 (NEC), ASME compliance, and others are also included within this section.

Section *1.8 Delivery, Storage, and Handling*

This section includes the instructions on shipping and handling of materials or equipment from the manufacturer to the jobsite, as well as lifting and rigging instructions, onsite storage requirements, and coordination between shipping schedules, delivery dates, and installation dates.

Section *1.9 Project Conditions*

Site condition disclaimers and disclaimers for field measurements that direct the contractor to verify all measurements prior to start of work fall under this category. This section is optional at the decision of the designer.

Section *1.10 Sequence and Scheduling*

This coordinates the various portions of the project and can cross trades. The section is optional as well because it is up to the general contractor, not the plumbing designer, to schedule and coordinate work that is under the contract.

Section *1.11 Warranty*

The designer lists any special warranties required or any warranty condition that is different from the manufacturer's standard warranty.

Section *1.12 Maintenance*

Contains any special maintenance requirements for the equipment installed under this section.

Section *1.13 Extra Materials*

A list of extra materials including those such as valve repair kits, faucet repair parts, extra belts, handles, lubricants, seals, elements, etc. Item and quantity required to be supplied to the owner by the contractor are also listed.

PART 2

This section deals with the products, materials, and equipment, as well as the manufacturers that will be included in the work.

Section *2.1 Manufacturers*

Under paragraph A, the contractor may supply products by any manufacturer that are compliant with the specification section covering that portion of the work. Most of the time the products to be supplied comply with the specifications but sometimes they do not. Paragraph B states that the designer decides which manufacturers of a particular product will be allowed and which will not. Under this paragraph, the contractor is given a list of approved manufacturers to choose from. The designer has both researched the product and tested manufacturers to make sure the products meet or exceed the standards set forth by that section of the specification. For example, a listing for a water closet would be:

1. Water closet, floor outlet, flushometer
   a) Manufacturer "A"
   b) Manufacturer "B"
   c) Manufacturer "C"
   d) Manufacturer "D"
   e) Substitutions

Under this arrangement, the contractor would have to supply the water closet by one of the four manufacturers listed above. With the use of a substitution option, the designer may elect to allow substitutions of a water closet by a non-listed manufacturer *as long as it is proven to be equal to the others*. Many designers feel that allowing no substitutions levels the bidding field and takes away the problems of a bidder getting a lower bid by using substandard product. Under this section, the decision can be made about the product as well as the manufacturer. Only one of these methods should be used—either specify the manufacturer or product by an "open" as seen in paragraph A (of Appendix 3-C1) or "closed" as seen in paragraph B. The same is true for paragraphs C and D. As stated earlier in this chapter, the closed method gives the designer more control over the quality of the products being included in this project.

Sections 2.2, 2.3, and 2.4 are similar to Section 2.1. In Section 2.3 the materials that will be used are specified using either a descriptive specification or a performance specification. Both the performance and descriptive specification types were discussed earlier.

Sections 2.5, 2.6, 2.7, 2.8, and 2.9 are not usually included in plumbing specifications. However, that does not mean they cannot be used if the designer feels they are needed.

PART 3

Section *3.1 Examination*

This section is concerned with the installation of the products or materials into the project. The first part involves instructions to the contractor to examine the sites, plans, existing or constructed walls, floors and ceilings that must be installed. This section should also instruct the contractor not to proceed with the work until all unsatisfactory items have been corrected. Following sections deal with the general and specific installation requirements of the products and/or materials being used. Often included, but not mandatory by CSI standards, is a section on connections (shown as Section 3.5). It is in this section that connection requirements for owner furnished, contractor installed (often seen as OFCI or GFCI on government projects) are found. A good example of this would be in the case of a commercial kitchen where the kitchen equipment supplier sets the equipment but the plumber connects them to the utilities.

Section *3.6 Field Quality Control*

The designer deals with testing laboratory services (including who pays for it), which tests are to be made, and which standard(s) must be met. Also included is what remedy must be made if the tests prove that the products and/or materials are not compliant with the standard set forth in the specification section. In addition, if a piece of equipment that is assembled onsite appears to be complicated, etc., this is where the designer could put a requirement for the services of a factory-authorized service technician to supervise the assembly.

Section *3.7 Adjusting and Cleaning*

A section that covers the adjustment, cleaning, and calibration of the products included in this project is well advised. One of the most common sections would probably be the cleaning and disinfection of the potable water system.

Section *3.8 Commissioning*

Another section that is not mandated by the current CSI format, but is gaining in use and will probably be included as part of the new CSI format (tentatively scheduled for release late 2004) is *Commissioning* or placing the building into service for the owner to use. Items that should be addressed include: (1) Equipment start up by factory authorized service technicians; (2) Testing and adjusting of controls and safeties with the replacement of all malfunctioning parts; (3) Providing adequate training to the owner's maintenance staff with regard to the start up and shut down of equipment, troubleshooting, servicing, and maintenance; and (4) Reviewing the data in the O&M manuals with the maintenance staff.

USE OF COMPUTERS IN PRODUCING SPECIFICATIONS

Very few plumbing specifications today are written as an original document, otherwise known as "from scratch." In most cases, the project specifications are created using an office prepared "master specification," or a set of commercially prepared specifications that have been published by various industry organizations such as Masterspec or Spectext. The American Institute of Architects (AIA) publishes Masterspec. Spectext is published by the Constructed Science Research Foundation, which is affiliated with the Construction Specifications Institute (CSI). The use of a master specification to prepare a project specification is certainly more cost efficient than "starting from scratch" with each new project.

The process begins with the designer or specifier choosing the sections that will be needed for the project manual. This list is then given to the word-processing department to put together the copy for each section and return it to the designer. It is then reviewed and rewritten as required to suit the project's particular requirements. The revised "master" copy is then returned to the word-processing department to make the necessary rewrite to the master copy. This revised copy will be returned to the designer, who will proofread it and make any further changes that might be required. This process continues until the project is finalized. As you see, this method of specification is very labor intensive.

Fortunately for specification writers, there are computerized or computer assisted specification programs to aid in the writing of specifications. These programs do for specification writing what computer aided drafting and design (CADD) did for drafting. One of the first computer aids was utilizing word-processing programs to write, edit, and more importantly, store finished documents in an electronic format. This allows documents to be copied instantaneously instead of spending a lengthy time at the typewriter and/or copy machine. Another benefit that came with the use of computers is the size of space required to store the specifications. A specification that might require an entire file cabinet drawer of information can be reduced to one or two floppy disks or one CD-ROM disk.

The specification programs that have evolved over past years and are available today have merged word processing, data storage, and acquisition programs into single powerful programs that allow specifications to be produced by a single person. This is a drastic change from the past when it took the designer(s) and several other personnel to produce the specification. One of the best features of the new master specification programs is that there are periodic updates with new sections being added and obsolete sections being deleted. Also, in these updates, the reference standards that are included in each section are updated to the latest standard. For any specifier who has spent several hours searching these standards, this feature is worth the price of the program.

Computer programs continue to improve at a dizzying speed. What was cutting edge technology five years ago is now obsolete. These programs have evolved beyond just being a specialized word processing program to an interactive program that contains checklists or interactive input dialogue for the specifier to utilize. Also, there are programs being written and developed that will interface with the CADD systems to produce the specifications and even estimates.

CONCLUSION

Writing good, effective specifications requires broad experience as a plumbing designer. In most engineering offices, specifications are prepared by the project engineer or team leader. The designer must remember that the essence of plumbing specifications is communication between the persons involved with the project. Plumbing specifiers must develop skills to communicate the project requirements in a clear, concise, and easy-to-understand manner. This requires the ability to write in a clear, precise, technical style and a precise legal style *combined into a single style*.

The one thing that probably has changed the least in specification writing is the amount of time allotted by the project managers to complete the specifications. The amount of time given is never enough.

Like most plumbing engineering skills, specification writing is "learned on the job." This is because university level courses in specification writing are rare (actually almost non-existent). Classes may be available as continuing education programs offered by the Construction Specifications Institute (CSI) at both the national and local level. Local chapter members of CSI teach local courses. Interested parties should contact their local CSI chapters for more information about what is available.

Plumbing designers who have at least five years of specification writing experience can demonstrate their proficiency and understanding by taking the Certified Construction Specifier (CCS) Examination that is given by CSI. Successful completion of this exam will earn the designer the title of Certified Construction Specifier (CCS). There is a growing number of plumbing engineers that can include "CCS" after "CPD" (Certified Plumbing Designer) when citing their professional credentials.

In this world of continually changing work places and corporate restructuring, the plumbing designer who demonstrates the ability to produce a clear, concise set of specification documents is a valuable asset to the project design teams.

APPENDIX 3-A1

CSI UNIFORMAT – UNIFORM CLASSIFICATION – (1995 Edition)

SUBSTRUCTURE

A10 Foundations
A20 Basement Construction

SHELL

B10 Superstructure
B20 Exterior Closure
B30 Roofing

C. INTERIORS

C10 Interior Construction
C20 Stairways
C30 Interior Finishes

D. SERVICES

D10 Conveying Systems
D20 Plumbing Systems
D30 Heating Ventilation and Air Conditioning (HVAC) systems
D40 Fire Protection Systems
D50 Electrical Systems

E. EQUIPMENT and FURNISHINGS

E10 Equipment
E20 Furnishings

F. OTHER BUILDING CONSTRUCTION

F10 Special Construction
F20 Selective Demolition

BUILDING SITEWORK

G10 Site Preparation
G20 Site Improvements
G30 Site Plumbing Utilities
G40 Site Heating, Ventilation, and Air Conditioning (HVAC) Utilities
G50 Site Electrical Utilities
G60 Other Site Construction

Z. GENERAL

Z10 General Requirements
Z20 Bidding Requirements, Contract Forms, and Conditions
Z90 Project Cost Estimate

APPENDIX 3-A2

CSI MASTERFORMAT – LEVEL ONE DIVISION TITLES – (1995 Edition)

01000 DIVISION 1 GENERAL REQUIREMENTS
02000 DIVISION 2 SITE CONSTRUCTION
03000 DIVISION 3 CONCRETE
04000 DIVISION 4 MASONRY
05000 DIVISION 5 METALS
06000 DIVISION 6 WOOD and PLASTICS
07000 DIVISION 7 THERMAL and MOISTURE PROTECTION
08000 DIVISION 8 DOORS AND WINDOWS
09000 DIVISION 9 FINISHES
10000 DIVISION 10 SPECIALTIES
11000 DIVISION 11 EQUIPMENT
12000 DIVISION 12 FURNISHINGS
13000 DIVISION 13 SPECIAL CONSTRUCTION
14000 DIVISION 14 CONVEYING SYSTEMS
15000 DIVISION 15 MECHANICAL
16000 DIVISION 16 ELECTRICAL

APPENDIX 3-A3

CSI MASTERFORMAT – LEVEL TWO SECTION TITLES – (1995 Edition)

DIVISION 1 GENERAL REQUIREMENTS

01100 SUMMARY OF WORK
01200 PRICE and PAYMENT PROCEEDURES
01300 ADMINISTRATIVE REQUIREMENTS
01400 QUALITY PROCEDURES
01500 TEMPORARY FACILITIES and CONTROLS
01600 PRODUCT REQUIREMENTS
01700 EXECUTION REQUIREMENTS
01800 FACILITY OPERATION
01900 FACILITY DECOMMISSIONING

DIVISION 2 SITE CONSTRUCTION

02050 BASIC SITE MATERIALS and METHODS
02100 SITE REMEDIATION
02200 SITE PREPARATION
02300 EARTHWORK
02400 TUNNELING, BORING, and JACKING
02450 FOUNDATION and LOAD BEARING ELEMENTS
02500 UTILITY SERVICES
02600 DRAINAGE and CONTAINMENT
02700 BASES, BALLASTS, PAVEMENTS, and APPURTENANCES
02800 SITE IMPROVEMENTS and AMENITIES
02900 PLANTING
02950 SITE RESTORATION and REHABILITATION

DIVISION 3 CONCRETE

03050 CONCRETE MATERIALS AND METHODS
03100 CONCRETE FORMS and ACCESSORIES
03200 CONCRETE REINFORCEMENT
03300 CAST-IN-PLACE CONCRETE
03400 PRE-CAST CONCRETE
03500 CEMENTITOUS DECKS and UNDERLAYMENT
03600 GROUTS
03700 MASS CONCRETE
03900 CONCRETE RESTORATION and CLEANING

DIVISION 4 MASONRY

04050 BASIC MASONRY MATERIALS AND METHODS
04200 MASONRY UNITS
04400 STONE
04500 REFRACTORIES
04600 CORROSION RESISTANT MASONRY
04700 SIMULATED MASONRY
04800 MASONRY ASSEMBLIES

04900 MASONRY RESTORATION AND CLEANING

DIVISION 5 METALS

05050 BASIC METAL MATERIALS AND METHODS
05100 STRUCTURAL METAL FRAMING
05200 METAL JOISTS
05300 METAL DECK
05400 COLD FORMED METAL FRAMING
05500 METAL FABRICATIONS
05600 HYDRAULIC FABRICATIONS
05650 RAILROAD TRACK AND ACCESSORIES
05700 ORNAMENTAL METAL
05800 EXPANSION CONTROL
05900 METAL RESTORATION AND CLEANING

DIVISION 6 WOOD AND PLASTICS

06050 BASIC WOOD AND PLASTIC MATERIALS AND METHODS
06100 ROUGH CARPENTRY
06200 FINISH CARPENTRY
06400 ARCHITECTURAL WOODWORK
06500 STRUCTURAL PLASTICS
06600 PLASTIC FABRICATIONS
06900 WOOD AND PLASTIC RESTORATION AND CLEANING

DIVISION 7 THERMAL AND MOISTURE PROTECTION

07050 BASIC THERMAL & MOISTURE PROTECTION MATERIALS AND METHODS
07100 DAMPPROOFING AND WATERPROOFING
07200 THERMAL PROTECTION
07300 SHINGLES, ROOF TILES AND ROOF COVERINGS
07400 ROOFING AND SIDING TILES
07500 MEMBRANE ROOFING
07600 FLASHING AND SHEET METAL
07700 ROOF SPECIALTIES AND ACCESSORIES
07800 FIRE AND SMOKE PROTECTION
07900 JOINT SEALERS

DIVISION 8 DOORS AND WINDOWS

08050 BASIC DOORS AND WINDOWS MATERIALS AND METHODS
08100 METAL DOORS AND FRAMES
08200 WOOD AND PLASTIC DOORS
08300 SPECIALTY DOORS
08400 ENTRANCES AND STORE FRONTS
08500 WINDOWS
08600 SKYLIGHTS
08700 HARDWARE
08800 GLAZING
08900 GLAZED CURTAIN WALL

DIVISION 9 FINISHES

09050 BASIC FINISHES MATERIALS AND METHODS
09100 METAL SUPPORT ASSEMBLIES
09200 PLASTER AND GYPSUM BOARD
09300 TILE
09400 TERRAZZO
09500 CEILINGS
09600 FLOORING
09700 WALL FINISHES
09800 ACOUSTICAL TREATMENT
09900 PAINTS AND COATINGS

DIVISION 10 SPECIALTIES

10100 VISUAL DISPLAY BOARDS
10150 COMPARTMENTS AND CUBICLES
10200 LOUVERS AND VENTS
10240 GRILLS AND SCREENS
10250 SERVICE WALLS
10260 WALL AND CORNER GUARDS
10270 ACCESS FLOORING
10290 PEST CONTROL
10300 FIREPLACES AND STOVES
10340 MANUFACTURED EXTERIOR SPECIALTIES
10350 FLAG POLES
10400 IDENTIFICATION DEVICES
10450 PEDESTRIAN CONTROL DEVICES
10500 LOCKERS
10520 FIRE PROTECTION SPECIALTIES
10530 PROTECTIVE COVERS
10550 POSTAL SPECIALTIES
10600 PARTITIONS
10670 STORAGE SHELVING
10700 EXTERIOR PROTECTION
10750 TELEPHONE SPECIALTIES
10800 TOILET, BATH AND LAUNDRY ACCESSORIES
10880 SCALES
10900 WARDROBE AND CLOSET SPECIALTIES

DIVISION 11 EQUIPMENT

11010 MAINTENANCE EQUIPMENT
11020 SECURITY AND VAULT EQUIPMENT
11030 TELLER AND SERVICE EQUIPMENT
11040 ECCLESIASTICAL EQUIPMENT
11050 LIBRARY EQUIPMENT
11060 THEATER AND STAGE EQUIPMENT
11070 INSTRUMENTAL EQUIPMENT
11080 REGISTRATION EQUIPMENT
11090 CHECK ROOM EQUIPMENT
11100 MERCANTILE EQUIPMENT
11110 COMMERCIAL LAUNDRY AND DRY CLEANING EQUIPMENT
11120 VENDING EQUIPMENT
11130 AUDIO VISUAL EQUIPMENT
11140 VEHICLE SERVICE EQUIPMENT
11150 PARKING CONTROL EQUIPMENT
11160 LOADING DOCK
11170 SOLID WASTE HANDLING EQUIPMENT
11190 DETENTION EQUIPMENT
11200 WATER SUPPLY AND TREATMENT EQUIPMENT
11280 HYDRAULIC GATES AND VALVES
11300 FLUID WASTE TREATMENT AND DISPOSAL EQUIPMENT

11400 FOOD SERVICE EQUIPMENT
11450 RESIDENTIAL EQUIPMENT
11460 UNIT KITCHENS
11470 DARK ROOM EQUIPMENT
11480 ATHLETIC, RECREATIONAL AND THERAPEUTIC EQUIPMENT
11500 INDUSTRIAL AND PROCESS EQUIPMENT
11600 LABORATORY EQUIPMENT
11650 PLANETARIUM EQUIPMENT
11660 OBSERVATORY EQUIPMENT
11680 OFFICE EQUIPMENT
11700 MEDICAL EQUIPMENT
11780 MORTUARY EQUIPMENT
11850 NAVIGATION EQUIPMENT
11870 AGRICULTURAL EQUIPMENT
11900 EXHIBIT EQUIPMENT

DIVISION 12 FURNISHINGS

12050 FABRICS
12100 ART
12300 MANUFACTURED CASEWORK
12400 FURNISHINGS AND ACCESSORIES
12500 FURNITURE
12600 MULTIPLE SEATING
12700 SYSTEMS FURNITURE
12800 INTERIOR PLANTS AND PLANTERS
12900 FURNISHINGS RESTORATION AND REPAIR

DIVISION 13 SPECIAL CONSTRUCTION

13010 AIR SUPPORTED STRUCTURES
13020 BUILDING MODULES
13030 SPECIAL PURPOSE ROOMS
13080 SOUND, VIBRATION AND SEISMIC CONTROL
13090 RADIATION PROTECTION
13100 LIGHTNING PROTECTION
13110 CATHODIC PROTECTION
13120 PRE-ENGINEERED STRUCTURES
13150 SWIMMING POOLS
13160 AQUARIUMS
13165 AQUATIC PARK FACILITIES
13170 TUBS AND POOLS
13175 ICE RINKS
13185 KENNELS AND ANIMAL SHELTERS
13190 SITE CONSTRUCTED INCINERATORS
13200 STORAGE TANKS
13220 FILTER UNDERDRAINS AND MEDIA
13230 DIGESTER COVERS AND APPURTENANCES
13240 OXYGENATION SYSTEMS
13260 SLUDGE CONDITIONING SYSTEMS
13280 HAZARDOUS MATERIAL REMEDIATION
13400 MEASUREMENT AND CONTROL INSTRUMENTATION
13500 RECORDING INSTRUMENTATION
13550 TRANSPORTATION CONTROL INSTRUMENTATION
13600 SOLAR AND WIND ENERGY EQUIPMENT\
13700 SECURITY ACCESS AND SURVEILLANCE
13800 BUILDING AUTOMATION AND CONTROL
13850 DETECTION AND ALARM
13900 FIRE SUPPRESSION

DIVISION 14 CONVEYING SYSTEMS

14100 DUMBWAITERS
14200 ELEVATORS
14300 ESCALATORS AND MOVING WALKS
14400 LIFTS
14500 MATERIAL HANDLING
14600 HOISTS AND CRANES
14700 TURNTABLES
14800 SCAFFOLDING
14900 TRANSPORTATION

DIVISION 15 MECHANICAL

15050 BASIC MECHANICAL MATERIALS AND METHODS
15100 BUILDING SERVICES PIPING
15200 PROCESS PIPING
15300 FIRE PROTECTION PIPING (SEE 13900)
15400 PLUMBING FIXTURES AND EQUIPMENT
15500 HEAT GENERATION EQUIPMENT
15600 REFRIGERATION EQUIPMENT
15700 HEATING, VENTILATION AND AIR CONDITIONING EQUIPMENT
15800 AIR DISTRIBUTION
15900 HVAC INSTRUMENTATION
15950 TESTING, ADJUSTING AND BALANCING

DIVISION 16 ELECTRICAL

16050 BASIC ELECTRICAL MATERIALS AND METHODS
16100 WIRING METHODS
16200 ELECTRICAL POWER
16300 TRANSMISSION AND DISTRIBUTION
16400 LOW VOLTAGE DISTRIBUTION
16500 LIGHTING
16700 COMMUNICATIONS
16800 SOUND AND VIDEO

APPENDIX 3-A4

CSI MASTERFORMAT – LEVEL THREE SECTION TITLES – (1995 Edition) (SELECTED SECTIONS)

13900 FIRE SUPPRESSION
13920 BASIC FIRE SUPPRESSION MATERIALS AND METHODS
13930 WET-PIPE FIRE SUPPRESSION SPRINKLERS
13935 DRY-PIPE FIRE SUPPRESSION SPRINKLERS
13940 PRE-ACTION FIRE SUPPRESSION SPRINKLERS
13945 COMBINATION DRY-PIPE AND PRE-ACTION F.S.S.
13950 DELUGE FIRE SUPPRESSION SPRINKLERS
13955 FOAM FIRE EXTINGUISHING
13960 CARBON DIOXIDE FIRE EXTINGUISHING
13965 ALTERNATIVE FIRE EXTINGUISHING SYSTEMS
13970 DRY CHEMICAL FIRE EXTINGUISHING
13975 STANDPIPES AND HOSES

15100 BUILDING SERVICES PIPING
15105 PIPES AND TUBES
15110 VALVES
15120 PIPING SPECIALTIES
15130 PUMPS
15140 DOMESTIC WATER PIPING
15150 SANITARY WASTE AND VENT PIPING
15160 STORM DRAINAGE PIPING
15170 SWIMMING POOL AND FOUNTAIN PIPING
15180 HEATING AND COOLING PIPING
15190 FUEL PIPING

15200 PROCESS PIPING
15210 PROCESS AIR AND GAS PIPING
15220 PROCESS WATER AND WASTE PIPING
15230 INDUSTRIAL PROCESS PIPING

15400 PLUMBING FIXTURES AND EQUIPMENT
15410 PLUMBING FIXTURES
15440 PLUMBING PUMPS
15450 POTABLE WATER STORAGE TANKS
15460 DOMESTIC WATER CONDITIONING EQUIPMENT
15470 DOMESTIC WATER FILTRATION EQUIPMENT
15480 DOMESTIC WATER HEATERS
15490 POOL AND FOUNTAIN EQUIPMENT

APPENDIX 3-A5

CSI MASTERFORMAT – LEVEL FOUR SECTION TITLES – (1995 Edition) (SECTION SELECTED FROM DIVISION 15; SECTION 200)

15200 PROCESS PIPING
15210 PROCESS AIR AND GAS PIPING
15211 AIR COMPRESSORS
15212 COMPRESSED AIR PIPING
15213 GAS EQUIPMENT
15214 GAS PIPING
15215 NITROGEN PIPING
15216 NITROUS OXIDE PIPING
15217 OXYGEN PIPING
15218 VACUUM PUMPS
15219 VACUUM PIPING

15220 PROCESS WATER AND WASTE PIPING
15221 DEIONIZED WATER PIPING
15223 DISTILLED WATER PIPING
15225 LABORATORY ACID WASTE AND VENT PIPING
15227 PROCESS PIPING INTERCEPTORS
15229 REVERSE OSMOSIS WATER PIPING

15230 INDUSTRIAL PROCESS PIPING
15231 DRY PRODUCT PIPING
15232 FLUID PRODUCT PIPING

APPENDIX 3-B1

CSI MASTERFORMAT DIVISIONS (2004 EDITION) PROCUREMENT and CONTRACTING DOCUMENTS GROUP

DIVISION 00 – PROCUREMENT and CONTRACTING REQUIREMENTS: *This Division is essentially the same in scope as it was in MasterFormat95.*

SPECIFICATIONS GROUP

GENERAL REQUIREMENTS SUBGROUP

DIVISION 01 – GENERAL REQUIREMENTS: *The area for performance requirements was added to allow for the writing of performance requirements for the elements that are found in more than one work section such as building envelope, structure, etc. This new feature will allow for the specifier to include a mixture of broad performance specifications and descriptive specifications into the project manual.*

FACILITY CONSTRUCTION SUBGROUP

DIVISION 02 – EXISTING CONDITIONS: *Division 2 is now restricted to the "existing conditions" that is, construction tasks that relate to the items at the site when the project commences – selective demolition, subsurface and other investigations, surveying , site decontamination and/ or remediation to mention a few. (ALL site construction as well as heavy civil and infrastructure items including pavement and utilities has been relocated to the Site and Infrastructure Subgroup)*

DIVISION 03 – CONCRETE: *This division will remain essentially as it was under MasterFormat95*

DIVISION 04 – MASONRY: *This division will remain essentially as it was under MasterFormat95*

DIVISION 05 – METALS: This *division will remain essentially as it was under MasterFormat95*

DIVISION 06 – WOOD, PLASTICS and COMPOSITES: *This Division will remain essentially as it was under MasterFormat95, but also will include expanded areas for plastics and other composite materials.*

DIVISION 07 – THERMAL and MOISTURE PROTECTION: *This division will remain essentially as it was Under MasterFormat95.*

DIVISION 08 – OPENINGS: *This section was Doors and Windows under MasterFormat95, and remains essentially unchanged but was renamed to with the addition of other openings such as louvers and grilles*

DIVISION 09 – FINISHES: *This division will remain essentially as it was under MasterFormat95*

DIVISION 10 – SPECIALTIES: *This division will remain essentially as it was under MasterFormat95*

DIVISION 11 – EQUIPMENT: *This Division will remain as is with the exception of that equipment related to process engineering has been relocated to the Process Equipment Subgroup and that equipment related to Infrastructure has been relocated to the Site and Infrastructure subgroup.*

DIVISION 12 – FURNISHINGS: *This division will remain essentially as it was under MasterFormat95*

DIVISION 13 – SPECIAL CONSTRUCTION: *This division will remain essentially as it was under MasterFormat95 except that special construction related to process engineering has been relocated to the Process Equipment Subgroup. Security, building automation, detection and alarm as well as fire suppression have been relocated to the Facility Services Subgroup.*

DIVISION 14 – CONVEYING EQUIPMENT: *This division has been renamed with process related material Handling equipment relocated to the Process Equipment Subgroup*

DIVISION 15 – RESERVED FOR FUTURE EXPANSION: *This Division has been assigned for any future expansion and Division 15 has been separated and relocated to Division 22 – Plumbing a and Division 23 – Heating, Ventilation, and Air Conditioning in the Facility Services Subgroup.*

DIVISION 16 – RESERVED FOR FUTURE EXPANSION: *This Division has been assigned for any future expansion and Division 16 has been separated and relocated to Division 26 – Electrical and Division 27 – Communications in the Facility Services Subgroup.*

DIVISION 17 – RESERVED FOR FUTURE EXPANSION

DIVISION 18 – RESERVED FOR FUTURE EXPANSION

DIVISION 19 – RESERVED FOR FUTURE EXPANSION

FACILITY SERVICES SUBGROUP

DIVISION 20 – RESERVED

DIVISION 21 – FIRE SUPPRESSION: *This division contains the Fire Suppression sections relocated from Division 13 in MasterFormat95.*

DIVISION 22 – PLUMBING: *This division contains the Plumbing sections relocated from Division 15 in MasterFormat95.*

DIVISION 23 – HEATING, VENTILATION and AIR CONDITIONING: *This division contains the Heating Ventilation and Air Conditioning Sections from Division 15 in MasterFormat95*.

DIVISION 24 – RESERVED

DIVISION 25 – INTEGRATED AUTOMATION: *This Division contains the expanded integrated automation sections that were relocated from Division 13 in MasterFormat95*.

DIVISION 26 – ELECTRICAL: *This Division contains the Electrical and Lighting sections relocated from Division 16 in MasterFormat95*

DIVISION 27 – COMMUNICATIONS: *This Division contains the expanded Communications sections relocated from Division 16 in MasterFormat95*

DIVISION 28 – ELECTRONIC SAFETY and SECURITY: *This Division contains the expanded Electronic Safety and Security sections relocated from Division 13 in MasterFormat95*

DIVISION 29 – RESERVED

SITE and INFRASTRUCTURE SUBGROUP

DIVISION 30 – RESERVED FOR FUTURE EXPANSION

DIVISION 31 – EARTHWORK: *Site Construction sections, predominately below grade, that have been relocated from Division 02 in MasterFormat95*.

DIVISION 32 – EXTERIOR IMPROVEMENTS: *Site Construction sections, predominately above grade, that have been relocated from Division 02 in MasterFormat95*

DIVISION 33 – UTILITIES: *Utility sections with expansions that have been relocated from Division 02 in MasterFormat95*.

DIVISION 34 – TRANSPORTATION: *Transportation sections with expansions relocated from the various divisions in MasterFormat95*

DIVISION 35 – WATERWAY and MARINE: *Expanded waterway and other marine section from Division 02 and other divisions in MasterFormat95*.

DIVISION 36 – RESERVED FOR FUTURE EXPANSION

DIVISION 37 – RESERVED FOR FUTURE EXPANSION

DIVISION 38 – RESERVED FOR FUTURE EXPANSION

DIVISION 39 – RESERVED FOR FUTURE EXPANSION

PROCESS EQUIPMENT SUBGROUP

DIVISION 40 – RESERVED FOR FUTURE EXPANSION

DIVISION 41 – MATERIAL PROCESSING and HANDLING EQUIPMENT: *Equipment for the processing and conditioning of raw materials; material handling equipment for bulk materials as well as discrete units; manufacturing equipment and machinery; test equipment and packaging/ shipping systems.*

DIVISION 42 – PROCESSING HEATING, COOLING and DRYING EQUIPMENT: *Equipment for process heating, cooling and drying of materials, liquids, gases, and manufactured items and/or materials.*

DIVISION 43 – PROCESS GAS and LIQUID HANDLING, PURIFICATION and STORAGE EQUIPMENT: *Equipment for handling purification and storage of process liquids, gases, and slurries including atmospheric tanks as well as pressure vessels.*

DIVISION 44 – POLLUTION CONTROL EQUIPMENT: *Equipment for controlling emission of contaminants from manufacturing processes and treatment of air, soil, and water contaminants.*

DIVISION 45 – INDUSTRY SPECIFIC MANUFACTURING EQUIPMENT*: A division in which the owners can specify equipment that is used ONLY within a single industry. (All industries currently identified in the North American Industry Classification System, NAICS, are allocated space within this division).*

DIVISION 46 – SOLID WASTE EQUIPMENT: *Not defined at this time*

DIVISION 47 – RESERVED FOR FUTURE EXPANSION

DIVISION 48 – ELECTRICAL POWER GENERATION: *Plants and equipment for the generation and control of electrical power from fossil fuel, nuclear energy, hydroelectric, wind, solar energy, geothermal energy, electrochemical energy and fuel cells*.

DIVISION 49 – RESERVED FOR FUTURE EXPANSION

APPENDIX 3-B2

MASTERFORMAT 2004

FACILITY CONSTRUCTION SUBGROUP

DIVISION 21 – FIRE SUPPRESSION

21 00 00 – FIRE SUPPRESSION

21 01 00 – OPERATION and MAINTENANCE of FIRE SUPPRESSION
21 02 00 – RESERVED
21 03 00 – RESERVED
21 04 00 – RESERVED
21 05 00 – COMMON WORK RESULTS for FIRE SUPPRESSION
21 06 00 – SCHEDULES for FIRE SUPPRESSION
21 07 00 – FIRE SUPPRESSION SYSTEMS INSULATION
21 08 00 – COMMISIONING of FIRE SUPPRESSION SYSTEMS
21 09 00 – INSTRUMENTATION and CONTROL for FIRE SUPPRESSION SYSTEMS

21 10 00 – WATER BASED FIRE SUPPRESSION SYSTEMS

21 11 00 – FACILITY FIRE SUPPRESSION WATER SERVICE PIPING
21 12 00 – FIRE SUPPRESSION STANDPIPES
21 13 00 – FIRE SUPPRESSION SPRINKLER SYSTEMS
21 14 00 – RESERVED
21 15 00 – RESERVED
21 16 00 – RESERVED
21 17 00 – RESERVED
21 18 00 – RESERVED
21 19 00 – RESERVED

21 20 00 – FIRE EXTINGUISHING SYSTEMS

21 21 00 – CARBON DIOXIDE FIRE EXTINGUISHING SYSTEMS
21 22 00 – CLEAN AGENT FIRE EXTINGUISHING SYSTEMS
21 23 00 – WET CHEMICAL FIRE EXTINGUISHING SYSTEMS
21 24 00 – DRY CHEMICAL FIRE EXTINGUISHING SYSTEMS
21 25 00 – RESERVED
21 26 00 – RESERVED
21 27 00 – RESERVED
21 28 00 – RESERVED
21 29 00 – RESERVED

21 30 00 – FIRE PUMPS

21 31 00 – CENTRIFUGAL FIRE PUMPS
21 32 00 – VERTICAL TURBINE FIRE PUMPS
21 33 00 – POSITIVE DISPLACEMENT FIRE PUMPS
21 34 00 – RESERVED
21 35 00 – RESERVED
21 36 00 – RESERVED
21 37 00 – RESERVED
21 38 00 – RESERVED
21 39 00 – RESERVED

21 40 00 – FIRE SUPPRESSION WATER STORAGE

21 41 00 – STORAGE TANKS for FIRE SUPPRESSION WATER
21 42 00 – RESERVED
21 43 00 – RESERVED
21 44 00 – RESERVED
21 45 00 – RESERVED
21 46 00 – RESERVED
21 47 00 – RESERVED
21 48 00 – RESERVED
21 49 00 – RESERVED

21 50 00 – RESERVED

21 60 00 – RESERVED

21 70 00 – RESERVED

21 80 00 – RESERVED

21 90 00 – RESERVED

APPENDIX 3-B3

MASTERFORMAT 2004

FACILITY CONSTRUCTION SUBGROUP

DIVISION 21 – FIRE SUPPRESSION

21 00 00 – FIRE SUPPRESSION

21 01 00 – OPERATION and MAINTENANCE of FIRE SUPPRESSION

21 01 10 – OPERATION and MAINTENANCE OF WATER BASED FIRE SUPPRESSION SYSTEMS
21 01 20 – OPERATION and MAINTENANCE of FIRE EXTINGUISHING SYSTEMS
21 01 30 – OPERATION and MAINTENANCE of FIRE SUPPRESSION EQUIPMENT

21 02 00 – RESERVED

21 03 00 – RESERVED

21 04 00 – RESERVED

21 05 00 – COMMON WORK RESULTS for FIRE SUPPRESSION

21 05 13 – COMMON MOTOR REQUIREMENTS for FIRE SUPPRESSION EQUIPMENT
21 05 16 – EXPANSION FITTINGS and LOOPS for FIRE SUPPRESSION PIPING
21 05 19 – METERS and GAGES for FIRE SUPPRESSION SYSTEMS
21 05 23 – GENERAL DUTY VALVES for WATER BASED FIRE SUPPRESSION PIPING
21 05 29 – HANGERS and SUPPORTS for FIRE SUPPRESSION PIPING and EQUIPMENT
21 05 33 – HEAT TRACING FOR FIRE SUPPRESSION PIPING
21 05 48 – VIBRATION and SEISMIC CONTROLS for FIRE SUPPRESSION PIPING and EQUIPMENT
21 05 53 – IDENTIFICATION for FIRE SUPPRESSION PIPING and EQUIPMENT

21 06 00 – SCHEDULES for FIRE SUPPRESSION

21 06 10 – SCHEDULES for WATER BASED FIRE SUPPRESSION SYSTEMS
21 06 20 – SCHEDULES for FIRE EXTINGUISHING SYSTEMS
21 06 30 – SCHEDULES for FIRE SUPPRESSION EQUIPMENT

21 07 00 – FIRE SUPPRESSION SYSTEMS INSULATION

21 07 10 – FIRE SUPPRESSION EQUIPMENT INSULATION
21 07 20 – FIRE SUPPRESSION PIPING INSULATION

21 08 00 – COMMISIONING of FIRE SUPPRESSION SYSTEMS

21 09 00 – INSTRUMENTATION and CONTROL for FIRE SUPPRESSION SYSTEMS

21 10 00 – WATER BASED FIRE SUPPRESSION SYSTEMS

21 11 00 – FACILITY FIRE SUPPRESSION WATER SERVICE PIPING

21 11 16 – FACILITY FIRE HYDRANTS
21 11 19 – FIRE DEPARTMENT CONNECTIONS

21 12 00 – FIRE SUPPRESSION STANDPIPES

21 12 13 – FIRE SUPPRESSION HOSES and NOZZLES
21 12 16 – FIRE SUPPRESSION HOSE REELS
21 12 19 – FIRE SUPPRESSION HOSE RACKS
21 12 23 – FIRE SUPPRESSION HOSE VALVES
21 12 26 – FIRE SUPPRESSION VALVE and HOSE CABINETS

21 13 00 – FIRE SUPPRESSION SPRINKLER SYSTEMS

21 13 13 – WET PIPE SPRINKLER SYSTEMS
21 13 16 – DRY PIPE SPRINKLER SYSTEMS
21 13 19 – PRE-ACTION SPRINKLER SYSTEMS
21 13 23 – COMBINED DRY and PRE-ACTION SPRINKLER SYSTEMS
21 13 26 – DELUGE FIRE SUPPRESSION SPRINKLER SYSTEMS
21 13 29 – WATER SPRAY FIXED SYSTEMS
21 13 36 – ANTIFREEZE SPRINKLER SYSTEMS
21 13 39 – FOAM-WATER SYSTEMS

21 14 00 – RESERVED

21 15 00 – RESERVED

21 16 00 – RESERVED

21 17 00 – RESERVED

21 18 00 – RESERVED

21 19 00 – RESERVED

21 20 00 – FIRE EXTINGUISHING SYSTEMS

21 21 00 – CARBON DIOXIDE FIRE EXTINGUISHING SYSTEMS

21 21 13 – CARBON DIOXIDE FIRE EXTINGUISHING PIPING
21 21 16 – CARBON DIOXIDE FIRE EXTINGUISHING EQUIPMENT

21 22 00 – CLEAN AGENT FIRE EXTINGUISHING SYSTEMS

21 22 13 – CLEAN AGENT FIRE EXTINGUISHING PIPING
21 22 16 – CLEAN AGENT FIRE EXTINGUISHING EQUIPMENT

21 23 00 – WET CHEMICAL FIRE EXTINGUISHING SYSTEMS

21 23 13 – WET CHEMICAL FIRE EXTINGUISHING PIPING
21 23 16 – WET CHEMICAL FIRE EXTINGUISHING EQUIPMENT

21 24 00 – DRY CHEMICAL FIRE EXTINGUISHING SYSTEMS

21 24 13 – DRY CHEMICAL FIRE EXTINGUISHING PIPING
21 24 16 – DRY CHEMICAL FIRE EXTINGUISHING EQUIPMENT

21 25 00 – RESERVED

21 26 00 – RESERVED

21 27 00 – RESERVED

21 28 00 – RESERVED

21 29 00 – RESERVED

21 30 00 – FIRE PUMPS

21 31 00 – CENTRIFUGAL FIRE PUMPS

21 31 13 – ELECTRIC DRIVE, CENTRIFUGAL FIRE PUMPS
21 31 16 – DIESEL DRIVE, CENTRIFUGAL FIRE PUMPS

21 32 00 – VERTICAL TURBINE FIRE PUMPS

21 32 13 – ELECTRIC DRIVE, VERTICAL TURBINE FIRE PUMPS
21 32 16 – DIESEL DRIVE, VERTICAL TURBINE FIRE PUMPS

21 33 00 – POSITIVE DISPLACEMENT FIRE PUMPS

21 33 10 – ELECTRIC DRIVE, POSITIVE DISPLACEMENT FIRE PUMPS
21 33 16 – DIESEL DRIVE, POSITIVE DISPLACEMENT FIRE PUMPS

21 34 00 – RESERVED

21 35 00 – RESERVED

21 36 00 – RESERVED

21 37 00 – RESERVED

21 38 00 – RESERVED

21 39 00 – RESERVED

21 40 00 – FIRE SUPPRESSION WATER STORAGE

21 41 10 – STORAGE TANKS for FIRE SUPPRESSION WATER

21 41 13 – PRESSURIZED STORAGE TANKS for FIRE SUPPRESSION WATER
21 41 16 – ELEVATED STORAGE TANKS for FIRE SUPPRESSION WATER
21 41 19 – ROOF MOUNTED STORAGE TANKS for FIRE SUPPRESSION WATER
21 41 23 – GROUND SUCTION STORAGE TANKS for FIRE SUPPRESSION WATER
21 41 26 – UNDERGROUND STORAGE TANKS for FIRE SUPPRESSION WATER
21 41 29 – STORAGE TANKS for FIRE SUPPRESSION WATER ADDITIVES

21 42 00 – RESERVED

21 43 00 – RESERVED

21 44 00 – RESERVED

21 45 00 – RESERVED

21 46 00 – RESERVED

21 47 00 – RESERVED

21 48 00 – RESERVED

21 49 00 – RESERVED

21 50 00 – RESERVED

21 60 00 – RESERVED

21 70 00 – RESERVED

21 80 00 – RESERVED

21 90 00 – RESERVED

APPENDIX 3-B4

MASTERFORMAT 2004

FACILITY CONSTRUCTION SUBGROUP

22 00 00 – PLUMBING

22 01 00 – OPERATION and MAINTENANCE of PLUMBING

22 01 10 – OPERATION and MAINTENANCE of PLUMBING PIPING and PUMPS
22 01 20 – RESERVED
22 01 30 – OPERATION and MAINTENANCE of PLUMBING EQUIPMENT
22 01 40 – OPERATION and MAINTENANCE of PLUMBING FIXTURES
22 01 50 – OPERATION and MAINTENANCE of POOL and FOUNTAIN PLUMBING SYSTEMS
22 01 60 – OPERATION and MAINTENANCE of LABORATORY and HEALTHCARE SYSTEMS
22 01 70 – RESERVED
22 01 80 – RESERVED
22 01 90 – RESERVED

22 02 00 – RESERVED

22 03 00 – RESERVED

22 04 00 – RESERVED

22 05 00 – COMMON WORK RESULTS for PLUMBING

22 05 13 – COMMON MOTOR REQUIREMENTS for PLUMBING EQUIPMENT
22 05 16 – EXPANSION FITTINGS and LOOPS for PLUMBING PIPING
22 05 19 – METERS and GAGES for PLUMBING PIPING
22 05 23 – GENERAL DUTY VALVES for PLUMBING PIPING
22 05 29 – HANGERS and SUPPORTS for PLUMBING PIPING and EQUIPMENT
22 05 33 – HEAT TRACING for PLUMBING PIPING
22 05 48 – VIBRATION and SEISMIC CONTROLS for PLUMBING PIPING and EQUIPMENT
22 05 53 – IDENTIFICATION for PLUMBING PIPING and EQUIPMENT
22 05 73 – FACILITY DRAINAGE MANHOLES
22 05 76 – FACILITY DRAINAGE CLEANOUTS

22 06 00 – SCHEDULES for PLUMBING

22 06 10 – SCHEDULES for PLUMBING PIPING and PUMPS
22 06 12 – SCHEDULES for FACILITY POTABLE WATER STORAGE
22 06 15 – SCHEDULES for GENERAL SERVICE COMPRESSED AIR EQUIPMENT
22 06 30 – SCHEDULES for PLUMBING EQUIPMENT
22 06 40 – SCHEDULES for PLUMBING FIXTURES
22 06 50 – SCHEDULES for POOL and FOUNTAIN PLUMBING SYSTEMS
22 06 60 – SCHEDULES for LABORATORY and HEALTHCARE SYSTEMS

22 07 00 – PLUMBING INSULATION

22 07 16 – PLUMBING EQUIPMENT INSULATION
22 07 19 – PLUMBING PIPING INSULATION

22 08 00 – COMMISSIONING of PLUMBING

22 09 00 – INSTRUMENTATION and CONTROL of PLUMBING

22 10 00 – PLUMBING PIPING and PUMPS

22 11 00 – FACILITY WATER DISTRIBUTION

22 11 13 – FACILITY WATER DISTRIBUTION PIPING
22 11 16 – DOMESTIC WATER PIPING
22 11 19 – DOMESTIC WATER PIPING SPECIALTIES
22 11 23 – DOMESTIC WATER PUMPS

22 12 00 – FACILITY POTABLE WATER STORAGE TANKS

22 12 13 – FACILITY ROOF MOUNTED, POTABLE WATER STORAGE TANKS
22 12 16 – FACILITY ELEVATED, POTABLE WATER STORAGE TANKS
22 12 19 – FACILITY GROUND MOUNTED, POTABLE WATER STORAGE TANKS

22 12 23 – FACILITY INDOOR POTABLE WATER STORAGE TANKS

22 13 00 – FACILITY SANITARY SEWERAGE

22 13 13 – FACILITY SANITARY SEWERS
22 13 16 – SANITARY WASTE and VENT PIPING
22 13 19 – SANITARY WASTE PIPING SPECIALTIES
22 13 23 – SANITARY WASTE INTERCEPTORS
22 13 26 – SANITARY WASTE SEPARATORS
22 13 29 – SANITARY SEWERAGE PUMPS
22 13 33 – PACKAGED, SUBMERSIBLE SEWERAGE PUMP UNITS
22 13 36 – PACKAGED, WASTEWATER PUMP UNITS
22 13 43 – FACILITY PACKAGED SEWAGE PUMPING STATIONS
22 13 53 – FACILITY SEPTIC TANKS

22 14 00 – FACILITY STORM DRAINAGE

22 14 13 – FACILITY STORM DRAINAGE PIPING
22 14 16 – RAINWATER LEADERS
22 14 19 – SUMP PUMP DISCHARGE PIPING
22 14 23 – STORM DRAINAGE PIPING SPECIALTIES
22 14 26 – FACILITY STORM DRAINS
22 14 29 – SUMP PUMPS
22 14 33 – PACKAGED, PEDESTAL, DRAINAGE PUMP UNITS
22 14 36 – PACKAGED, SUBMERSIBLE, DRAINAGE PUMP UNITS

22 15 00 – GENERAL SERVICE COMPRESSED AIR SYSTEMS

22 15 13 – GENERAL SERVICE COMPRESSED AIR PIPING
22 15 16 – GENERAL SERVICE COMPRESSED AIR VALVES
22 15 19 – GENERAL SERVICE PACKAGED AIR COMPRESSORS and RECEIVERS

22 16 00 – RESERVED

22 17 00 – RESERVED

22 18 00 – RESERVED

22 19 00 – RESERVED

22 20 00 – RESERVED

22 30 00 – PLUMBING EQUIPMENT

22 31 00 – DOMESTIC WATER SOFTENERS

22 31 13 – RESIDENTIAL DOMESTIC WATER SOFTENERS
22 31 16 – COMMERCIAL DOMESTIC WATER SOFTENERS

22 32 00 – DOMESTIC WATER FILTRATION EQUIPMENT

22 32 13 – DOMESTIC WATER BAG TYPE FILTERS
22 32 16 – DOMESTIC WATER FREE STANDING CARTRIDGE FILTERS
22 32 19 – DOMESTIC WATER OFF FLOOR CARTRIDGE FILTERS
22 32 23 – DOMESTIC WATER CARBON FILTERS
22 32 26 – DOMESTIC WATER SAND FILTERS

22 33 00 – ELECTRIC DOMESTIC WATER HEATERS

22 33 13 – INSTANTANEOUS ELECTRIC DOMESTIC WATER HEATERS
22 33 30 – RESIDENTIAL, ELECTRIC DOMESTIC WATER HEATERS
22 33 33 – LIGHT COMMERCIAL ELECTRIC DOMESTIC WATER HEATERS
22 33 36 – COMMERCIAL DOMESTIC WATER ELECTRIC BOOSTER HEATERS

22 34 00 – FUEL FIRED DOMESTIC WATER HEATERS

22 34 13 – INSTANTANEOUS, TANKLESS, GAS DOMESTIC WATER HEATERS
22 34 30 – RESIDENTIAL GAS DOMESTIC WATER HEATERS
22 34 36 – COMMERCIAL GAS DOMESTIC WATER HEATERS
22 34 46 – OIL FIRED DOMESTIC WATER HEATERS
22 34 56 – DUAL FUEL FIRED DOMESTIC WATER HEATERS

22 35 00 – DOMESTIC WATER HEAT EXCHANGERS

22 35 13 – INSTANTANEOUS DOMESTIC WATER HEAT EXCHANGERS
22 35 23 – CIRCULATING DOMESTIC WATER HEAT EXCHANGERS
22 35 29 – NON-CIRCULATING DOMESTIC WATER HEAT EXCHANGERS
22 35 36 – DOMESTIC WATER BRAZED PLATE HEAT EXCHANGERS
22 35 39 – DOMESTIC WATER PLATE and FRAME HEAT EXCHANGERS
22 35 43 – DOMESTIC WATER HEAT RECLAIMERS

22 36 00 – RESERVED

22 37 00 – RESERVED

22 38 00 – RESERVED

22 39 00 – RESERVED

22 40 00 – PLUMBING FIXTURES

22 41 00 – RESIDENTIAL PLUMBING FIXTURES

22 41 13 – RESIDENTIAL WATER CLOSETS, URINALS and BIDETS
22 41 16 – RESIDENTIAL LAVATORIES and SINKS
22 41 19 – RESIDENTIAL BATHTUBS
22 41 23 – RESIDENTIAL SHOWER RECEPTORS and BASINS
22 41 26 – RESIDENTIAL DISPOSERS
22 41 36 – RESIDENTIAL LAUNDRY TRAYS
22 41 39 – RESIDENTIAL FAUCETS, SUPPLIES and TRIM

22 42 00 – COMMERCIAL PLUMBING FIXTURES

22 42 13 – COMMERCIAL WATER CLOSETS, URINALS and BIDETS
22 42 16 – COMMERCIAL LAVATORIES and SINKS
22 42 19 – COMMERCIAL BATHTUBS
22 42 23 – COMMERCIAL SHOWER RECEPTORS and BASINS
22 42 26 – COMMERCIAL DISPOSERS
22 42 29 – SHAMPOO BOWLS
22 42 33 – WASH FOUNTAINS
22 42 36 – COMMERCIAL LAUNDRY TRAYS
22 42 39 – COMMERCIAL FAUCETS, SUPPLIES and TRIM
22 42 43 – FLUSHOMETERS

22 43 00 – HEALTHCARE PLUMBING FIXTURES

22 43 13 – HEALTHCARE WATER CLOSETS
22 43 16 – HEALTHCARE SINKS
22 43 19 – HEALTHCARE BATHTUBS and SHOWERS
22 43 23 – HEALTHCARE SHOWER RECEPTORS and BASINS
22 43 26 – HEALTHCARE FAUCETS
22 43 43 – HEALTHCARE PLUMBING FIXTURE FLUSHOMETERS

22 44 00 – RESERVED

22 45 00 – EMERGENCY PLUMBING FIXTURES

22 45 13 – EMERGENCY SHOWERS
22 45 16 – EYEWASH EQUIPMENT
22 45 19 – SELF CONTAINED EYEWASH EQUIPMENT
22 45 23 – PERSONAL EYEWASH EQUIPMENT
22 45 26 – EYE/ FACE WASH EQUIPMENT
22 45 29 – HAND HELD EMERGENCY DRENCH HOSES
22 45 33 – COMBINATION EMERGENCY FIXTURE UNITS
22 45 36 – EMERGENCY FIXTURE WATER TEMPERING UNITS

22 46 00 – SECURITY PLUMBING FIXTURES

22 46 13 – SECURITY WATER CLOSETS and URINALS
22 46 16 – SECURITY LAVATORIES and SINKS
22 46 39 – SECURITY FAUCETS, SUPPLIES and TRIM
22 46 43 – SECURITY PLUMBING FIXTURE FLUSHOMETERS
22 46 53 – SECURITY PLUMBING FIXTURE SUPPORTS

22 47 00 – DRINKING FOUNTAINS and WATER COOLERS

22 47 13 – DRINKING FOUNTAINS
22 47 16 – PRESSURE WATER COOLERS
22 47 19 – WATER STATION WATER COOLERS
22 47 23 – REMOTE WATER COOLERS

22 48 00 – RESERVED

22 49 00 – RESERVED

22 50 00 – POOL and FOUNTAIN PLUMBING SYSTEMS

22 51 00 – SWIMMING POOL PLUMBING SYSTEMS

22 51 13 – SWIMMING POOL PIPING
22 51 16 – SWIMMING POOL PUMPS
22 51 19 – SWIMMING POOL WATER TREATMENT EQUIPMENT
22 51 23 – SWIMMING POOL EQUIPMENT CONTROLS

22 52 00 – FOUNTAIN PLUMBING SYSTEMS

22 52 13 – FOUNTAIN PIPING
22 52 16 – FOUNTAIN PUMPS
22 52 19 – FOUNTAIN WATER TREATMENT EQUIPMENT
22 52 23 – FOUNTAIN EQUIPMENT CONTROLS

22 53 00 – RESERVED

22 54 00 – RESERVED

22 55 00 – RESERVED

22 56 00 – RESERVED

22 57 00 – RESERVED

22 58 00 – RESERVED

22 59 00 – RESERVED

22 60 00 – GAS and VACUUM SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 61 00 – COMPRESSED AIR SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 61 13 – COMPRESSED AIR PIPING for LABORATORY and HEALTHCARE FACILITIES
22 61 19 – COMPRESSED AIR EQUIPMENT for LABORATORY and HEALTHCARE FACILITIES

22 62 00 – VACUUM SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 62 13 – VACUUM PIPING for LABORATORY and HEALTHCARE FACILITIES
22 62 19 – VACUUM EQUIPMENT for LABORATORY and HEALTHCARE FACILITIES
22 62 23 – WASTE ANESTHESIA GAS PIPING

22 63 00 – GAS SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 63 13 – GAS PIPING for LABORATORY and HEALTHCARE FACILITIES
22 63 19 – GAS STORAGE TANKS for LABORATORY and HEALTHCARE FACILITIES

22 64 00 – RESERVED

22 65 00 – RESERVED

22 66 00 – CHEMICAL WASTE SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 66 53 – LABORATORY CHEMICAL WASTE and VENT PIPING
22 66 70 – HEALTH CARE CHEMICAL WASTE and VENT PIPING
22 66 83 – CHEMICAL WASTE TANKS

22 67 00 – PROCESSED WATER SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 67 13 – PROCESSED WATER PIPING for LABORATORY and HEALTHCARE FACILITIES
22 67 19 – PROCESSED WATER EQUIPMENT for LABORATORY and HEALTHCARE FACILITIES

22 68 00 – RESERVED

22 69 00 – RESERVED

22 70 00 – RESERVED

22 80 00 – RESERVED

22 90 00 – RESERVED

APPENDIX 3-B5

MASTERFORMAT 2004

FACILITY CONSTRUCTION SUBGROUP

22 00 00 – PLUMBING

22 01 00 – OPERATION and MAINTENANCE of PLUMBING

22 01 10 – OPERATION and MAINTENANCE of PLUMBING PIPING and PUMPS
22 01 20 – RESERVED
22 01 30 – OPERATION and MAINTENANCE of PLUMBING EQUIPMENT
22 01 40 – OPERATION and MAINTENANCE of PLUMBING FIXTURES
22 01 50 – OPERATION and MAINTENANCE of POOL and FOUNTAIN PLUMBING SYSTEMS
22 01 60 – OPERATION and MAINTENANCE of LABORATORY and HEALTHCARE SYSTEMS
22 01 70 – RESERVED
22 01 80 – RESERVED
22 01 90 – RESERVED

22 02 00 – RESERVED

22 03 00 – RESERVED

22 04 00 – RESERVED

22 05 00 – COMMON WORK RESULTS for PLUMBING

22 05 13 – COMMON MOTOR REQUIREMENTS for PLUMBING EQUIPMENT
22 05 16 – EXPANSION FITTINGS and LOOPS for PLUMBING PIPING
22 05 19 – METERS and GAGES for PLUMBING PIPING
22 05 23 – GENERAL DUTY VALVES for PLUMBING PIPING
22 05 29 – HANGERS and SUPPORTS for PLUMBING PIPING and EQUIPMENT
22 05 33 – HEAT TRACING for PLUMBING PIPING
22 05 48 – VIBRATION and SEISMIC CONTROLS for PLUMBING PIPING and EQUIPMENT
22 05 53 – IDENTIFICATION for PLUMBING PIPING and EQUIPMENT
22 05 73 – FACILITY DRAINAGE MANHOLES
22 05 76 – FACILITY DRAINAGE CLEANOUTS

22 06 00 – SCHEDULES for PLUMBING

22 06 10 – SCHEDULES for PLUMBING PIPING and PUMPS
22 06 10 13 – Plumbing Pump Schedule
22 06 12 – SCHEDULES for FACILITY POTABLE WATER STORAGE
22 06 15 – SCHEDULES for GENERAL SERVICE COMPRESSED AIR EQUIPMENT
22 06 30 – SCHEDULES for PLUMBING EQUIPMENT
22 06 30 13 – Domestic Water Heater Schedule
22 06 40 – SCHEDULES for PLUMBING FIXTURES
22 06 40 13 – Plumbing Fixture Schedule
22 06 50 – SCHEDULES for POOL and FOUNTAIN PLUMBING SYSTEMS
22 06 60 – SCHEDULES for LABORATORY and HEALTHCARE SYSTEMS

22 07 00 – PLUMBING INSULATION

22 07 16 – PLUMBING EQUIPMENT INSULATION
22 07 19 – PLUMBING PIPING INSULATION

22 08 00 – COMMISSIONING of PLUMBING

22 09 00 – INSTRUMENTATION and CONTROL of PLUMBING

22 10 00 – PLUMBING PIPING and PUMPS

22 11 00 – FACILITY WATER DISTRIBUTION

22 11 13 – FACILITY WATER DISTRIBUTION PIPING
22 11 16 – DOMESTIC WATER PIPING
22 11 19 – DOMESTIC WATER PIPING SPECIALTIES
22 11 23 – DOMESTIC WATER PUMPS
22 11 23 13 – *Domestic Water Packaged Booster Pumps*
22 11 23 23 – *Close Coupled, In-Line, Seal-Less Centrifugal Domestic Water Pumps*
22 11 23 26 – *Close Coupled, Horizontally Mounted, In-Line, Centrifugal Domestic Water Pumps*
22 11 23 29 – *Close Coupled, Vertically Mounted, In-Line, Centrifugal Domestic Water Pumps*
22 11 23 33 – *Separately Coupled, In-Line, Centrifugal Domestic Water Pumps*
22 11 23 36 – *Separately Coupled, Horizontally Mounted, In-Line, Centrifugal Domestic Water Pumps*

22 12 00 – FACILITY POTABLE WATER STORAGE TANKS

22 12 13 – FACILITY ROOF MOUNTED, POTABLE WATER STORAGE TANKS
22 12 16 – FACILITY ELEVATED, POTABLE WATER STORAGE TANKS
22 12 19 – FACILITY GROUND MOUNTED, POTABLE WATER STORAGE TANKS
22 12 23 – FACILITY INDOOR POTABLE WATER STORAGE TANKS
22 12 23 13 – Facility Steel, Indoor Potable Water Storage, Pressure Tanks
22 12 23 16 – Facility Steel, Indoor Potable Water Storage, Non-Pressure Tanks

22 12 23 23 – Facility Plastic, Indoor Potable Water Storage, Pressure Tanks
22 12 23 26 – Facility Plastic, Indoor Potable Water Storage, Non-Pressure Tanks

22 13 00 – FACILITY SANITARY SEWERAGE

22 13 13 – FACILITY SANITARY SEWERS
22 13 16 – SANITARY WASTE and VENT PIPING
22 13 19 – SANITARY WASTE PIPING SPECIALTIES
22 13 19 13 – Sanitary Drains
22 13 19 23 – Fats, Oils, and Grease Disposal Systems
22 13 19 26 – Grease Removal Devices
22 13 19 33 – Backwater Valves
22 13 19 36 – Air Admittance Valves
22 13 23 – SANITARY WASTE INTERCEPTORS
22 13 26 – SANITARY WASTE SEPARATORS
22 13 29 – SANITARY SEWERAGE PUMPS
22 13 29 13 – Wet Pit Mounted, Vertical Sewerage Pumps
22 13 29 16 – Submersible Sewerage Pumps
22 13 29 23 – Sewerage Pump Reverse Flow Assemblies
22 13 29 33 – Sewerage Pump Basins and Pits
22 13 33 – PACKAGED, SUBMERSIBLE SEWERAGE PUMP UNITS
22 13 36 – PACKAGED, WASTEWATER PUMP UNITS
22 13 43 – FACILITY PACKAGED SEWAGE PUMPING STATIONS
22 13 43 13 – Facility Dry Well Packaged Sewage Pumping Stations
22 13 43 16 – Facility Wet Well Packaged Sewage Pumping Stations
22 13 53 – FACILITY SEPTIC TANKS

22 14 00 – FACILITY STORM DRAINAGE

22 14 13 – FACILITY STORM DRAINAGE PIPING
22 14 16 – RAINWATER LEADERS
22 14 19 – SUMP PUMP DISCHARGE PIPING
22 14 23 – STORM DRAINAGE PIPING SPECIALTIES
22 14 23.23 – Fats, Oils, and Grease Disposal Systems
22 14 23.26 – Grease Removal Devices
22 14 23.33 – Backwater Valves
22 14 23.36 – Air Admittance Valves
22 14 26 – FACILITY STORM DRAINS 22 14 26.13 – Roof Drains 22 14 26.16 – Facility Area Drains 22 14 26.19 – Facility Trench Drains
22 14 29 – SUMP PUMPS
22 14 29.13 – Wet Pit Mounted, Vertical Sump Pumps
22 14 29.16 – Submersible Sump Pumps
22 14 29.19 – Sump Pump Basins and Pits
22 14 33 – PACKAGED, PEDESTAL, DRAINAGE PUMP UNITS
22 14 36 – PACKAGED, SUBMERSIBLE, DRAINAGE PUMP UNITS

22 15 00 – GENERAL SERVICE COMPRESSED AIR SYSTEMS

22 15 13 – GENERAL SERVICE COMPRESSED AIR PIPING
22 15 16 – GENERAL SERVICE COMPRESSED AIR VALVES
22 15 19 – GENERAL SERVICE PACKAGED AIR COMPRESSORS and RECEIVERS
22 15 19.13 – General Service Packaged Reciprocating Air Compressors
22 15 19.16 – General Service Packaged Liquid Ring Air Compressors
22 15 19.19 – General Service Packaged Rotary Screw Air Compressors
22 15 19.23 – General Service Packaged Sliding Vane Air Compressors

22 16 00 – RESERVED

22 17 00 – RESERVED

22 18 00 – RESERVED

22 19 00 – RESERVED

22 20 00 – RESERVED

22 30 00 – PLUMBING EQUIPMENT

22 31 00 – DOMESTIC WATER SOFTENERS

22 31 13 – RESIDENTIAL DOMESTIC WATER SOFTENERS
22 31 16 – COMMERCIAL DOMESTIC WATER SOFTENERS

22 32 00 – DOMESTIC WATER FILTRATION EQUIPMENT

22 32 13 – DOMESTIC WATER BAG TYPE FILTERS
22 32 16 – DOMESTIC WATER FREE STANDING CARTRIDGE FILTERS
22 32 19 – DOMESTIC WATER OFF FLOOR CARTRIDGE FILTERS
22 32 23 – DOMESTIC WATER CARBON FILTERS
22 32 26 – DOMESTIC WATER SAND FILTERS
22 32 26.13 – Domestic Water Circulating Sand Filters
22 32 26.16 – Domestic Water Multimedia Sand Filters
22 32 26 19 – Domestic Water Greensand Filters

22 33 00 – ELECTRIC DOMESTIC WATER HEATERS

22 33 13 – INSTANTANEOUS ELECTRIC DOMESTIC WATER HEATERS
22 33 13.13 – Flow Control, Instantaneous Electric Domestic Water Heaters
22 33 13.16 – Thermostat Controlled, Instantaneous Electric Domestic Water Heaters
22 33 30 – RESIDENTIAL, ELECTRIC DOMESTIC WATER HEATERS
22 33 30.13 – Residential, Small Capacity Electric Domestic Water Heaters
22 33 30.16 – Residential, Storage Electric Domestic Water Heaters
22 33 30.23 – Residential, Collector to Tank, Solar – Electric Domestic Water Heaters

22 33 30.26 – Residential, Collector to Tank, Heat Exchanger Coil, Solar-Electric Domestic Water Heaters
22 33 33 – LIGHT COMMERCIAL ELECTRIC DOMESTIC WATER HEATERS
22 33 36 – COMMERCIAL DOMESTIC WATER ELECTRIC BOOSTER HEATERS
22 33 36.13 – Commercial Domestic Water Electric Booster Heaters
22 33 36.16 – Commercial Storage Electric Domestic Water Heaters

22 34 00 – FUEL FIRED DOMESTIC WATER HEATERS

22 34 13 – INSTANTANEOUS, TANKLESS, GAS DOMESTIC WATER HEATERS
22 34 30 – RESIDENTIAL GAS DOMESTIC WATER HEATERS
22 34 30.13 – Residential, Atmospheric, Gas Domestic Water Heaters
22 34 30.16 – Residential, Direct Vent, Gas Domestic Water Heaters
22 34 30.19 – Residential, Power Vent, Gas Domestic Water Heaters
22 34 36 – COMMERCIAL GAS DOMESTIC WATER HEATERS
22 34 36.13 – Commercial, Atmospheric, Gas Domestic Water Heaters
22 34 36.16 – Commercial, Power Burner, Gas Domestic Water Heaters
22 34 36.19 – Commercial, Power Vent, Gas Domestic Water Heaters
22 34 36.23 – Commercial, High Efficiency, Gas Domestic Water Heaters
22 34 36.26 – Commercial, Coil Type, Finned Tube, Gas Domestic Water Heaters
22 34 36.29 – Commercial, Grid Type, Finned Tube, Gas Domestic Water Heaters
22 34 46 – OIL FIRED DOMESTIC WATER HEATERS
22 34 46.13 – Large Capacity, Oil Fired Domestic Water Heaters
22 34 56 – DUAL FUEL FIRED DOMESTIC WATER HEATERS

22 35 00 – DOMESTIC WATER HEAT EXCHANGERS

22 35 13 – INSTANTANEOUS DOMESTIC WATER HEAT EXCHANGERS
22 35 13.13 – Heating Fluid in Coil, Instantaneous Domestic Water Heat Exchanger
22 35 13.16 – Domestic Water in Coil, Instantaneous Domestic Water Heat Exchanger
22 35 13.19 – Heating Fluid in a U-Tube Coil, Instantaneous Domestic Water Heat Exchanger
22 35 23 – CIRCULATING DOMESTIC WATER HEAT EXCHANGERS
22 35 23.13 – Circulating, Compact Domestic Water Heat Exchangers
22 35 23.16 – Circulating, Storage Domestic Water Heat Exchangers
22 35 29 – NON-CIRCULATING DOMESTIC WATER HEAT EXCHANGERS
22 35 29.13 – Non-Circulating, Compact Domestic Water Heat Exchangers
22 35 29.16 – Non-Circulating, Storage Domestic Water Heat Exchangers
22 35 36 – DOMESTIC WATER BRAZED PLATE HEAT EXCHANGERS
22 35 39 – DOMESTIC WATER PLATE and FRAME HEAT EXCHANGERS
22 35 43 – DOMESTIC WATER HEAT RECLAIMERS

22 36 00 – RESERVED

22 37 00 – RESERVED

22 38 00 – RESERVED

22 39 00 – RESERVED

22 40 00 – PLUMBING FIXTURES

22 41 00 – RESIDENTIAL PLUMBING FIXTURES

22 41 13 – RESIDENTIAL WATER CLOSETS, URINALS and BIDETS
22 41 16 – RESIDENTIAL LAVATORIES and SINKS
22 41 19 – RESIDENTIAL BATHTUBS
22 41 23 – RESIDENTIAL SHOWER RECEPTORS and BASINS
22 41 26 – RESIDENTIAL DISPOSERS
22 41 36 – RESIDENTIAL LAUNDRY TRAYS
22 41 39 – RESIDENTIAL FAUCETS, SUPPLIES and TRIM

22 42 00 – COMMERCIAL PLUMBING FIXTURES

22 42 13 – COMMERCIAL WATER CLOSETS, URINALS and BIDETS
22 42 16 – COMMERCIAL LAVATORIES and SINKS
22 42 19 – COMMERCIAL BATHTUBS
22 42 23 – COMMERCIAL SHOWER RECEPTORS and BASINS
22 42 26 – COMMERCIAL DISPOSERS
22 42 29 – SHAMPOO BOWLS
22 42 33 – WASH FOUNTAINS
22 42 36 – COMMERCIAL LAUNDRY TRAYS
22 42 39 – COMMERCIAL FAUCETS, SUPPLIES and TRIM
22 42 43 – FLUSHOMETERS

22 43 00 – HEALTHCARE PLUMBING FIXTURES

22 43 13 – HEALTHCARE WATER CLOSETS
22 43 16 – HEALTHCARE SINKS
22 43 19 – HEALTHCARE BATHTUBS and SHOWERS
22 43 23 – HEALTHCARE SHOWER RECEPTORS and BASINS
22 43 26 – HEALTHCARE FAUCETS
22 43 43 – HEALTHCARE PLUMBING FIXTURE FLUSHOMETERS

22 44 00 – RESERVED

22 45 00 – EMERGENCY PLUMBING FIXTURES

22 45 13 – EMERGENCY SHOWERS
22 45 16 – EYEWASH EQUIPMENT
22 45 19 – SELF CONTAINED EYEWASH EQUIPMENT
22 45 23 – PERSONAL EYEWASH EQUIPMENT
22 45 26 – EYE/ FACE WASH EQUIPMENT
22 45 29 – HAND HELD EMERGENCY DRENCH HOSES
22 45 33 – COMBINATION EMERGENCY FIXTURE UNITS
22 45 36 – EMERGENCY FIXTURE WATER TEMPERING UNITS

22 46 00 – SECURITY PLUMBING FIXTURES

22 46 13 – SECURITY WATER CLOSETS and URINALS
22 46 16 – SECURITY LAVATORIES and SINKS
22 46 39 – SECURITY FAUCETS, SUPPLIES and TRIM
22 46 43 – SECURITY PLUMBING FIXTURE FLUSHOMETERS
22 46 53 – SECURITY PLUMBING FIXTURE SUPPORTS

22 47 00 – DRINKING FOUNTAINS and WATER COOLERS

22 47 13 – DRINKING FOUNTAINS
22 47 16 – PRESSURE WATER COOLERS
22 47 19 – WATER STATION WATER COOLERS
22 47 23 – REMOTE WATER COOLERS

22 48 00 – RESERVED

22 49 00 – RESERVED

22 50 00 – POOL and FOUNTAIN PLUMBING SYSTEMS

22 51 00 – SWIMMING POOL PLUMBING SYSTEMS

22 51 13 – SWIMMING POOL PIPING
22 51 16 – SWIMMING POOL PUMPS
22 51 19 – SWIMMING POOL WATER TREATMENT EQUIPMENT
22 51 23 – SWIMMING POOL EQUIPMENT CONTROLS

22 52 00 – FOUNTAIN PLUMBING SYSTEMS

22 52 13 – FOUNTAIN PIPING
22 52 16 – FOUNTAIN PUMPS
22 52 19 – FOUNTAIN WATER TREATMENT EQUIPMENT
22 52 23 – FOUNTAIN EQUIPMENT CONTROLS

22 53 00 – RESERVED

22 54 00 – RESERVED

22 55 00 – RESERVED

22 56 00 – RESERVED

22 57 00 – RESERVED

22 58 00 – RESERVED

22 59 00 – RESERVED

22 60 00 – GAS and VACUUM SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 61 00 – COMPRESSED AIR SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 61 13 – COMPRESSED AIR PIPING for LABORATORY and HEALTHCARE FACILITIES
22 61 13.53 – Laboratory Compressed Air Piping
22 61 13.70 – Healthcare Compressed Air Piping
22 61 13.74 – Dental Compressed Air Piping
22 61 19 – COMPRESSED AIR EQUIPMENT for LABORATORY and HEALTHCARE FACILITIES
22 61 19.53 – Laboratory Compressed Air Equipment
22 61 19.70 – Healthcare Compressed Air Equipment
22 61 19.74 – Dental Compressed Air Equipment

22 62 00 – VACUUM SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 62 13 – VACUUM PIPING for LABORATORY and HEALTHCARE FACILITIES
22 62 13.53 – Laboratory Vacuum Piping
22 62 13.70 – Healthcare, Surgical Vacuum Piping
22 62 13.74 – Dental Vacuum Piping
22 62 19 – VACUUM EQUIPMENT for LABORATORY and HEALTHCARE FACILITIES
22 62 19.53 – Laboratory Vacuum Equipment
22 62 19.70 – Healthcare Vacuum Equipment
22 62 19.74 – Dental Vacuum and Evacuation Equipment
22 62 23 – WASTE ANESTHESIA GAS PIPING

22 63 00 – GAS SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 63 13 – GAS PIPING for LABORATORY and HEALTHCARE FACILITIES
22 63 13.53 – Laboratory Gas Piping
22 63 13.70 – Healthcare Gas Piping
22 63 19 – GAS STORAGE TANKS for LABORATORY and HEALTHCARE FACILITIES
22 63 19.53 – Laboratory Gas Storage Tanks
22 63 19.70 – Healthcare Gas Storage Tanks

22 64 00 – RESERVED

22 65 00 – RESERVED

22 66 00 – CHEMICAL WASTE SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 66 53 – LABORATORY CHEMICAL WASTE and VENT PIPING
22 66 70 – HEALTH CARE CHEMICAL WASTE and VENT PIPING
22 66 83 – CHEMICAL WASTE TANKS
22 66 83.13 – Chemical Waste Dilution Tanks
22 66 83.16 – Chemical Waste Neutralization Tanks

22 67 00 – PROCESSED WATER SYSTEMS for LABORATORY and HEALTHCARE FACILITIES

22 67 13 – PROCESSED WATER PIPING for LABORATORY and HEALTHCARE FACILITIES
22 67 13.13 – Distilled Water piping
22 67 13.16 – Reverse Osmosis Water Piping
22 67 13.19 – De-ionized Water Piping
22 67 19 – PROCESSED WATER EQUIPMENT for LABORATORY and HEALTHCARE FACILITIES
22 67 19.13 – Distilled Water Equipment
22 67 19.16 – Reverse Osmosis Water Equipment
22 67 19.19 – De-ionized Water Equipment

22 68 00 – RESERVED

22 69 00 – RESERVED

22 70 00 – RESERVED

22 80 00 – RESERVED

22 90 00 – RESERVED

APPENDIX 3-C SECTION SHELL OUTLINE

This shell outline has been developed by the American Institute of Architects conforming to the CSI *Manual of Practice*.

SECTION XXXXX
XXXXXXXXXXXXXXXXXXXX

PART 1—GENERAL

1.1 SUMMARY

A. This section includes [description of essential unit of work included in section].

B. Products furnished but not installed under this section include [description].

C. Products installed but not furnished under this section include [description].

D. Related Sections: The following relate to this section:

1. Division [#] Section [“Title”] for [description of related unit of work].
2. Division [#] Section [“Title”] for [description of related unit of work].
3. Division [#] Section [“Title”] for [description of related unit of work].
4. Division [#] Section [“Title”] for [description of related unit of work].

E. Allowances:

F. Unit Prices:

G. Alternates:

1.2 REFERENCES

1.3 DEFINITIONS

1.4 SYSTEM DESCRIPTION

1.5 SYSTEM PERFORMANCE REQUIREMENTS

A. Performance Requirements: Provide [system] complying with performance requirements specified.

1.6 SUBMITTALS

A. General: Submit the following:

B. Product data for each type of [products] specified, including details of construction relative to materials, dimensions of individual components, profiles, and finishes.

C. Product data for the following products:

1. [Product].
2. [Product].

3. [Product].
4. [Product].

D. Shop drawings from manufacturer detailing equipment assemblies and indicating dimensions, weights, loadings, required clearances, method of field assembly, components, utility requirements, and location and size of each field connection.

E. Include setting drawings, templates, and directions for installation of anchor bolts and other anchorages to be installed as unit of work of other sections.

F. Coordination drawings for [unit of work].

G. Coordination drawings for reflected ceiling plans drawn accurately to scale and coordinating penetrations and ceiling-mounted items, including sprinklers, diffusers, grilles, light fixtures, speakers, and access panels.

H. Wiring diagrams from manufacturer for electrically operated equipment.

I. Wiring diagrams detailing wiring for power, signal, and control systems, differentiating between manufacturer and field-installed wiring.

J. Material certificates signed by manufacturer certifying that each material item complies with requirements, in lieu of laboratory test reports, when permitted by architect.

K. Product certificates signed by manufacturers of [products] certifying that their products comply with requirements.

L. Welder certificates signed by contractor certifying that welders comply with requirements of "quality-assurance" article.

M. Qualifications data for firms and persons specified in "quality-assurance" article to demonstrate their capabilities and experience. Include list of completed projects with project name, addresses, name of architects and owners, plus other information specified.

N. Test reports from, and based on tests performed by, qualified independent testing laboratory evidencing compliance of [product] with requirements based on comprehensive testing.

O. Maintenance data for [materials and products], for inclusion in operating and maintenance manuals.

1.7 QUALITY ASSURANCE

A. Installer Qualifications: Engage an experienced installer who has successfully completed [unit of work] similar in material, design, and extent to that indicated for project.

B. Installer's Field Supervision: Require installer to maintain an experienced full-time supervisor who is on jobsite during times that [unit of work] is in progress.

C. Testing Laboratory Qualifications: Demonstrate experience and capability to conduct testing indicated without delaying progress of the work based on evaluation of laboratory-submitted criteria conforming to ASTM E 699.

D. Qualify welding process and welding operators in accordance with ASME "Boiler and Pressure Vessel Code," Section IX, "Welding and Brazing Qualifications."

E. Regulatory Requirements: Fabricate and stamp [product] to comply with [code].

F. Regulatory requirements: Comply with following codes.
   1. [Itemize codes in form of separate subparagraphs under above].

G. UL Standard: Provide [products] complying with UL [designation, title].

H. Electrical Component Standard: Provide components complying with NFPA 70 "National Electrical Code" and which are listed and labeled by UL where available.

I. UL and NEMA Compliance: Provide [components] required as part of [product or system] which are listed and labeled by UL and comply with applicable NEMA standards.

J. ASME Compliance: Fabricate and stamp [product] to comply with ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

K. Single Source Responsibility: Obtain [system] components from single source having responsibility and accountability to answer and resolve problems regarding proper installation, compatibility, performance, and acceptance.

L. Manufacturer and Product Selection: The drawings indicate sizes, profiles, and dimensional requirements of [product or system]. A [product or system] having equal performance characteristics with deviations from indicated dimensions and profiles may be considered, provided deviations do not change the design concept or intended performance. The burden of proof of equality is on the proposer.

1.8 DELIVERY, STORAGE, AND HANDLING

A. Deliver materials and equipment to site in such quantities and at such times to ensure continuity of installation. Store them at site to prevent cracking, distortion, staining, and other physical damage and so that markings are visible.

B. Lift and support equipment only at designated lifting or supporting points as shown on final shop drawings.

C. Deliver [product] as a factory assembled unit with protective crating and covering.

D. Store [products] on elevated platforms in a dry location.

E. Coordinate delivery of [product] in sufficient time to allow movement into building.

1.9 PROJECT CONDITIONS

A. Site Information: Data on indicated subsurface conditions are not intended as representations or warranties of accuracy or continuity of these conditions {between soil borings}. It is expressly understood that owner and engineer will not be responsible for interpretations or conclusions drawn therefrom by contractor. Data are made available for convenience of contractor (and are not guaranteed to represent conditions that may be encountered).

B. Field Measurements: Verify dimensions by field measurements. Verify that [name of system, product, or equipment] may be installed in compliance with the original design and referenced standards.

1.10 SEQUENCING AND SCHEDULING

A. Coordinate the size and location of concrete equipment pads. Cast anchor bolt inserts into pad. Concrete reinforcement and formwork requirements are specified in Division 3.

B. Coordinate the installation of roof penetrations. Roof specialties are specified in Division 7.

1.11 WARRANTY

A. Special Project Warrant: Submit written warranty, executed by manufacturer, agreeing to repair or replace [product] which fails in materials or workmanship within specified warranty period. This warranty shall be in addition to, and not limitation of, other rights the owner may have against the contractor under the contract documents.

   1. Warranty period is 1 year after date of substantial completion.

1.12 MAINTENANCE

1.13 EXTRA MATERIALS

A. Deliver extra materials to owner. Furnish extra materials described below matching products installed, packaged with protective covering for storage and identified with labels clearly describing contents.

PART 2—PRODUCTS

2.1 MANUFACTURERS

A. *Available Manufacturers:* Subject to compliance with requirements, manufacturers offering products which may be incorporated in the work include, but are not limited to, the following:

B. *Manufacturers:* Subject to compliance with requirements, provide products by one of the following:

   1. [Name of Product]:
      a. [Manufacturer's Name].
      b. [Manufacturer's Name].
      c. [Manufacturer's Name].
   2. [Name of Product]:
      a. [Manufacturers Name].
      b. [Manufacturer's Name].
   3. [Name of Product]:
      a. [Manufacturer's Names].
   4. [Name of Product]:
      a. [Manufacturer's Names].

C. *Available Products:* Subject to compliance with requirements, products which may be incorporated in the work include, but are not limited to, the following:

D. *Products:* Subject to compliance with requirements, provide one of the following:

E. *Manufacturer:* Subject to compliance with requirements, provide product by [Manufacturer's Name].

2.2 MATERIALS [PRODUCT NAME]

A. [Material or Product Name]: [Nonproprietary description of material] complying with [standard designation] (for type, grade, etc.).

B. [Material or Product Name]: [Nonproprietary description of material] complying with [standard designation] (for type, grade, etc.).

C. [Material or Product Name]: [Standard designation], [type, grade, etc. as applicable to referenced standard].

D. [Material or Product Name]: [Standard designation], [type, grade, etc. as applicable to referenced standard].

2.3 MATERIALS, GENERAL [PRODUCTS, GENERAL]

A. [Description] Standard: Provide [product or material] which complies with [standard designation].

B. [Description] Standard: Provide [product or material] which complies with [standard designation].

C. [Kind of Performance] Characteristics: [Insert requirements for kind of performance involved and test method as applicable unless requirements included under Part 1 Article ("System Description).]

D. [Kind of Performance] Characteristics: [Insert requirements for kind of performance involved and test method as applicable unless requirements included under Part 1 Article ("System Description").]

2.4 EQUIPMENT [NAME OF MANUFACTURED UNIT]

A. [Equipment or Unit Name]: [Nonproprietary description of…] complying with [standard designation] (for type, grade, etc.).

B. [Equipment or Unit Name]: [Nonproprietary description of…] complying with [standard designation] (for type, grade, etc.).

C. [Equipment, Unit, or Product Name]: [standard designation], (type, grade, etc. as applicable to referenced standard).

D. [Equipment, Unit, or Product Name]: [standard designation], (type, grade, etc. as applicable to referenced standard).

2.5 COMPONENTS

A. [Component Name]:… [Nonproprietary description of…] complying with [standard designation] (for type, grade, etc.).

B. [Component Name]: [Nonproprietary description of…] complying with [standard designation] (for type, grade, etc.).

2.6 ACCESSORIES

A. Manufacturer's standard factory finish.

2.7 MIXES

2.8 FABRICATION

2.9 SOURCE OF QUALITY CONTROL

PART 3—EXECUTION

3.1 EXAMINATION

A. Examine [substrates] [areas] [and] [conditions] [with Installer present] for compliance with requirements for [maximum moisture content], installation tolerances, [other specific conditions], and other conditions affecting performance of [unit of work of this section]. Do not proceed with installation until unsatisfactory conditions have been corrected.

B. Examine rough-in drawings for [name] piping systems to verify actual locations of piping connections prior to installation.

C. Examine walls, floors, roof, and [description] for suitable conditions where [name of products or system] are to be installed.

D. Do not proceed until unsatisfactory conditions have been corrected.

3.2 PREPARATION

A. Protection:

3.3 INSTALLATION, GENERAL [APPLICATION, GENERAL]

A. [Description] Standard: Install [name of product, material, or system] to comply with [standard designation].

3.4 INSTALLATION {OF [NAME]} {APPLICATION OF [NAME]}

A. Install [name of unit of work] level and plumb, in accordance with manu-facturer's written instructions, rough-in drawings, the original design, and referenced standards.

3.5 CONNECTIONS (NOT A CSI ARTICLE—BUT USEFUL FOR DIVISION 15)

A. Piping installation requirements are specified in other sections. Drawings indicate general arrangement of piping, fittings, and specialties. The following are specific connection requirements:

B. Install piping adjacent to equipment to allow servicing and maintenance.

3.6 FIELD QUALITY CONTROL

A. Testing Laboratory: Owner will employ and pay an independent testing laboratory to perform field quality control testing.

B. Testing Laboratory: Provide the services of an independent testing laboratory experienced in the testing of [unit of work] and acceptable to the engineer, to perform field quality control testing.

C. Extent and Testing Methodology: Arrange for testing of completed [unit of work] in successive stages in areas of extent described below; do not proceed with [unit of work] of next area until test results for previously completed work verify compliance with requirements.

D. Testing laboratory shall report test results promptly and in writing to contractor and engineer.

E. Repair or replace [unit of work] within areas where test results indicate [unit of work] does not comply with requirements.

F. Manufacturer's Field Service: Provide services of a factory-authorized service representative to supervise field assembly of components, installation of [products] including piping and electrical connections, and to report results in writing.

3.7 ADJUSTING [CLEANING] [ADJUSTING AND CLEANING]

3.8 COMMISSIONING (NOT A CSI ARTICLE — BUT USEFUL FOR DIVISION 15 [DEMONSTRATION])

A. Start-Up Services, General: Provide services of a factory-authorized service representative to provide start-up service and to demonstrate and train owner's maintenance personnel as specified below.

B. Test and adjust controls and safeties. Replace damaged or malfunctioning controls and equipment.

C. Train owner's maintenance personnel on procedures and schedules related to start-up and shut-down, troubleshooting, servicing, and preventative maintenance.

D. Review data in operating and maintenance manuals. Refer to Division 1, Section ["Project Closeouts"] ["Operating and Maintenance Manuals"].

E. Schedule training with owner through architect, with at least 7 days advance notice.

3.9 PROTECTION

3.10 SCHEDULES

4 Plumbing Cost Estimation

Cost estimating involves matching specific project information with a database of known construction costs to predict the cost of the project. When the project varies from the assumptions of the database, the predicted cost is adjusted appropriately. The specific project information is generally identified as groups of repeated activities. The database, called unit costs, is a compilation of costs to do each activity. Quantities of each activity are multiplied by the unit costs and added up for a sum of costs. Multipliers are then applied to this sum and the number is rounded up.

Mathematically, the process is multiplying two vectors, called a dot product, and then multiplying this dot product by a scalar. The first vector is the quantity of activities. The second vector is the cost of each activity. A database may be developed over time or obtained with a vendor's estimating software program. The mathematics is generally set up with tabular sheets, an ordinary spreadsheet program, or a vendor's program.

The database of unit costs is usually different for projects having a completed design than for projects in a schematic phase. For estimating design development, where final sizes are not known, approximate sizes are estimated, and the same database used on final projects is applied, but then a more liberal contingency factor is used.

Plumbing construction costs can be broken down into these categories:

- Material
- Preparation
- Fixtures
- Appurtenances

Material includes pipe, fittings, valves, pipe supports, sleeves, low-voltage wiring, fire stopping, insulation, drains, cleanouts, fixture carriers, sprinkler heads, medical gas outlets, and similar commodity items as well as general material handling. Preparation includes demolition work, excavation and backfill, cutting and patching, and survey and marking. Fixtures include water closets, lavatories, urinal, shower, and service sink. Appurtenances include interceptors, pumps, alarms, water meters, backflow preventers, pressure vessels, water heaters, and water-treatment equipment.

Cost estimating is broken down into two convenient sets of sums: Material costs are estimated separately from labor costs. Thus, we have equations 4-1 and 4-2 to create a tabular take-off sheet for manual estimating or writing a spreadsheet.

Equation 4-1

$$\mathbf{E1} = ([A][B]\,\mathbf{d} + [C][D]\,\mathbf{w})$$

where:

E1 = The estimate of one category of construction
[A] = The quantity vector of each material on a specific job
[B] = The unit price vector of each material, typically taken from a vendor's catalog
d = A multiplier, such as 0.65, to represent a contractor's discount
[C] = The quantity vector of each labor activity (it may be equal to [A])
[D] = The time vector for a single worker to do each type of activity
w = A multiplier to represent the hourly cost for such a worker including all taxes, insurance costs, and benefits

Equation 4-2

$$\mathbf{Et} = \text{Sum}\,(\mathbf{E1, E2, E3 \ldots En})\,\mathbf{m} + \mathbf{O}$$

where:

Et = The sum of all categories of construction
E1, E2, E3 …En = The estimate of one category of construction
m = The product of factors such as geography, job size, contingency, sales tax, and contractor overhead
O = A sum of fixed costs such as permits, equipment mobilization, bonds, chlorination, certification, record keeping costs, equipment rental, and submittal preparation

The product of factors, m, is often called a markup. If the conditions of the project match the database and sales tax does not apply, then **m** ranges from 1.10

to 1.12 to reflect a 10 to 12% overhead for the plumbing contractor. The final installed cost will include the additional overhead of the general contractor ranging from 6 to 15%. If geography and job size are ideal, but the design is incomplete, then a 15% contingency may be considered as well as the 10% overhead. Thus, **m** = 1.15 x1.10 = 1.265. The geography factor ranges from 0.87 to 1.10 for most of North America. Sales tax ranges from 0 to 7% with state and local variations of how it is applied. The size of a job causes the largest range of factors and is discussed later in the chapter. Thus, a job's mark-up on its sum of costs for geography, job size, contingency, sales tax, and plumbing contractor overhead may be 1.12, 1.00, 1.02, 1.06, and 1.10, respectively, resulting in **m** = 1.33 (m = 1.12 x 1.00 x 1.02 x 1.06 x 1.10).

Some estimators prefer to consider each factor separately in terms of the amount of additional costs for each factor. Thus, in the last example, 12% of the sum of costs is derived to give the added cost for geography. Then the geography factor is added to the sum of costs. The 2% contingency is derived from this last sum. Then the 6% sales tax is similarly derived. The overhead may be derived before or after adding the sales tax, depending on local practice.

It should be noted how mark-ups are considered in estimates for alternative materials or construction methods. The application of mark-ups should be the same to the original cost and to the alternate cost. If an alternate is presented without the mark-up, it may erroneously appear to be attractive over the original. Conversely, beware of an alternate including the mark-up when it is compared to the original that is part of a larger estimate. The original will not have the mark-up included if it is only a line item because the mark-up is applied later in the estimate. Hence, the alternate may not appear attractive, even though it is.

Example 1

Table 4-1 Piping Take-off Sample

Item	Qty.	Unit Material	Total	Joints	Unit Labor	Total
1-in. [25mm] copper L , 50/50 solder						
ft. [m] of pipe	237 [72.2]	$2.05	$486			
couplings	24	1.56	$ 37	2	0.25	12 hr
elbows	19	1.78	$ 34	2	0.25	9.5
tees	5	4.03	$20	3	0.25	3.8
ball valves	2	31.80	$64	2	0.25	1
hangers (ring type)	46	3.48	$160		0.50	23
Sub-total			$801			49.3 hr
		Deduct Discount	$280			
		Elevated work adjustment	(10%)			54.2 hr
		Wage rate ($/hr per person)				$55/hr
Sub-Total (Materials and Installation)			$520			$2980
Total						$3500

LABOR COSTS

The following parts of a labor rate are applied to the gross wage rate to reflect a labor cost of construction.

- Social Security and Medicare taxes that employers pay
- Workmens compensation insurance premium
- Unemployment tax
- Health insurance premium
- Holiday and vacation pay
- Retirement cost

The estimated cost of labor is the labor rate multiplied by the estimated time to complete the work.

TAKE-OFF ESTIMATING METHOD

The take-off method requires measuring the length of each size and type of pipe using scaled drawings. In addition, the method requires counting all fittings, valves, fixtures, appurtenances, and other material. This tedious process is then combined with known material costs, expected productivity rates, and labor rates to obtain the sum of costs. The method has an established record of providing accurate cost estimates.

One method to create the tabular take-off sheet is shown in Table 4-1. The material quantity vector [A] is in the second column. The product of the second column and the fifth column will create the labor quantity vector. This method reflects some fittings having 2 joints while others have 3. The time accounted for preparing the hangers and joints will cover the labor for installing the pipe. Various work situations can be adjusted. Table 4-1 shows an extra 10 percent adjustment to reflect work on a scissors lift. When piping is installed at two elevations, separate sheets are utilized to analyze cost at each level.

Each category of construction is put into a table in a similar manner. Tabulation sheets are then added together before being adjusted by the factor **m** to give the final estimate. If necessary, premium labor rates are applied for non-standard working hours. Overtime labor rates are further adjusted to reflect lower productivity for longer workdays.

Another aspect of take-off estimation reflects the fact construction consists of crews of varying skills and labor rates. The database shows productivity of certain sizes of crews. For

Table 4-2 Hours to Excavate 100 Feet [30.5 m] of Trench

Depth (ft)	Width (in)	Volume (yd³)	All Work by Hand: Sandy	Medium	Hard	Mechanical: Modest Length	Long Length	Chain Trencher[a]	Final Hand Grading[b]
1	18	6	7	11	16	1	1	2	3
1½	18	8	11	17	24	2	1	3	3
2	18	11	14	22	32	2	1	3	3
2½	18	14	18	28	40	3	2	4	4
3	24	22	21	34	48	3	2	4	4
3½	24	26	25	40	56	3	2	-	4
4	24	30	28	44	64	4	3	-	4
4½	24	33	32	50	72	4	3	-	4
5	24	37	48	76	105	6	5	-	4
5½	24	41	53	84	116	6	5	-	4
6	48	89	57	90	124	7	6	-	4
6½	48	96	62	100	138	7	6	-	6
7	48	104	91	130	208	8	7	-	6
7½	48	111	100	143	228	8	7	-	6
8	48	118	106	150	240	9	7	-	6
8½	48	126	113	160	256	9	8	-	6
9	48	133	120	170	272	10	9	-	6
10	48	148	134	188	300	11	10	-	8
11	48	163	148	208	332	12	11	-	8
12	48	178	163	228	364	13	12	-	8
13	48	192	275	455	675	14	13	-	8
14	48	207	303	500	751	16	14	-	8

Conversion factors: 1 in. = 25.4 mm, 1 ft. = 0.3048 m, 1 yd³ = 0.7646 m³, 1 ft³ = 0.037 yd³

Notes:

a "Chain Trencher" refers to a gasoline-driven trenching machine, which digs a maximum of 10 in. wide x 3 1⁄3 ft deep.

b Add hand grading for mechanical trenching only if required.

example, one plumber and one apprentice, each with their own wage, can install so many feet of 3-inch [75 mm] PVC pipe per day.

PRODUCTIVITY RATES

Tables 4-2 through 4-8 provide labor units for estimating a plumbing project. Table 4-9 provides some modifiers for various job conditions. The information was originally derived from the National Association of Plumbing-Heating-Cooling Contractors (NAPHCC) based on surveys solicited of 150 plumbing contractors from all areas of the United States.

Notice the cost difference between hand trenching and machine trenching in Table 4-2. For example, a trench 3 feet [0.91 m] deep 100 feet [30.5 m] long takes 2 or 3 hours by machine and up to 48 man-hours by hand. Four hours of additional time is applied to the machine method if hand grading is required. The trench width and material volume are revised in Table 2 from earlier "Data Book" editions to reflect excavation with trench boxes and other shoring methods. For handwork, the volume should be adjusted to reflect a typical 24-inch trench width for excavation and backfill volumes. For exterior work or other clear spaces accommodating larger machinery, hours may be reduced substantially from that indicated. Sawcutting may be faster than as shown in Table 4-3 if space allows for larger equipment. Breaking pavement with heavier pneumatics or removing whole pieces of sawcut concrete will reduce the times shown in Table 4-4.

Table 4-5 shows the time for one laborer to hand backfill and mechanically hand-tamper medium backfill (a trench 3 feet [0.91 m] deep 100 feet [30.5 m] long) is 17 hours. The same table shows the time to do it by machine is 1.8 hours. However, 12 additional hours are required for hand tamping the first layer of a 4-inch [100 mm] pipe and 0.8 hours of labor to assist the backfilling. If certain types of fill material are used, such as ¾- to 1-inch [19 to 25 mm] stone, compacting the fill is not required.

Notice in Table 4-6 that a single 4-inch [100 mm] brazed joint takes the most time (1.11 hours), and a single hubless joint takes the least time (0.4 hours).

Example 2

Using Tables 4-2 and 4-5, estimate the cost to excavate and backfill a trench 5 feet [1.52 m] deep 210

Table 4-3 To Sawcut 100 Feet [30.5 m] of ConcreteTrench

Depth			
Inches	3	4	5
mm	75	100	125
Hours	5	6	7

Table 4-4 To Break 100 Feet [30.5 m] of Pavement

Method	Pavement	Width	Hours
Hand Pneumatic	Concrete	24 in. [600 mm]	10

Table 4-5 Hours to Backfill 100 Feet [30.5 m] of Trench

Depth (ft)	Volume (yd^3)	All Work by Hand: Sandy	Medium	Hard	Pipe Bedding: 3″ dia	4-10″ dia	Mechanical Backfill[a]	Mechanical Compaction
1	6	5	6	7	8	12	0.3	-
1½	8	7	8	11	8	12	0.4	0.5
2	11	9	11	15	8	12	0.5	0.5
2½	14	11	14	20	8	12	0.6	0.5
3	23	14	17	24	8	12	0.8	1
3½	26	16	20	28	8	12	0.9	1
4	30	18	22	29	8	12	1	1
4½	33	20	25	33	8	12	2	1
5	37	31	38	50	8	12	2	1
5½	41	34	42	55	8	12	2	1
6	89	36	45	59	8	12	2	2
6½	96	40	49	63	8	12	3	2
7	104	42	52	68	8	12	3	2
7½	111	46	57	74	8	12	3	2
8	118	48	60	78	8	12	3	3
8½	126	51	64	83	8	12	3	4
9	133	55	68	89	8	12	4	4
10	144	60	75	98	8	12	4	5
11	164	67	83	108	8	12	5	[b]
12	178	73	91	119	8	12	5	[b]
13	192	80	99	130	8	12	6	[b]
14	207	88	110	143	8	12	6	[b]

Conversion factors: 1 in. = 25.4 mm, 1 ft. = 0.3048 m, 1 yd3 = 0.7646 m3, 1 ft3 = 0.037 yd3

Notes:

a Must add for stand-by hand laborer.

b Call equipment company for hours to compact backfill.

Table 4-6 Hours to Complete 100 Joints

Method	Size														Note
Inch	½	¾	1	1¼	1½	2	2½	3	4	5	6	8	10	12	
Mm	13	19	25	32	38	51	64	76	102	127	152	203	254	305	
Screw thread	25	27	30	36	38	40	90	95	100	145	150	200	-	-	
50/50 solder	20	21	25	27	30	32	63	75	85	123	127	170	-	-	
DWV solder	-	-	-	33	36	39	76	90	102	148	153	204	-	-	
Brazed	26	27	33	35	39	42	82	96	111	160	165	-	-	-	
Groove steel	-	-	30	36	38	40	72	76	80	116	120	160	184	208	
Groove copper	-	-	30	36	38	40	72	76	80	116	120	160	184	208	
Plastic	20	21	25	26	27	28	40	50	60	98	101	136	162	216	1
Hub and caulk	-	-	-	-	-	50	-	55	60	65	70	120	130	150	2
Hub and gasket	-	-	-	-	-	40	-	45	50	55	60	100	110	125	2
Hubless	-	-	-	-	30	30	-	35	40	45	50	80	90	100	-
Water main, mech. Joint	-	-	-	-	-	-	-	60	62	-	70	72	80	82	3, 4
Water main, compression	-	-	-	-	-	-	-	47	48	-	50	52	54	56	3

Notes:

1 Solvent joint. For heat fusion, multiply value by 1.5

2 Hub and spigot, service weight cast-iron pipe. For extra heavy, multiply value by 1.02.

3 Labor for 300 feet [90 m] minimum. Add crane cost.

4 Material weighing more than 150 lb. (68.2kg)

Table 4-7 Hours to Install 100 Pipe Hangers

Type	Size												
Inch	¾	1	1¼	1½	2	2½	3	4	5	6	8	10	12
mm	19	25	32	38	51	64	76	102	127	152	203	254	305
Ring[a]	50	50	50	50	50	60	60	70	70	80	100	100	100
Roller						140	140	160	160	180	220	220	220

Notes:

a Included in hanger, rod, and insert

feet [64 m] long by machine. Final hand grading will be required. The pipe will be 4-inch [100 mm], and spoils will be backfilled.

Solution: Select the required unit hours and apply it to the trench length of this example. Add equipment rental charge (or ownership hourly rate). Table 4-10 shows the take-off tabulation.

Example 3

Using Tables 4-2 and 4-5, estimate the cost to excavate and backfill trenches, by machine, totaling 120 feet, of 3-foot average depth; 130 feet, of 2-foot average depth; and a variety of trenches totaling 250 feet of 18 inch average depth. Excavated material will be dumped offsite and replaced by new fill. Final hand grading will be required and the pipe will be 4-inch [100 mm].

Solution: Determine the required unit hours and apply it to the various trench lengths. Add equipment rental charge (or ownership hourly rate). Add hauling cost of excavated material and delivery of backfill material. Since excavated material increases in volume by the excavation process, appropriately adjust the volume to account for this swelling. Table 4-11 shows the take-off tabulation for each step.

OTHER ESTIMATING METHODS

A less-precise estimating method is to count fixtures and major appurtenances and apply time-proven costs per fixture or appurtenance to arrive at the total cost. Piping and material costs are included in the per-fixture cost. The particular level of trim and quality of the specific project should be comparable with those of the database. For example, if the project requires cast-brass faucets, caulked cast-iron piping, and frequent valves on the supply distribution, then apply a per-fixture cost derived from a project that used similar material.

The advantage of the per-fixture method is it can be performed without a piping layout. A disadvantage is it fails to distinguish between projects with fixtures concentrated in a few areas compared to fixtures spread about the building.

Another less-precise estimating method is the square foot [m^2] method. This method provides a reasonable cost estimate even with little project information. A cost estimate is determined simply by multiplying the building area by a per-area cost. Per-area cost must be carefully selected to the level of trim and quality of the particular project. Additionally, the concentration or dispersed distribution of fixtures and the building application for fixtures must be addressed when per-area cost is applied. For example, a medical

Table 4-8 Hours to Install Fixtures

Fixture	Type	Time
Bathtub	-	3.0
Drinking Fountain	Wall mount	2.0
Lavatory	Wall mount	2.0
Lavatory	Counter	2.5
Mop Basin	-	2.0
Shower	Built-up stall	1.0
Sink	Single compartment	2.0
Sink	Double compartment	2.5
Service Sink	-	3.0
Urinal	Wall mount	2.8
Urinal	Stall	3.8
Water closet	Floor mount	1.8
Water closet	Wall mount	2.7
Water cooler	Wall mount	2.5

Table 4-9 Adjustments From Standard Conditions

Activity	Condition	Multiplier
Crawl space or tunnel	3-foot [1 m] high	1.50
Distribution of material		
Distance from stock:	100 feet [30 m]	1.00
	300 feet [90 m]	1.03
	500 feet [150 m]	1.04
	1000 feet [300 m]	1.05
Equipment room piping	-	1.20
Food service piping	-	1.10
Laboratory piping	-	1.10
Overhead piping	8-foot [2.5 m] ladder	1.00
	10-foot [3 m] ladder	1.03
	powered lift	1.10
Trench piping	3-foot [1 m] deep	1.00
	5-foot [1.5 m] deep	1.10
	8-foot [2.44 m] deep-shored	2.00
	10-foot [3.05 m] deep-shored	2.25
	12-foot [3.66 m] deep-shored	2.50

Table 4-10 Solution to Example 2

Item	Length, feet [m]	Unit Hours	Total hours
Excavate	210 [64]	0.05	10.5
Hand grading	210 [64]	0.04	8.4
Pipe bedding	210 [64]	0.12	25.2
Backfill	210 [64]	0.02	4.2
Added labor	210 [64]	0.02	4.2
Compaction	210 [64]	0.01	2.1
Total labor hours			54.6
Labor rate [$/hr per person]			$55/hr
Total labor cost [$55/hr x 54.6 hrs]			$3003
Total machine hours			17
Machine cost [$120/hr x 17 hrs]			$2040
Total cost			$5043

Table 4-11 Solution to Example 3

Item	Length, feet [m]	Unit Hours	Hours	Volume
Trenches 1½ feet [457mm] deep				
Excavate	250 [76]	0.02	5	
Hand grading	250 [76]	0.03	7.5	
Pipe bedding	250 [76]	0.12	30	
Backfill	250 [76]	0.004	1	
Added labor	250 [76]	0.004	1	
Compaction	250 [76]	0.005	1.25	
Hours			**45.8**	
Cubic Yards [m³]	250 [76]	0.08 [0.06]		**20 [15.3]**
Trenches 2 feet [610mm] deep				
Excavate	130 [40]	0.02	2.6	
Hand grading	130 [40]	0.03	3.9	
Pipe bedding	130 [40]	0.12	15.6	
Backfill	130 [40]	0.005	0.65	
Added labor	130 [40]	0.005	0.65	
Compaction	130 [40]	0.005	0.65	
Hours			**24.1**	
Cubic Yards [m³]	130 [40]	0.11 [0.08]		**14.3 [10.93]**
Trenches 3 feet [915mm] deep				
Excavate	120 [37]	0.03	3.6	
Hand grading	120 [37]	0.04	4.8	
Pipe bedding	120 [37]	0.12	14.4	
Backfill	120 [37]	0.008	0.96	
Added labor	120 [37]	0.008	0.96	
Compaction	120 [37]	0.01	1.2	
Hours			**25.9**	
Cubic Yards [m³]	120 [37]	0.22 [0.17]		**26.4 [20.19]**
Total labor hours			**95.7**	
Cubic Yards [m³]				**60.7 [46.41]**
Adjusted Cu. Yards [m³] (~15%)				**69.8 [53.4]**
Labor Rate [$/hr per person]			$55/hr	
Total labor cost			$5265	
Total machine hours			16.9	
Machine cost @ $120/hour			$2028	
Haul excavated material @ $6/cubic yard [$8/m³]			$ 364	
Fill-material cost @ $8/cubic yard [$10/m³]			$ 486	
Total			$8142	

office usually has a higher number of fixtures per building area than an ordinary office building. Regulations and probable demand vary with different types of occupancy and will influence infrastructure requirements.

More-precise estimating methods are now available through computer programs and certain types of hardware peripherals. While the value of using an appropriate database has already been emphasized, several vendors are now addressing entering precise counts and lengths. The value of accurate data entry helps avoid costly errors and speeds up the estimating process. Some peripherals allow the user to overlay scaled drawings over a digitizing pad so pipes can be picked at each end and the software accounts for its length. Other software works with electronic versions of the drawing, and the users highlight each pipe as they enter key information such as its diameter. When the counts and lengths of material are accurately and quickly gathered, a more-precise cost estimate can be determined. However, a selected estimating package should address current needs without being too complicated. The vendor should be experienced with building construction and offer upgrades as the estimating technology evolves.

OTHER COST FACTORS

Most cost estimating assumes certain conditions in establishing the estimator's database. Among such assumptions are quality of work, standard working hours, general crew productivity, size of a project, allotment of a reasonable time frame for construction, new or renovation of existing plumbing systems, geographic location of the project, weather, season of the year, contractor management, collective bargaining agreements, utility availability, and general business conditions. The size of a job favors larger projects because of economies of scale. The location of a job affects shipping costs as well as the market for skilled labor.

For repair work and renovations, consider slower work productivity because of limited physical access, material-handling restrictions, more-precise cutting to match existing systems, efforts to protect existing finishes, non-standard work hours, unexpected delays, unplanned piping offsets, and general economies of scale. Existing job conditions are probably the most common reason for inaccurate estimates.

For cost-estimating changes to an ongoing construction project, other cost factors may be necessary to consider even though they may not have been applicable to the original project. For example, the size may be smaller and out of a planned sequence, the time frame may be constricted, or the plumbing change is now within a finished space.

In conclusion, cost estimating involves the matching of specific project information with a database of known construction costs. Variations from the database affect the cost estimate, and an appropriate adjustment is used to arrive at an accurate estimate. The amount of adjustment involves many factors, from geography to job size. The estimator's experience determines the best adjustment, while the estimator's careful examination of the specific project gives the needed information to match with established unit costs. Hence, seasoned judgment with tedious review of the project documents yields a precise and accurate prediction of plumbing costs.

5 Job Preparation, Drawings, and Field Reports

A significant portion of time spent on a project is devoted to communication. While good design practices and accurate engineering analyses are important, it will be of little benefit if communication fails to reach the receiver. Hence, effective means are required to assure information is passed faithfully among the design team, contractors, and building owner. In proper preparation of a job, general expectations of the job are established including scope of work, regulatory requirements, specification formats (see Chapter 3), drawing title blocks, and design-team directory.

The drawings are prepared as the primary method to communicate the design of the plumbing. Then, as construction proceeds, the engineer provides feedback to the plumbing contractor after observing progress of the plumbing work. To assist in providing thorough communication, engineering offices frequently use lists to prepare quality documents and to make field observations during construction.

(Note: Refer to Chapter 1 for definitions of terms. Refer to other data book chapters for further design information.)

JOB-PREPARATION GUIDELINES

1. Identify relevant codes and standards, including local amendments and date of issue. Relevant issues include:
   - Energy and water conservation
   - Hot-water production and maintenance
   - Cross-connection control
   - Interceptors
   - Clearwater disposal
   - Rainfall rates
   - Secondary drainage
   - Storm-water management
   - Fire sprinklers and standpipes (occupancy class)
   - Fuel gas code
   - Medical gases and other healthcare matters
2. Establish directory of project team members. Organize project schedule with staff availability.
3. Contact the plumbing-code official and fire-protection authority having jurisdiction. Contact water, sewer, and gas utilities, and establish connection requirements.
4. Identify phasing issues and whether there will be concurrent occupancy.
5. Review survey and other documents for size, location, and depth of sanitary and storm sewers, water mains, and gas mains. (Work with civil engineer as well.)
6. Obtain water flow and pressure data (static and residual) at given elevation. Determine if a fire pump and a domestic booster pump are required. Select and size pumps as required.
7. For building alteration or addition, check if existing plumbing services, distribution, and equipment are adequate (capacity and life of systems or equipment), including water heaters, water-treatment equipment, pumps, compressors, water meter, backflow preventers, and interceptors.
8. Identify the energy source: gas, electric, steam, hydronic.
9. Determine if water treatment is required. Obtain water-quality analysis.
10. Determine if there are unusual occupancy-related plumbing requirements.
11. Within the limits of the code, determine the architect's preferred method of cleanout design.
12. Establish and coordinate electrical voltages and phases for motors and controls with the electrical engineer.
13. Determine the need for other systems, such as compressed air, vacuum, deionized water, acid waste, fuel oil, and steam.
14. Review the cost estimate and time estimate against recent project developments.

PLUMBING DRAWING GUIDELINES

1. Review elevation of storm and sanitary sewers to determine that gravity flow is feasible or if lift stations are needed. Determine that storm and sanitary drain pipes do not conflict. Consider backwater valves where appropriate.
2. Review utility regulations and provide water-service requirements. Provide an approved backflow preventer where required. Provide pressure-reducing valves for domestic water systems where the static pressure exceeds 80 psi (550 kPa).
3. Review fire-protection standards and local requirements, including class of standpipes and classification of occupancy. Determine water demand, including flow at required residual pressure. Provide service with an approved backflow preventer or other approved cross-connection control. Select wet, dry, or anti-freeze type sprinkler system. Special extinguishing systems may be required.
4. Coordinate fire-department-connection location and fire-hydrant requirements with the architect, site civil engineer, and landscape designer.
5. Review the code-minimum rainfall rate and whether a higher rate should be considered. Size roof drains, conductors, and storm drain accordingly. Review secondary drainage requirements and coordinate them with the architect.
6. Determine size and extent of subsoil drainage based on soils report and wall structural requirements.
7. Review storm-water management issues. Review clearwater disposal restrictions.
8. Send electrical-control and power requirements of plumbing and fire-protection equipment to the electrical engineer. These requirements may include pumps, air compressors, water heaters, water coolers, heat tracing, solenoids, high-water alarms, medical gas alarms and manifolds, fire-sprinkler switches, and fire-alarm bells. Among various pumps consider fire pumps, domestic boosters, circulation pumps, vacuum pumps, sump pumps, and sewage ejectors.
9. Evaluate hot-water-demand requirements. Select and size water heater, mixing valve, and circulation pump. Provide hot-water system with a circulating return unless the distance between the heater and the farthest fixture is relatively short.
10. Determine combustion air requirements for atmospheric gas-fired water heaters.
11. Address scald-hazard concerns and pathological hazards within the hot-water system.
12. Determine water-treatment requirements. Select and size treatment equipment for anticipated occupancy demand and client preferences.
13. Review selection of pipe material for each part of the plumbing system from supply systems to drain systems. Consider purity requirements, corrosion issues, fluid temperature, fluid pressure, joining methods, hanger spacing, code issues, and physical protection.
14. Coordinate drawing details with specifications.
15. Review pipe-insulation requirements thermally and acoustically.
16. Review noise and vibration considerations of piping systems and plumbing equipment. Review water-hammer requirements. Review noise concerns from rotary vacuum pumps and similar equipment.
17. Consider building-expansion requirements and design concerns that affect tenant-occupancy changes. (Coordinate plumbing-system locations with architect.)
18. Arrange plumbing piping logically while considering obstructions, occupancy restrictions, accessibility, control, future expansion, designer's preferences, other building systems (existing or new), and economics. In general, run piping clear of structural beams. Where necessary, in consultation with the structural engineer, penetrate through the web of steel beams and the middle third of wood or concrete beams. Keep piping out of elevator shafts, electric and data communication rooms, similar restricted rooms, as well as stairs and exit discharge corridors. Size piping for required supply and drainage fixture units.
19. Provide pipe-expansion loops or expansion joints where required.
20. Provide valves on distribution branches, on branches off supply risers, and at the base of supply risers. Provide drain valves with hose threads at the base of risers and in the low portions of piping.
21. Provide hose bibs around the building. Select frost-proof hose bibs if required. Review landscape irrigation connection point where required. Confirm if hose bibs are to be key-operated.
22. Note piping elevation changes on plans. Pipes rising within a story should be noted as "rise". Pipes rising to another story should be noted as "up". Pipes dropping to another story should be noted as "down". Pipes at ceiling should be noted as "at ceiling" when exposed and "above ceiling" when concealed. Pipes under the floor, other than obvious fixture drain pipes, should be noted as "below floor," "at ceiling below," or "above ceiling below."

23. Select location and spacing of cleanouts. Confirm compliance with local authority having jurisdiction.
24. Locate fire standpipes and hose connections.
25. Locate alarm panels and motor controllers.
26. Locate roof leaders, main stacks, and supply risers. Coordinate wall thicknesses, beam clearances, and footing clearances with the architect and structural engineer.
27. Coordinate structural penetrations and housekeeping pads with the architect and structural engineer. Review weight of water heater and other equipment with the structural engineer.
28. Select fixtures and fixture trim, including faucets, shut-off valves, flush valves, carriers, strainers, drains, traps, and wall flanges. Send fixture cut sheets to the architect. Include dimensioned drawings of fixtures and fixture trim.
29. Select sprinkler-head designs including escutcheons or covers, finish type or color. Send sprinkler-head cut sheets to the architect.
30. Determine medical gas outlet types, shut-off valve box designs, and alarm panel layouts. Send equipment cut sheets to the architect. Include dimensioned drawings and selection of options.
31. Review plans for mop-basin, drinking fountain, and floor-drain requirements.
32. Provide floor drains for public toilet rooms, at least one floor drain at the lowest floor level of the building, and in pits such as elevator pits.
33. Review and coordinate water-supply connection and drain requirements for:
    - Backflow preventers (adequate drain for relief port)
    - Beverage machines
    - Boilers
    - Chillers
    - Compressors
    - Cooling towers
    - Cooling coils (drain only)
    - Emergency eyewash/shower
    - Fire sprinklers and fire pumps
    - Food-service areas, including dishwashers, walk-in refrigerators and freezers, steam kettles, scullery sinks
    - High-efficiency burners (drain only)
    - Humidifiers
    - Ice machines
    - Laboratory equipment
    - Laundry
    - Pressure relief valves (drain only)
    - Sterilizers
    - Vacuum pumps
    - Other equipment
34. Review and coordinate natural-gas connections for water heaters, food-service equipment, and other equipment as required.
35. Select size and design of floor drains and receptors to meet requirements. If required, segregate clearwater wastes from sanitary wastes. Connect clearwater system to the storm-drain system.
36. Identify infrequently used drains and provide with trap primers.
37. Offset roof drains and vent terminals 12 to 18 inches [0.3 to 0.5 m] away from parapet walls, roof openings, and other roofing elements.
38. Review canopies and porte-cocheres for adequate drainage.
39. Provide cross-connection control for potable water supply connections to building equipment and systems, for all fixtures, and for appurtenances as required. In particular, provide air gaps or approved backflow preventers for connections to boilers and to sprinkler supplies. Provide air gaps for relief ports of backflow preventers, for pressure-relief valves, and generally for fixture faucet outlets.
40. Provide interceptors as required, including subsoil receivers, exterior-pavement catch basins, garage catch basins, grease interceptors, oil and sand interceptors, laundry interceptors, plaster interceptors, acid and caustic dilution or neutralization basins, and special industrial treatment systems.

PLUMBING-DRAWINGS CHECKLIST

Modify checklist to suit client requirements and the policy of your firm. Initial checked items. Label NA where not applicable.

Plans

1. ____ Is it evident that the architectural backgrounds are current? Check at phases of job or other increments to be established.
2. ____ Does the title block have correct format, proper date, and proper nouns spelled correctly?
3. ____ Are the drawings legible and of sufficient scale?
4. ____ Are arrangements coordinated so that drawing sheet index and project-manual table of contents match the final set of drawing sheets and the final sections of the plumbing specification, respectively?
5. ____ Are more recent requirements coordinated with the architect, electrical engineer, HVAC engineer, and structural engineer?

6. ____ Do pipes clear structural members, high ceilings, skylights, and clerestories?
7. ____ Do all pipes show sizes? Are fixture units shown? Are invert elevations shown?
8. ____ Are valves and cleanouts accessible?
9. ____ Are all fixtures connected to supply, waste, and vent piping?
10. ____ Do toilet rooms have floor drains where required? Lowest level, elevator pit, and other pits?
11. ____ Is piping kept out of elevator shafts, electric and data-communication rooms, similar restricted rooms, stairs, and exit-discharge corridors? Are pipes clear of ductwork?
12. ____ Are stacks, conductors, and risers within interior partitions of sufficient thickness?
13. ____ Are ceiling spaces and similar concealed spaces prone to freezing?
14. ____ Is cutting and patching addressed clearly?
15. ____ Do roof-drain locations coordinate with architectural requirements?
16. ____ Are drawing notes complete and edited for the specific job?
17. ____ Are plumbing vents spaced sufficiently from air intakes and operable windows?
18. ____ Is the mechanical room coordinated and well laid out with sufficient access to service equipment, including equipment removal? Are equipment connections and drains coordinated?
19. ____ Does the direction of the north arrow agree with the architect's plans?

Risers and Details

1. ____ Are risers legible? Are references, such as drawing references, room numbers and fixture tags, clearly presented? Are fixture traps oriented correctly?
2. ____ Are all vents properly connected? Are vent stacks, relief vents, and yoke vents shown where required?
3. ____ Are pipe sizes consistent between risers and plans?
4. ____ Are details shown for accessible fixtures, interceptors, backflow preventers, water heaters, water-treatment systems, sump pumps, and sewage ejectors?
5. ____ Are pipe supports, sleeves and fire-stopping systems detailed properly?
6. ____ Is the water-service design detailed properly and coordinated with the utility?
7. ____ Does the fire-riser design meet requirements?
8. ____ Are detail references coordinated with the plans?

Schedules and Specifications

1. ____ Is the inclusion of fixtures and equipment consistent in both the drawings and the specifications?
2. ____ Are fixtures and equipment consistently referenced on plans, risers, schedules, and specifications?
3. ____ Are pumps selected for proper flow and head?
4. ____ Is voltage and other electric data consistent with schedules, the equipment supplier, and the electrical engineer?
5. ____ Does the schedule of supply and drainage-fixture units show the original total, removed total, and new total?
6. ____ Is a water-supply uniform-pressure calculation or other sizing method included? Is the street pressure correct? Is the controlling-fixture pressure correct? Is the maximum length accurate?
7. ____ Do faucets and flush valves meet water-conservation requirements? Does the fixture trim meet requirements for handle design, strainer design, and spout height? Does the client accept the vendor selection?
8. ____ Are legends, symbols, and abbreviations included?

FIELD CHECKLIST

Field visits can be broken down into three phases: Underground, rough-in, and final. Important items to observe when visiting a job site are listed as follows and shall be in reference to requirements of the construction documents. Initial observed items. Label NA where not applicable. Add comments regarding deficiencies.

Building Drains

1. ____ General alignment and conformity to plans
2. ____ Workmanship of joints, general compactness of soil below, and around pipe
3. ____ General slope of piping
4. ____ Spacing and accessibility of cleanouts
5. ____ Vent connections
6. ____ Branch to building drain not connected near base of stack or conductor
7. ____ Pipe sleeves and water stopping
8. ____ Pipe sizes and invert elevations

9. ____ Manholes, sumps, receivers, grease interceptors, sand and oil interceptors, trench drains, and other structures; workmanship, specified size, invert elevations, and rim elevations
10. ____ Trap-primer connections
11. ____ Temporary terminations covered or capped to prevent entry of foreign material
12. ____ Acid-waste and vent piping and acid-dilution tank

Water and Gas Services

1. ____ Compliance with water-service requirements, including service location, pipe depth, thrust blocks, and shut-off valves
2. ____ Compliance with natural-gas-service requirements, such as service location and shut-off valves

Above Grade Rough-in

1. ____ Compliance with water-service requirements such as location, shut-off valves, meters, meter registers, pressure-reducing valves, bypasses, backflow preventers, pressure gauges, and testing ports
2. ____ Compliance with natural-gas-service requirements such as location, shut-off valves, meters, meter registers, pressure-reducing valves, vent ports, and bypasses
3. ____ Piping at booster pumps, water heaters, and water-treatment devices
4. ____ Fire-protection-system piping
5. ____ Medical-gas-system piping, valves, outlets, panels, and source equipment such as cryogenic systems, high-pressure manifolds, vacuum pumps, air compressors as well as attendant dew-point and carbon-monoxide monitors, air dryers, and inlet, discharge, or relief piping to the exterior
6. ____ Adequacy of sump pumps, sub-soil receivers, and sewage ejectors
7. ____ General alignment, arrangement, and sizes of piping in conformity to plans
8. ____ Workmanship of joints
9. ____ Installation of pipe supports, expansion joints or expansion loops, and pipe swing joints
10. ____ Location of valves
11. ____ Clearances around pipes within sleeves
12. ____ Spacing and accessibility of cleanouts
13. ____ Fire stopping at fire walls, fire-rated floors, and other locations as required
14. ____ Vent connections: Close enough to trap to avoid air lock, above flood level, vertical where required
15. ____ Branch to stack offset not connected near upstream end of offset
16. ____ Pipe labeling and valve tags
17. ____ Installation of pipe insulation, including covers over valves and fittings.
18. ____ Adequacy of cooling-coil-condensate drains, combustion-condensate drains, relief-valve drains, and indirect waste pipes; supported properly and air break or air gap as required
19. ____ Adequacy of floor slope to floor drains and floor sinks; rims of indirect waste receptors are elevated to prevent entrance of debris
20. ____ Installation of small interceptors
21. ____ Vent terminals properly flashed, located away from air intakes and operable windows
22. ____ Motor starters, magnetic and manual
23. ____ Connection of plumbing to other building equipment, including boilers, chillers, cooling towers, air handlers or fan coils, food service, medical, laundry, and similar equipment; arrangement of piping, valves, cross-connection control, and drainage.

Final

1. ____ Adequacy of hot water at remote fixture
2. ____ ADA accessibility requirements
3. ____ Fixture support
4. ____ Water-closet bowl type and seat design
5. ____ Flush-valve performance
6. ____ Strainers and traps
7. ____ Faucet handles, outlet flow rating, outlet air gap
8. ____ Fixture supply-stop location
9. ____ Fixture mixing-valve location and temperature setting
10. ____ Mop-basin accessories
11. ____ Caulking at fixture
12. ____ Access panels for valves and cleanouts
13. ____ Cross-connection control type, application, installation, approval, product listing, drainage
14. ____ Sprinkler heads and standpipe hose connections
15. ____ Medical-gas valves, outlets, panels
16. ____ Owner equipment manuals
17. ____ Record drawings and/or as-built drawings
18. ____ Training and commissioning

COMMENTS:

6 Plumbing for People (or Persons) with Disabilities

INTRODUCTION

The plumbing engineer must be prepared to provide adequate facilities for people with disabilities, whether or not the requirements for these facilities are covered specifically in the local jurisdiction's applicable code. Most U.S. plumbing codes today include some type of provision for people with disabilities. Also, the Americans with Disabilities Act (ADA) of 1990 includes plumbing provisions. The plumbing engineer must determine which codes are applicable to the project he or she is designing and incorporate any provisions these codes require, in addition to ADA requirements.

This chapter presents background information on past and current legislation affecting plumbing for people with disabilities and design requirements for compliance with ANSI A117.1-1998 and the Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG), July 26, 1991. Throughout this chapter, there are references to standards and guidelines giving dates of issue. The reader must be sure to review and reference the latest editions of these documents, in accordance with those documents listed and referred to in local codes.

BACKGROUND

Many design and construction features of facilities cause problems for individuals with physical impairments. These architectural barriers make it difficult for people with disabilities to participate in educational, employment, and recreational activities.

In 1959, a general conference was called and those groups vitally interested in the problem of accessibility were invited to participate and be represented. The attendees recommended the initiation of a standards-development project to study the cases and to prepare a national document.

In 1961, the American Standards Association (now the American National Standards Institute) issued the American Standard *Specifications for Making Buildings and Facilities Usable by the Physically Handicapped*, ASA A117.1-1961. This document was reaffirmed in 1971 with no changes and redesignated as A117.1-1961 (R1971). In 1998, the standard was renamed *Accessible and Usable Buildings and Facilities*.

The U.S. Department of Housing and Urban Development (HUD), along with the National Easter Seal Society and the President's Committee on Employment of the Handicapped (the original co-secretariat of the A117 standards committee), sponsored two (2) years of research and development to revise the A117.1 standard in 1974. This work (extended to include residential environments) resulted in the 1980 version of this standard. The scope of ANSI A117.1-1980 was greatly expanded. Curb ramps, accessible bathrooms and kitchens, and other elements of housing were included in the standard; an appendix was added in order to assist the designer in understanding the standard's minimum requirements; and more illustrations were incorporated.

The standard was also upgraded in 1985, in compliance with ANSI standard practice, which requires a review every five years at the minimum. The standard, issued as ANSI A117.1-1986, further reinforced the concept that the standard is basically a resource for design specifications and leaves to the adopting, enforcing agency application criteria such as where, when, and to what extent such specifications will apply. Clarification of this "how-to" function of ANSI A117.1-1986 facilitated its referencing in building codes and federal design standards—a major step toward achieving uniformity in design specifications.

The technical data contained in ANSI A117.1-1986 were expanded greatly to incorporate additional elevator and plumbing data as well as, for the first time, specifications for alarm and communications systems for use by individuals with visual or hearing impairments.

The technical data contained in the 1986 issue have been used as the basis of most state and local codes, as well as the Uniform Federal Accessibility

Standard (UFAS) and the U.S. Architectural and Transportation Barriers Compliance Board (ATBCB) requirements.

As part of an ongoing review process, the A117.1 committee was reconvened in 1989 with the intention of reissuing the standard in 1990. The magnitude of the changes, both in technical data and in format, resulted in a delay in publication of the standard until December 15, 1992. This standard was the most comprehensive to date and the involvement from disability advocates and interested parties was remarkable. The 1992 standard is now referenced in several model codes and has resulted in improved accessibility in many regards.

In 1995, the A117.1 committee was called again and charged with the task of reviewing the standard for changes. The makeup of the committee had grown to include many disability advocacy groups, model code representatives, and associations—including the American Society of Plumbing Engineers (ASPE)—and design professionals. The committee worked for more than three (3) years, through three (3) public reviews, examining over 1,000 proposed changes, during 23 days of meetings, to produce the 1998 ANSI A117.1-1998 standard. The 1998 standard has been developed to work in harmony with federal accessibility laws, including the current *Fair Housing Accessibility Guidelines* and the proposed *Americans with Disabilities Act Accessibility Guidelines* (ADAAG).

New provisions for Type B dwelling units are intended to provide technical requirements consistent with the Fair Housing Accessibility Guidelines of the U.S. Department of Housing and Urban Development. HUD is currently in the process of reviewing the 1998 standard to determine equivalency with the guidelines. In addition, the A117.1 committee worked closely with the ADAAG Review Federal Advisory Committee to harmonize the 1998 edition with proposed revisions to ADAAG. The U.S. Architectural and Transportation Barriers Compliance Board (Access Board) published a "notice of proposed rule making" in the *Federal Register*, November 16, 1999. Twenty-five-hundred comments were received for the proposed rule. Until the rule is published in final form and the Federal Department modifies its standard to reflect the revised guidelines, the current standard would be in effect.

LEGISLATION

In 1969, Public Law 90-480 (known as the Architectural Barriers Act of 1968) was signed by President Lyndon B. Johnson. The main thrust of this legislation was that any building constructed, in whole or in part, with federal funds must be made accessible to, and usable by, the physically challenged. Public Law 93-112, known as the Rehabilitation Act of 1973, was passed by the federal government in 1973.

State and municipal governments also began issuing their own ordinances regarding architectural barriers. These legislative acts were usually modified versions of the ANSI A117.1 document. At the present time, just about every state has adopted some legislation covering this subject; however, there are major differences from one ordinance to another. Like the federal government, the original legislation usually applied to government-owned or government-financed structures, but now the requirements generally apply to all public accommodations.

The Americans with Disabilities Act (ADA) was enacted by the Congress and signed by President George Bush on July 26, 1990. The ADA prohibits discrimination based on physical or mental disabilities in private places of employment and public accommodation, in addition to requiring transportation systems and communication systems to facilitate access by the disabled. The Act is modeled, to a considerable extent, on the Rehabilitation Act of 1973, which applies to federal grantees and contractors.

The ADA is essentially civil rights legislation, but its implementation has a major impact on the construction industry. In order to clarify construction requirements, the Attorney General's office commissioned the U.S. Architectural and Transportation Barrier Compliance Board (ATBCB) to prepare architectural guidelines to ensure that the construction industry understood what was required in order to comply with the Act. The ATBCB, which is represented on the A117.1 committee, used much of the completed how-to data that was available from A117.1, and where-to data from the ongoing scoping work being done by the Board for Coordination of Model Codes (BCMC), its governmental experiences, and public comments to produce the guidelines commonly referred to as "ADAAG."

After incorporating public comments, the "final rule" was issued on July 26, 1991, in the federal register (28 CFR Part 36) as "Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities." The Act became effective on January 26, 1992, and applies to all construction with application for permit after January 26, 1992. This "final rule" preempted state and local laws affecting entities subject to the ADA, to the extent that those laws directly conflict with the statutory requirements of the ADA. The attorney general's office established as a procedure for the certification of state and local accessibility codes or ordinances that they meet or exceed the requirements of the ADA. It was hoped that, with such a certified code enforced by local inspectors, compliance with ADA would not be decided in the courts.

In 1994, the ATBCB commissioned a new committee to make recommendations for an improved document to replace the current *Americans with Disabilities Act Accessibility Guidelines* (ADAAG). This committee met for more than two (2) years to review proposed changes to the document and remove the ambiguities that have been a cause of contention to designers as well as code-enforcement officials. This new committee included 22 members representing: Advocacy groups (American Council of the Blind; Disability Rights Education and Defense Fund, Inc; Eastern Paralyzed Veterans Association; Maryland Association of the Deaf; World Institute on Disability), code enforcement officials [Virginia Building and Code Officials Association; Texas Department of Licensing and Regulation; Southern Building Code Congress International, Inc. (SBCCI); National Fire Protection Association (NFPA); National Conference of States on Building Codes and Standards; International Conference of Building Officials (ICBO); Council of American Building Officials (CABO); Building Officials and Code Administrators International, Inc. (BOCA)], and designers [American Institute of Architects (AIA), American Society of Interior Designers (ASID)]. The document that came from this committee's work was presented to the ATBCB on October 10, 1996. Design professionals must continue to review the ADA in its entirety, and forthcoming revisions, as well as state and local codes for application to their projects. Some states require preapproval of accessible plumbing fixtures. Approval of the fixtures is the responsibility of the fixture manufacturers, but the specifier must specify and approve only those fixtures that have received approval.

There are still a number of concerns regarding whether the established standards properly address the specific needs of children and the elderly. Children cannot necessarily reach fixtures set at established heights for people with disabilities. Also, the elderly may have trouble accessing fixtures set low to meet established height requirements for people with disabilities.

DESIGN

Although plumbing is only a small portion of the overall effort to create a totally barrier-free environment, it is one of the most important areas to be dealt with by engineers.

The following are the various classifications of disabilities:

- *Non-ambulatory disabilities*—Those that confine individuals to wheelchairs.
- *Semi-ambulatory disabilities*—Those that necessitate individuals to require the aid of braces, crutches, walkers, or some other type of device in order to walk.
- *Sight disabilities*—Total blindness and other types of impairment affecting an individual's sight.
- *Hearing disabilities*—Total deafness and other types of impairment affecting an individual's hearing.
- *Coordination disabilities*—Those caused by palsy due to cerebral, spinal, or peripheral nerve injury.
- *Aging disabilities*—Those brought on by the natural process of aging, which reduces mobility, flexibility, coordination, and perceptiveness in individuals. (Note: To some extent, various national standards—e.g., HUD's *Minimum Property Standards*—differentiate the elderly from "people with disabilities.")

The disability classifications that affect the plumbing engineer the most, in terms of design, are the non-ambulatory and the semi-ambulatory groups. Adequate plumbing facilities must be provided for these individuals. The architect is responsible for analyzing the needs of a person confined to a wheelchair and those forced to use walking aids such as crutches and braces. However, the plumbing designer should become familiar with the characteristics of the wheelchair and various associated types of equipment. At the present time, there are many variations in wheelchair design available on the market. The specifications in these guidelines are based on adult dimensions and anthropometrics. An illustration of a typical wheelchair design is shown in Figure 6-1 (Refer to Table 6-1 for graphic conventions).

In addition to the dimensions of the wheelchair, the plumbing engineer must take into consideration how wheelchairs are employed and how the person in a wheelchair utilizes plumbing fixtures.

The following information on fixture requirements for the use of people with disabilities is based on the recommended design criteria contained in the proposed ANSI A117.1-1998. A117.1-2003 is proposed to be published May of 2004. For convenient reference to the ANSI A117.1 text, the corresponding ANSI article numbers have been used (e.g., "601.1" and "602.5"). Illustrations, in most cases, are the same as or similar to those in ANSI A117.1. Therefore, A117.1 figure numbers (such as "Figure B4.15.2.1" and "Figure B4.20.3.1") have been included with the "Plumbing Engineering Design Handbook" figure numbers.

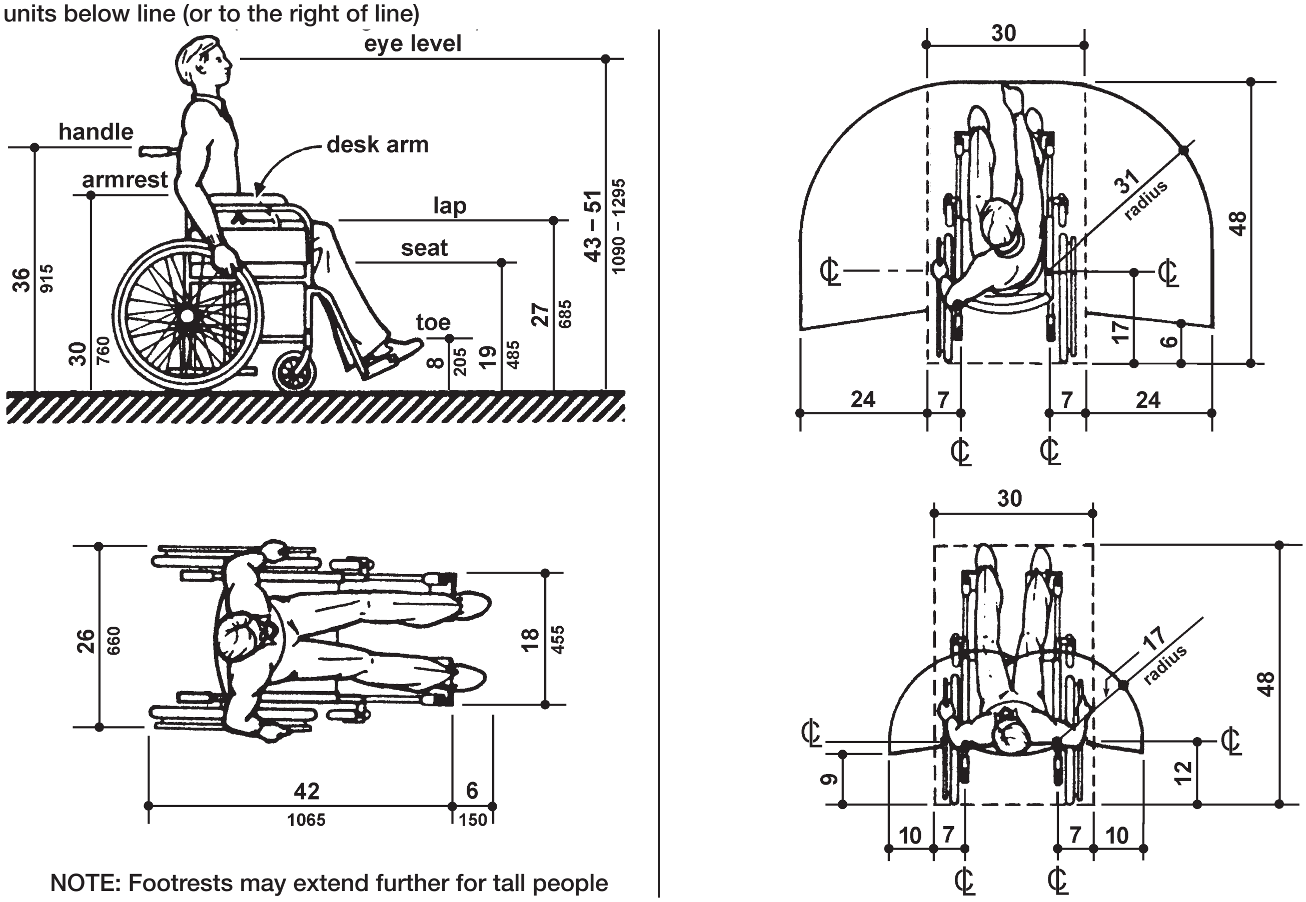
Explanatory notes have been added after the recommendations for each fixture, where deemed of value. Where there are differences between A117.1 and ADAAG other than of an editorial nature, it is also noted.

Table 6-1 Graphic Conventions

Convention	Description
36 / 915	Typical dimension line showing US customary units (in in.) above the line and SI units (in mm) below.
9 / 230	Dimensions for short distances indicated on extended line.
9 / 230, 36 / 915	Dimension line showing alternate dimensions required.
	Direction of approach.
max	Maximum.
min	Minimum.
- - - - - - - - - - -	Boundary of clear floor area.
——— - ——— - ——— - ℄	Centerline.

Note: Dimensions that are not marked "minumum" or "maximum" are absolute, unless indicated otherwise in text or captions.

US Customary units above line (or to left of line) and SI units below line (or to the right of line)



NOTE: Footrests may extend further for tall people

Figure 6-1 Dimensions of Adult-Sized Wheelchairs

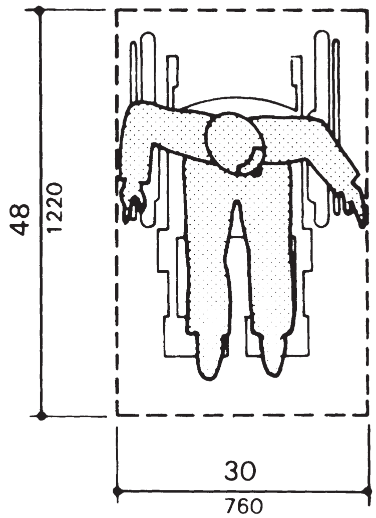


Figure 6-2 Clear Floor Space for Wheelchairs

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CLEAR FLOOR OR GROUND SPACE FOR WHEELCHAIRS

The minimum clear floor or ground space required to accommodate a single, stationary wheelchair and occupant is 30 inches – 48 inches (760 mm – 1220 mm). (See Figure 6-2-B4.2.4.1.) The minimum clear floor or ground space for wheelchairs may be positioned for forward or parallel approach to an object (see Figure 6-3-B4.2.4.2). Clear floor or ground space for wheelchairs may be part of the knee space required under some objects. One full, unobstructed side of the clear floor or ground space for a wheelchair shall adjoin another wheelchair clear floor space. If a clear floor space is located in an alcove or otherwise confined on all or part of three sides, additional maneuvering clearances shall be provided as shown in Figure 6-4 (B4.2.4.4).

Anthropometrics

Forward reach If the clear floor space only allows forward approach to an object, the maximum high forward reach allowed shall be 48 inches (1220 mm). (See Figure 6-5-B4.2.5.1.) The minimum low forward reach is 15 inches (380 mm). If the high forward reach is over an obstruction, reach and clearances shall be as shown in Figure 6-6 (B4.2.5.2).

Side reach If the clear floor space allows parallel approach by a person in a wheelchair, the maximum high side reach allowed shall be 48 inches (1220 mm), and the low side reach shall be 15 inches (380 mm) (see Figure 6-7-B4.2.6.1). If the side reach is over an obstruction, the reach and clearances shall be as shown in Figure 6-8 (B4.2.6.2).

PLUMBING ELEMENTS AND FACILITIES[1]

601 General

601.1 Scope Plumbing elements and facilities required to be accessible by scoping provisions adopted by the administrative authority shall comply with the applicable provisions of this chapter.

602 Drinking Fountains and Water Coolers

602.1 General Accessible fixed drinking fountains and water coolers shall comply with 602.

602.2 Clear floor or ground space A clear floor or ground space complying with 305 shall be provided.[2]

602.2.1 Forward approach Where a forward approach is provided, the clear floor or ground space shall be centered on the unit and shall include knee and toe clearance complying with 306.[2]

602.2.2 Parallel approach Where a parallel approach is provided, the clear floor or ground space shall be centered on the unit.

602.3 Operable parts Operable parts shall comply with 309.[2]

602.4 Spout height Spout outlets shall be 36 inches (915 mm) maximum above the floor or ground. (See Figure 6-9A-B4.15.2.1A.)

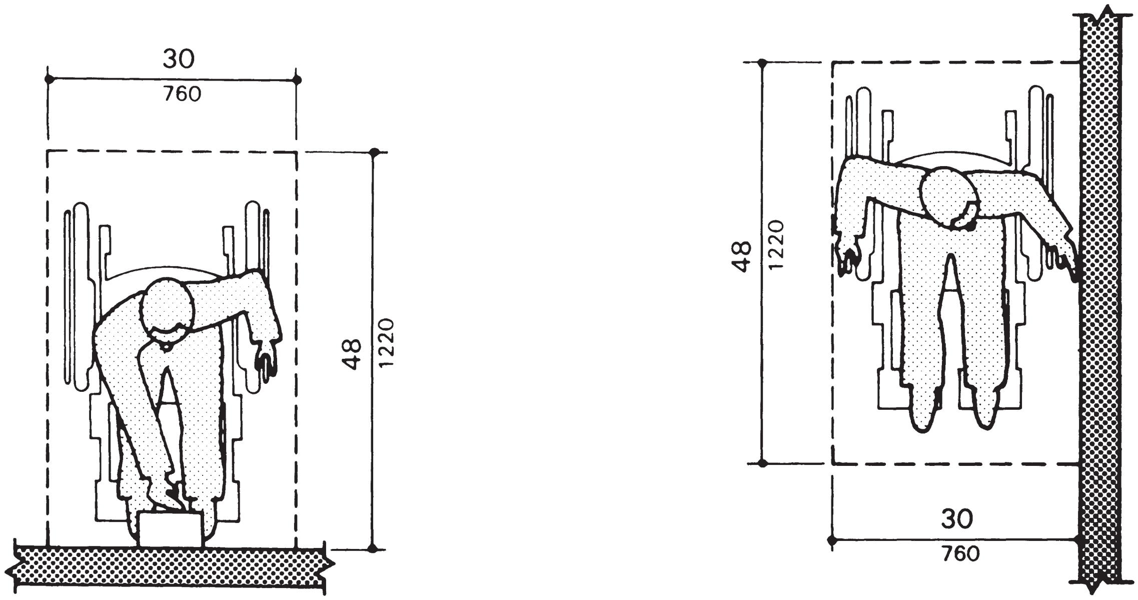
602.5 Spout location Units with a parallel approach shall have the spout 3½ inches (89 mm) maximum from the front edge of the unit, including bumpers. Units with a forward approach shall have the spout 15 inches (380 mm) minimum from the vertical support and 5 inches (125 mm) maximum from the front edge of the unit, including bumpers.

602.6 Water flow The spout shall provide a flow of water 4 inches (100 mm) high minimum to allow the insertion of a cup or glass under the flow of water. The angle of the water stream from spouts within 3 inches (75 mm) of the front of the unit shall be 30 degrees maximum. The angle of the water stream from spouts between 3 inches (75 mm) and 5 inches (125 mm) from the front of the unit shall be 15 degrees maximum. The angle of the water stream shall be measured horizontally, relative to the front face of the unit. (See Figure 6-10-B4.15.2.3.)

602.7 Protruding objects Units shall comply with 307.[2]

Drinking fountain note:

The easiest way for someone in a wheelchair to use a drinking fountain is to approach it from the side and lean to the side to reach the spout. The plumbing engineer should therefore specify a fountain or cooler with a spout located as



(a) Forward Approach

(b) Parallel Approach

Figure 6-3 Wheelchair Approaches

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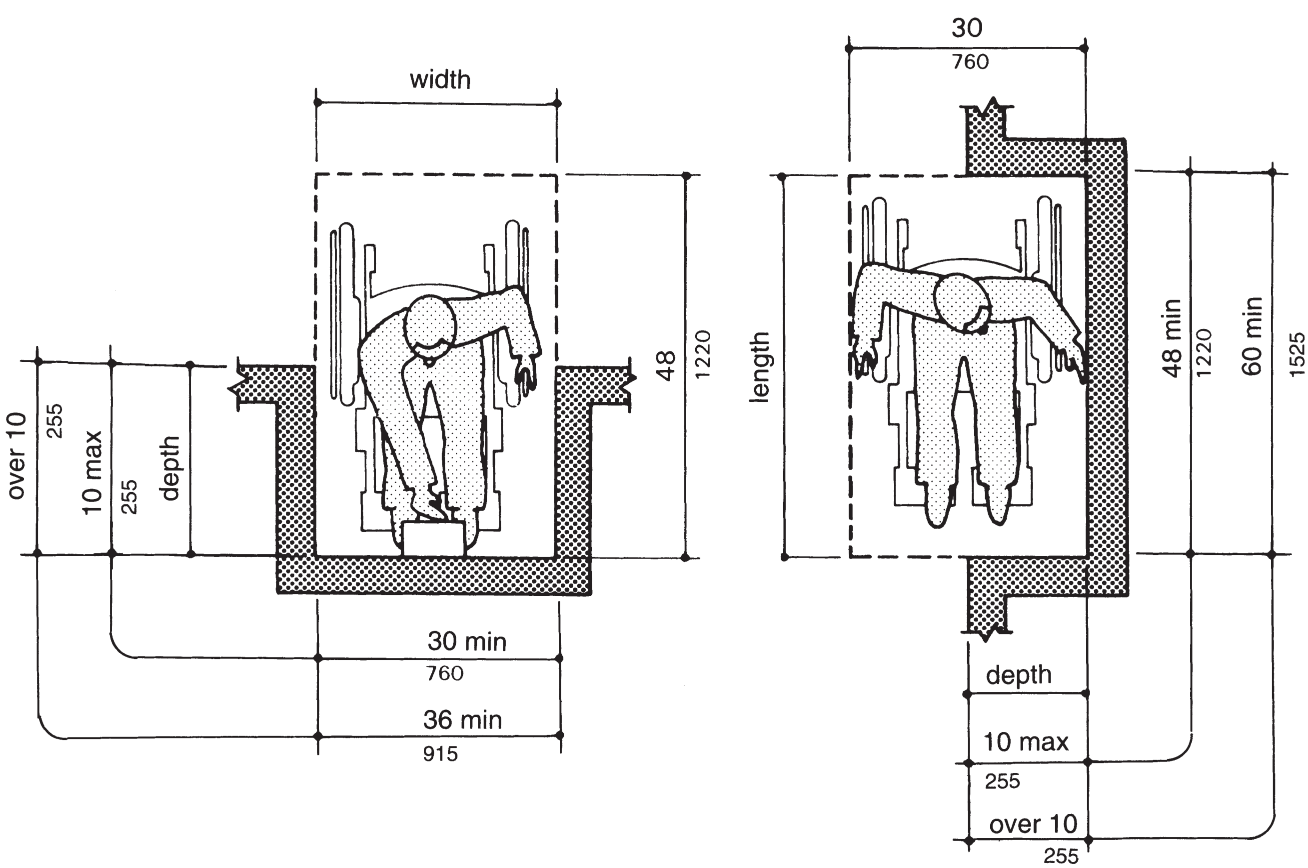

Figure 6-4 Clear Floor Space in Alcoves

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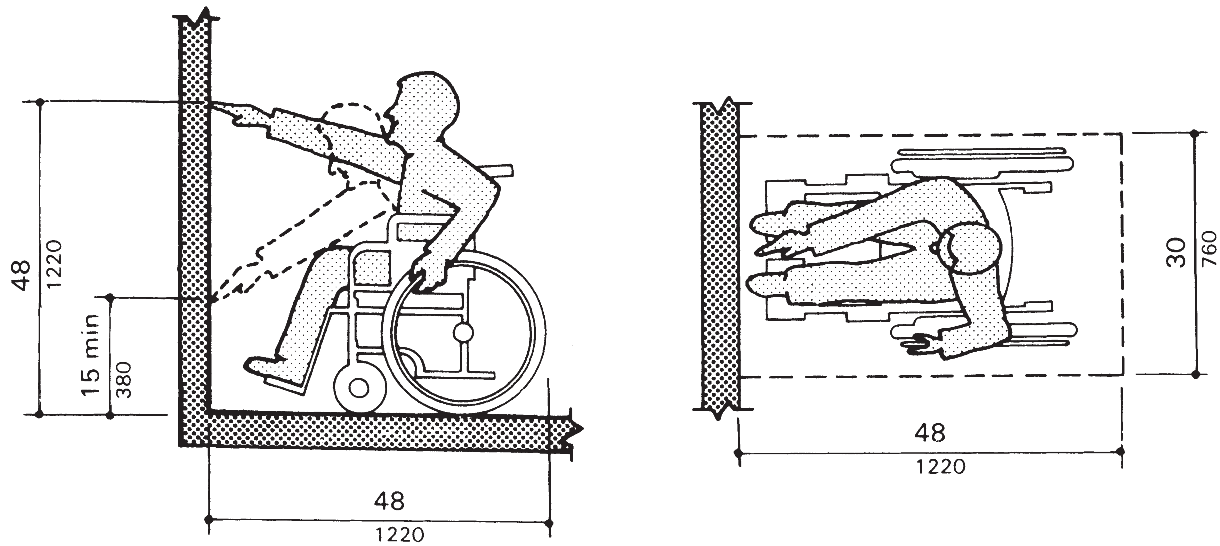

Figure 6-5 Unobstructed Forward Reach Limit

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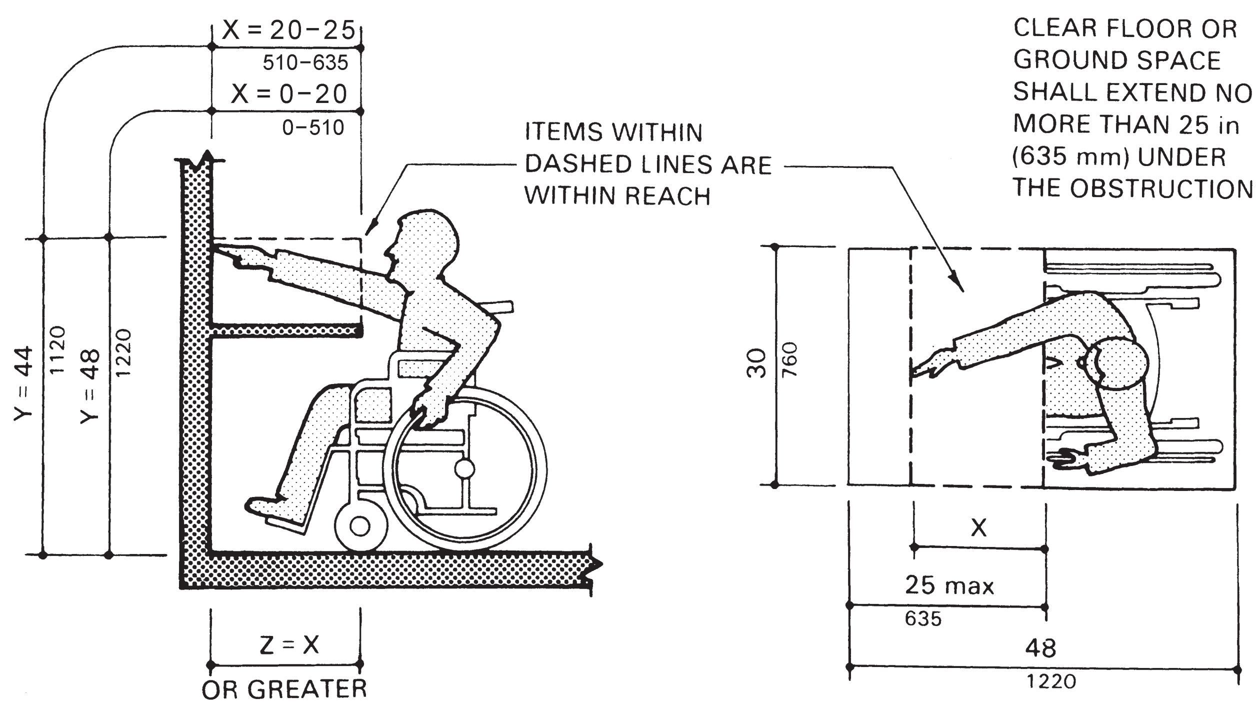

Figure 6-6 Forward Reach Over an Obstruction

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Note: X = Reach depth, Y = Reach height, Z = Clear knee space.
Z is the clear space below the obstruction, which shall be at least as deep as the reach distance, X.

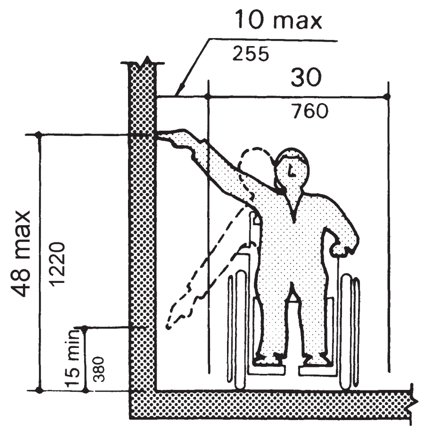

Figure 6-7 Unobstructed Side Reach Limit

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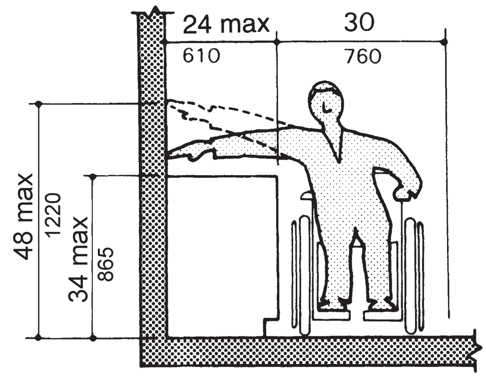

Figure 6-8 Obstructed Side Reach Limit

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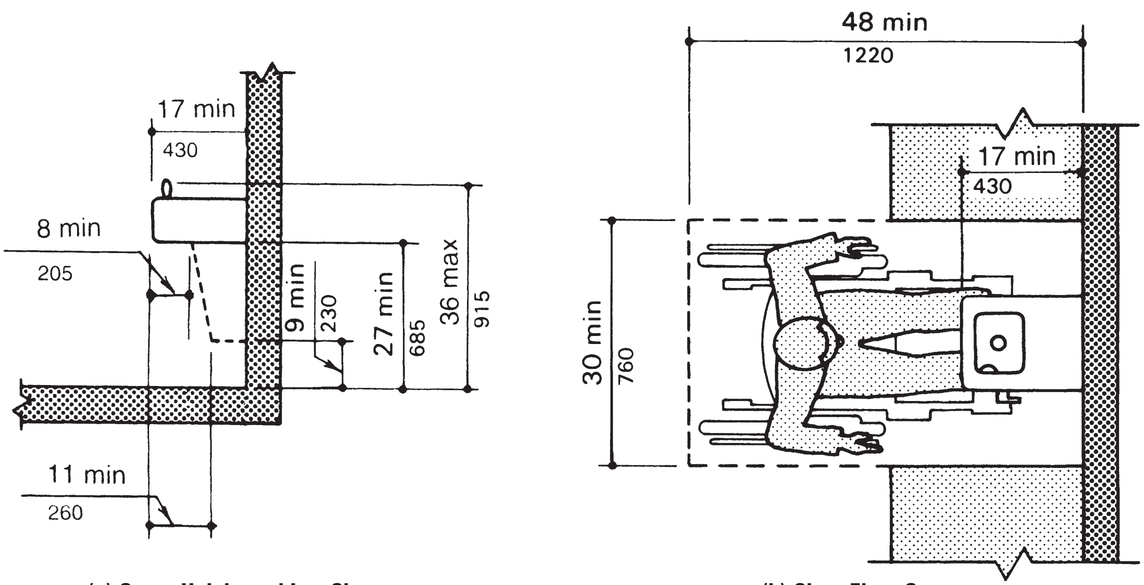

(a) Spout Height and Leg Clearance

(b) Clear Floor Space

Figure 6-9 Cantilevered Drinking Fountains and Water Coolers

Source: CABO/ANSI A117.1-1992, Reprinted with permission.

Note: Figure 6-9a only: Equipment permitted within dashed lines if mounted below apron.

close to the front edge and as low as possible. There are self-contained units available that can be mounted so that spout heights of 33 to 34 inches (839 to 864 mm) can be obtained, without interfering with required leg clearances.

Parallel approach units are more difficult to use than the cantilevered type and should be avoided if possible. If used, the spout should be mounted as close to 30 inches (762 mm) as the fountain will permit.

It is desirable to provide some water coolers or fountains with spout heights of approximately 42 inches (1067 mm) to serve semi-ambulatory users who can have difficulty bending to lower elevations.

Drinking fountains must be provided not only for wheelchair-bound individuals but also for back-disabled individuals (ADAAG section 4.1.3, item no. 10, and appendix A4.15.2). Where only one (1) fountain is required by code, it must be an accessible bi-level unit, or two (2) separate accessible units mounted at different heights must be provided. Where more than one (1) fountain is required by code, 50 percent must be installed for wheelchair-bound individuals.

603 Toilet and Bathing Rooms

603.1 General Accessible toilet and bathing rooms shall comply with 603.

603.2 Clearances

603.2.1 Wheelchair turning space A wheelchair turning space complying with 304 shall be provided within the room.[2]

1 Text source: CABO/ANSI A117.1-1998

2 See CABO/ANSI A117.1-1998

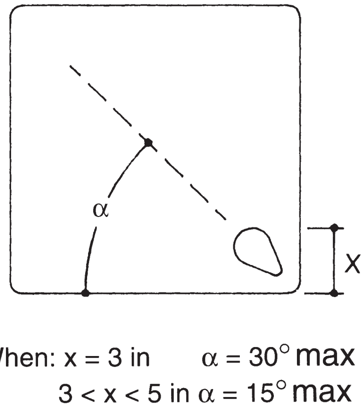

Figure 6-10 Horizontal Angle of Water Stream — Plan View

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603.2.2 Overlap Clear floor or ground spaces, clearances at fixtures, and wheelchair turning spaces shall be permitted to overlap.

603.2.3 Doors Doors shall not swing into the clear floor or ground space or clearance for any fixture.

EXCEPTION: Where the room is for individual use, and a clear floor or ground space complying with 305.3 is provided within the room beyond the arc of the door swing.[2]

603.3 Mirrors Mirrors shall be mounted with the bottom edge of the reflecting surface 40 inches (1015 mm) maximum above the floor or ground. (See Figure 6-11-B4.20.3.1.)

603.4 Coat hooks and shelves Coat hooks provided within toilet rooms shall accommodate a forward reach or side reach complying with 308.[2] Where provided, a fold-down shelf shall be 40 inches (1015 mm) minimum and 48 inches (1220 mm) maximum above the floor or ground.

Toilet and bathing rooms note:

When a door opens into a bathroom, sufficient maneuvering space is provided within the room for a person using a wheelchair to enter, close the door, use the fixtures, reopen the door, and exit without undue difficulty.

The wheelchair maneuvering space overlaps the required clear floor space at fixtures and extends under the lavatory 19 inches (480 mm) maximum because knee space is provided. However, because toe or knee space is not available at the toilet, the wheelchair maneuvering space is clear of the toilet. Design and location of floor drains should not impede the use of plumbing fixtures.

Medical cabinets or other methods for storing medical and personal care items are very useful to people with disabilities. Shelves, drawers, and floor-mounted cabinets should be within the reach ranges of a physically challenged person.

If mirrors are to be used by both ambulatory people and wheelchair users, then they should be 74 inches (1880 mm) high minimum at their topmost edge and 40 inches (1015 mm) maximum at their lowest edge. A single full-length mirror accommodates all people, including children.

604 Water Closets and Toilet Compartments

604.1 General Accessible water closets and toilet compartments shall comply with 604.

604.2 Location The water closet shall be positioned with a wall or partition to the rear and to one side. The centerline of the water closet shall be 16 inches (405 mm) minimum to 18 inches (455 mm) maximum from the side wall or partition, except that the water closet shall be centered in the ambulatory accessible compartment specified in 604.8.2. (See Figure 6-12-B4.18.4.)

604.3 Clearance

604.3.1 Size Clearance around the water closet shall be 60 inches (1220 mm) minimum, measured perpendicular from the side wall, and 56 inches (1420 mm) minimum, measured perpendicular from the rear wall. No other fixtures or obstructions shall be

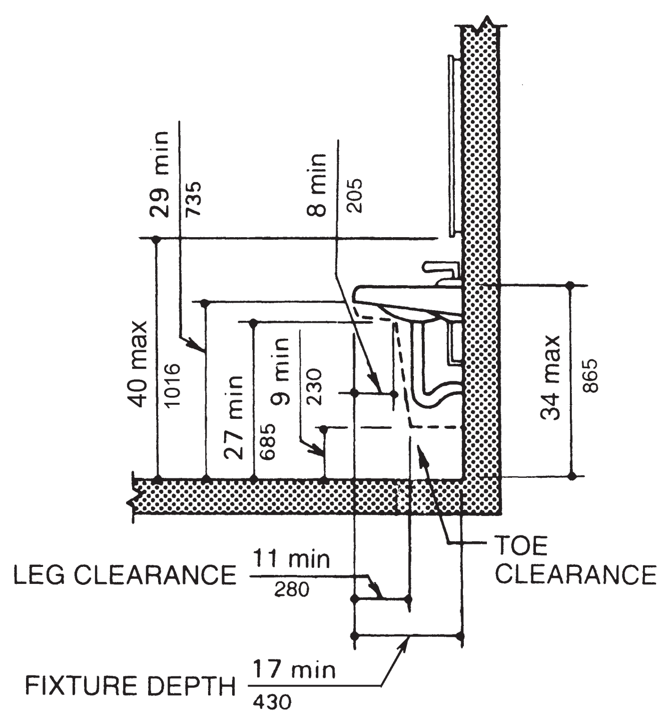

Figure 6-11 Leg Clearances

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Note: Dashed line indicates dimensional clearance of optional, under-fixture enclosure.

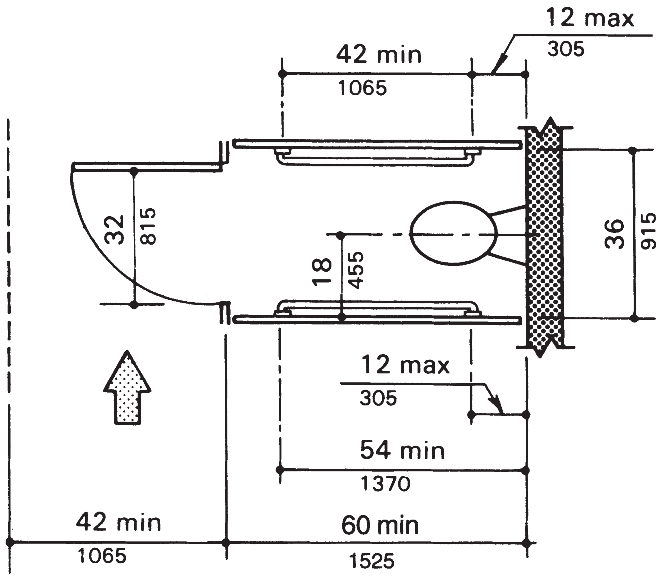

Figure 6-12 Ambulatory Accessible Stall

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within the water closet clearance. (See Figure 6-13-B4.18.3.1.)

604.3.2 Overlap The clearance around the water closet shall be permitted to overlap the fixture, associated grab bars, tissue dispensers, accessible routes and clear floor or ground space or clearances at other fixtures and the wheelchair turning space. Clear floor space shall comply with Figure 6-14 (B4.17.2).

604.4 Height The top of water closet seats shall be 17 inches (430 mm) minimum and 19 inches (485 mm) maximum above the floor or ground. Seats shall not return automatically to a lifted position. (See Figure 6-15-B4.17.3.)

604.5 Grab bars Grab bars for water closets shall comply with 609. Grab bars shall be provided on the rear wall and on the side wall closest to the water closet.

604.5.1 Side wall Side wall grab bar shall be 42 inches (1065 mm) long minimum, 12 inches (305 mm) maximum from the rear wall and extending 54 inches (1370 mm) minimum from the rear wall. (See Figure 6-15-B4.17.3.)

604.5.2 Rear wall The rear wall grab bar shall be 24 in. (610 mm) long minimum, centered on the water closet. Where space permits, the bar shall be 36 in. (915 mm) long minimum, with the additional length provided on the transfer side of the water closet. (See Figure 6-16-B4.17.4.)

604.6 Flush controls Flush controls shall be hand operated or automatic. Hand-operated flush controls shall comply with 309.[2]

604.7 Dispensers Toilet paper dispensers shall comply with 309.4 and shall be 7 inches (180 mm) minimum and 9 inches (230 mm) maximum in front of the water closet.[2] The outlet of the dispenser shall be 15 inches (380 mm) minimum and 48 inches (1220 mm) maximum above the floor or ground. There shall be a clearance of 1½ inches. (38 mm) minimum below and 12 inches (305 mm) minimum above the grab bar. Dispensers shall not be of a type that control delivery, or that do not allow continuous paper flow.

604.8 Toilet compartments Accessible toilet compartments shall comply with 604.8.1 through 604.8.5. Compartments containing more than one plumbing fixture shall comply with 603. Water closets in accessible toilet compartments shall comply with 604.1 through 604.7.

604.8.1 Wheelchair accessible compartments

604.8.1.1 Size Wheelchair accessible compartments shall be 60 inches (1525 mm) wide minimum measured perpendicular to the side wall, and 56 inches (1420 mm) deep minimum for wall-hung water closets and 59 inches (1500 mm) deep minimum for floor-

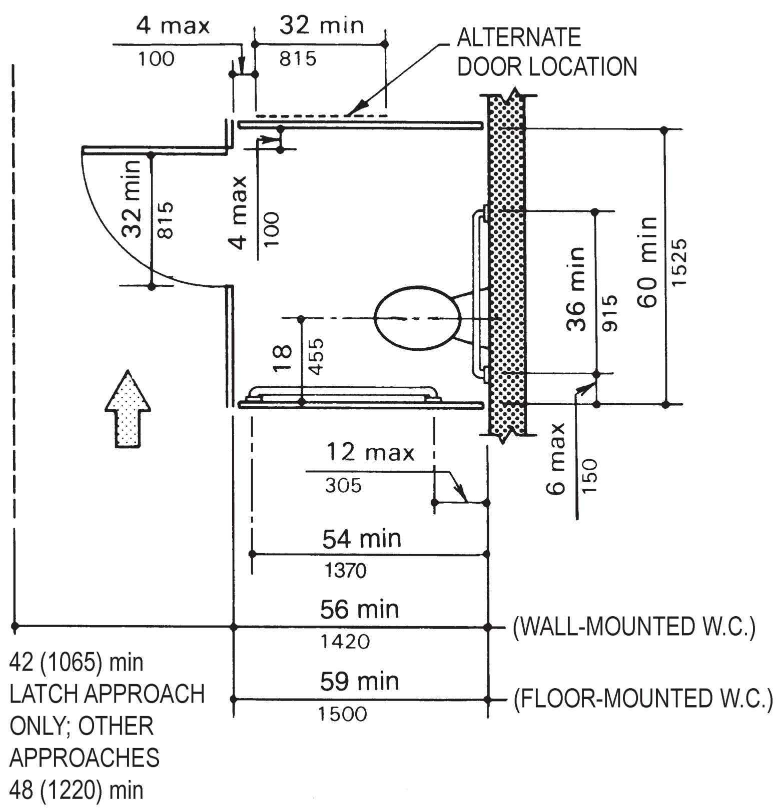

Figure 6-13 Wheelchair Accessible Toilet Stalls — Door Swing Out

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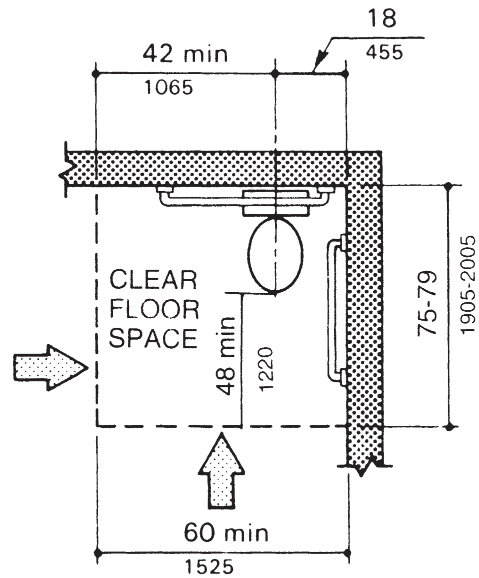

Figure 6-14 Clear Floor Space at Water Closets

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mounted water closets, measured perpendicular to the rear wall. (See Figure 6-13-B4.18.3.1.)

604.8.1.2 Doors Compartment doors shall not swing into the minimum required compartment area. (See Figure 6-17-B4.18.3.2.)

604.8.1.3 Approach Compartment arrangements shall be permitted for left-hand or right-hand approach to the water closet.

604.8.1.4 Toe clearance In wheelchair-accessible compartments, the front partition and at least one side partition shall provide a toe clearance complying with 306.2 and extending 6 inches (150 mm) deep beyond the compartment-side face of the partition, exclusive of partition support members.[2] Toe clearance at the front of the partition is not required in a compartment greater than 62 inches

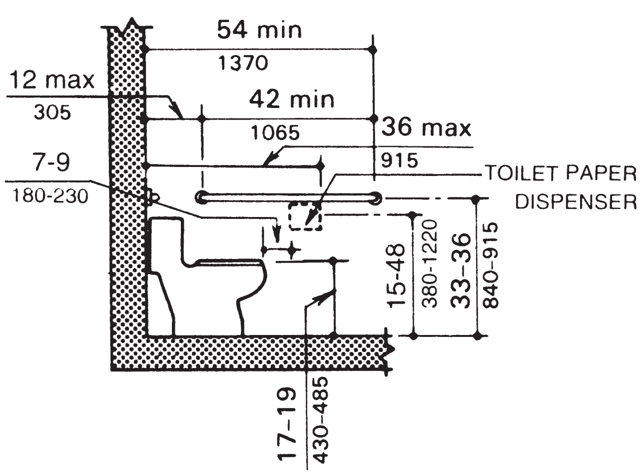

Figure 6-15 Water Closet — Side View

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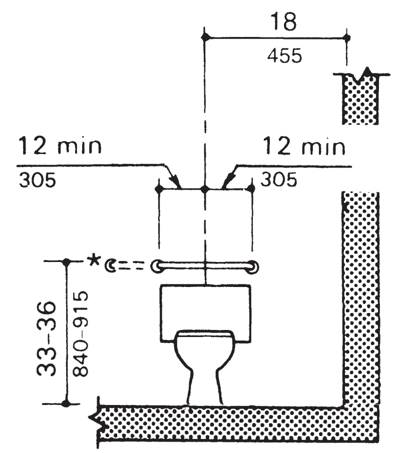
(1575 mm) deep with a wall-hung water closet or 65 inches (1650 mm) deep with a floor-mounted water closet. Toe clearance at the side partition is not required in a compartment greater than 66 inches (1675 mm) wide.

604.8.2 Ambulatory-accessible compartments Ambulatory-accessible compartments shall be 60 inches (1525 mm) deep minimum and 36 inches (915 mm) wide. Compartment doors shall not swing into the minimum required compartment area. (See Figure 6-12-B4.18.4.)

604.8.3 Doors Toilet compartment doors shall comply with 404, except that if the approach is to the latch side of the compartment door, the clearance between the door side of the compartment and any obstruction shall be 42 inches (1065 mm) minimum. The door shall be hinged 4 inches (100 mm) maximum from the adjacent wall or partition farthest from the water closet. The door shall be self-closing. A door



* Where space permits, extend grab bar on transfer side.

Figure 6-16 Water Closet — Front View

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pull complying with 404.2.7 shall be placed on both sides of the door near the latch.[2]

604.8.4 Grab bars Grab bars shall comply with 609.

604.8.4.1 Wheelchair-accessible compartments A side-wall grab bar complying with 604.5.1 shall be provided on the wall closest to the water closet, and a rear-wall grab bar complying with 604.5.2 shall be provided. (See Figure 6-13-B4.18.3.1.)

604.8.4.2 Ambulatory-accessible compartments A side-wall grab bar complying with 604.5.1 shall be provided on both sides of the compartment. (See Figure 6-12-B4.18.4.)

604.8.5 Coat hooks and shelves Coat hooks provided within toilet compartments shall be 48 inches

(1220 mm) maximum above the floor or ground. Where provided, a fold-down shelf shall be 40 inches (1015 mm) minimum and 48 inches (1220 mm) maximum above the floor or ground.

Water closets and toilet compartments note:

The centerline requirement for water closets has been adjusted to allow a range of 16 to 18 inches (407 to 457 mm) from the centerline of the fixture to the side wall, eliminating the fixed 18 inches (457 mm) dimensional requirement. Code enforcement officials in the field have successfully argued this change on the merits of allowing some flexibility. The greater or lesser accessibility of a water closet installed 16 inches (407 mm) from the side wall to the centerline of the toilet versus a water closet installed 18 inches (457 mm) from the side wall has yet to be answered to a majority of either committee.

The toilet seat height of 17 to 19 inches (432 to 483 mm) in public areas is intended to minimize the difference between the seat and the standard wheelchair seat height to aid the transfer process, without elevating the toilet seat to the point that stability problems are created.

The 60 inches (1525 mm) wide wheelchair-accessible compartment is preferred and should be designed. In the design of alterations to existing structures, it may not be possible to create the preferred compartment by combining two existing compartments, or physical conditions may not permit the full 60 inches (1525 mm) width. In these cases, the authority having jurisdiction may permit a narrower compartment. In no case should a width of less than 48 inches (1220 mm) be used.

The needs of a semi-ambulatory user are best served by a narrower, 36 inches max. (915 mm max.), compartment which premises use of grab bars on either or both sides of the compartment.

ADAAG note:

ADAAG has an exception to the height requirement of water closets and grab bars for water closets located in a toilet room for a single occupant, accessed only through a private office and not for common or public use. Where six (6) or more compartments are provided in a toilet room, one (1) must be a 60 inch (1525 mm) wheelchair-accessible compartment, and one (1) must be a 36 inch (915 mm) ambulatory compartment.

The flush valve handles should not exceed 44 inches (1118 mm) above the floor. The handles in standard accessible stalls must be at the wide side of the stall (ADAAG section 4.16.5). This means, depending on how the stall is configured, the handle must be on either the right or left side of the flush valve. This does not apply to tank-type units, although several manufacturers have now come up with a right-hand operator.

605 Urinals

605.1 General Accessible urinals shall comply with 605.

605.2 Height Urinals shall be of the stall type or shall be of the wall-hung type with the rim at 17 inches (430 mm) maximum above the floor or ground.

605.3 Clear floor or ground space A clear floor or ground space complying with 305 positioned for forward approach shall be provided.[2]

605.4 Flush controls Flush controls shall be hand operated or automatic. Hand-operated flush controls shall comply with 309.[2]

Urinal note:

It should be understood that the referenced urinal is not intended to be used by a wheelchair occupant for the normal urination process. It is intended for the drainage of bladder bags, a function normally performed in a water closet compartment, if available. Where an accessible urinal is required, it can serve as a child's urinal. Urinals must be provided with an elongated rim (ADAAG section 4.18.2). Although ADAAG does not define what constitutes an elongated urinal, the Department of Justice deferred to ANSI, which defines these fixtures as having a lip that protrudes a minimum of 14 in. (356 mm) from

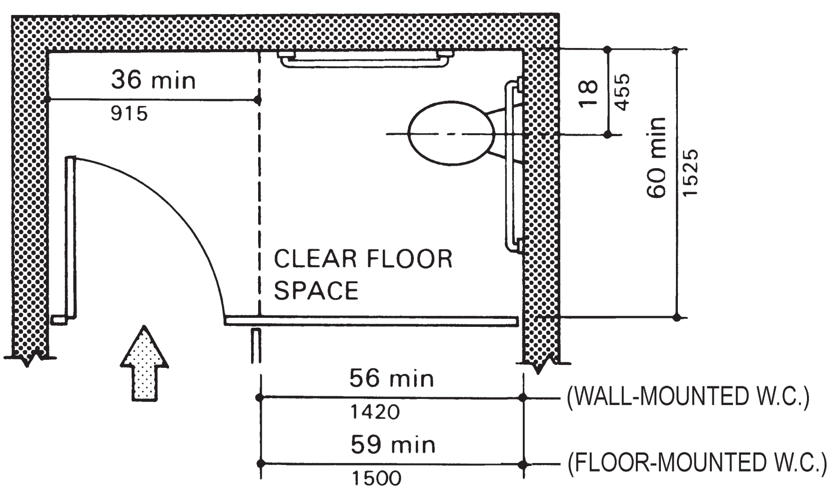

Figure 6-17 Wheelchair Accessible Toilet Stalls — Door Swing In

Source: CABO/ANSI A117.1-1992, Reprinted with permission *the wall. Flush valve handles should not exceed 48 inches (1220 mm) above the floor.*

606 Lavatories and Sinks

606.1 General Accessible lavatories and sinks shall comply with 606.

606.2 Clear floor or ground space A clear floor or ground space complying with 305.3, positioned for forward approach, shall be provided. Knee and toe clearance complying with 306 shall be provided.[2] (See Figure 6-18-B4.20.3.2.)

EXCEPTIONS:

1. A parallel approach shall be permitted to a kitchen sink in a space where a cook-top or conventional range is not provided.
2. The dip of the overflow shall not be considered in determining knee and toe clearances.

606.3 Height and clearances The front of lavatories and sinks shall be 34 inches (865 mm) maximum above the floor or ground, measured to the higher of the fixture rim or counter surface.

606.4 Faucets Faucets shall comply with 309.[2] Hand-operated, self-closing faucets shall remain open for 10 seconds minimum.

606.5 Bowl depth Sinks shall be 6½ inches (165 mm) deep maximum. Multiple-compartment sinks shall have at least one compartment complying with this requirement.

606.6 Exposed pipes and surfaces Water supply and drain pipes under lavatories and sinks shall be insulated or otherwise configured to protect against contact. (See Figure 6-11-B4.20.3.1.) There shall be no sharp or abrasive surfaces under lavatories and sinks.

Lavatories and sinks note:

Conventional slab-type lavatories are available to meet the dimensional requirements of A117.1, since the dip of the overflow can be ignored.

Built-in lavatories in countertops should be placed as close as possible to the front edge of the countertop to minimize the reach to the faucet. Single-lever faucets are preferred, but where aesthetics or fear of vandalism precludes their use, conventional quarter-turn handles are a good choice. Avoid faucets that require finger dexterity for grasping or twisting.

Both hot and cold water pipes, as well as drain pipes that are in the vicinity of the designated clear floor space under the fixture, must be concealed or insulated to protect wheelchair users who have no functioning sensory nerves. Insulation is not required on pipes beyond possible contact.

607 Bathtubs

607.1 General Accessible bathtubs shall comply with 607.

607.2 Clearance Clearance in front of bathtubs shall extend the length of the bathtub and shall be 30 inches (760 mm) wide minimum. A lavatory complying with 606 shall be permitted at the foot end of the clearance. (See Figure 6-19-B4.21.2.) Where a permanent seat is provided at the head end of the bathtub, the clearance shall extend a minimum of 15 inches (380 mm) beyond the wall at the head end of the bathtub.

607.3 Seat A permanent seat at the head end of the bathtub or a removable in-tub seat shall be provided. Seats shall comply with 610.

607.4 Grab bars Grab bars shall comply with 607.4 and 609.

607.4.1 Bathtubs with permanent seats For bathtubs with permanent seats, grab bars complying with 607.4.1.1 and 607.4.1.2 shall be provided.

607.4.1.1 Back wall Two grab bars shall be provided on the back wall, one complying with 609.4 and the other 9 inches (230 mm) above the rim of the bathtub. Each grab bar shall be 15 inches (380 mm) maximum from the head-end wall and 12 inches (305 mm) maximum from the foot-end wall.

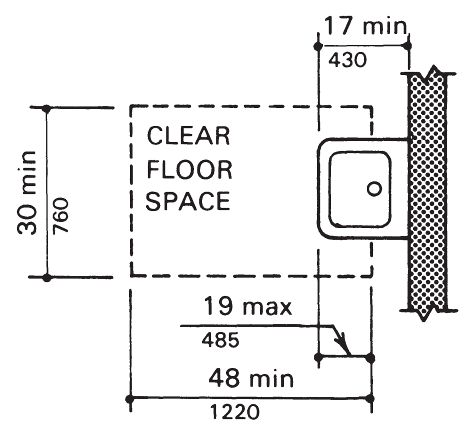

Figure 6-18 Clear Floor Space at Lavatories and Sinks

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607.4.1.2 Foot-end wall A grab bar 24 inches (610 mm) long minimum shall be provided on the foot-end wall at the front edge of the bathtub.

607.4.2 Bathtubs without permanent seats For bathtubs without permanent seats, grab bars complying with 607.4.2.1 through 607.4.2.3 shall be provided.

607.4.2.1 Back wall Two grab bars shall be provided on the back wall, one complying with 609.4 and the other 9 inches (230 mm) above the rim of the bathtub. Each grab bar shall be 24 inches (610 mm) long minimum and shall be 24 inches (610 mm) maximum from the head-end wall and 12 inches (305 mm) maximum from the foot-end wall.

607.4.2.2 Foot-end wall A grab bar 24 inches (610 mm) long minimum shall be provided on the foot-end wall at the front edge of the bathtub.

607.4.2.3 Head-end wall A grab bar 12 inches (305 mm) long minimum shall be provided on the head-end wall at the front edge of the bathtub.

607.5 Controls Controls, other than drain stoppers, shall be on an end wall. Controls shall be between the bathtub rim and grab bar, and between the open side of the bathtub and the midpoint of the width of the bathtub. Controls shall comply with 309.4.[2] (See Figure 6-20-B4.21.4.)

607.6 Shower unit A shower spray unit shall be provided, with a hose 59 inches (1500 mm) long minimum, that can be used as a fixed shower head and as a hand-held shower. If an adjustable-height shower head on a vertical bar is used, the bar shall not obstruct the use of grab bars.

607.7 Bathtub enclosures Bathtub enclosures shall not obstruct controls or transfer from wheelchairs onto bathtub seats or into bathtubs. Bathtub enclosures shall not have tracks on the rim of the bathtub.

Bathtub note:

A fixed seat at the head of the tub adds safety and convenience for transfer purposes, as does the 17 to 19 inches (432 to 483 mm) rim height. The rim height that is more in line with the tub seat does not require the use of a deeper tub; it is better to use a tub with a deeper apron or use a tile filler.

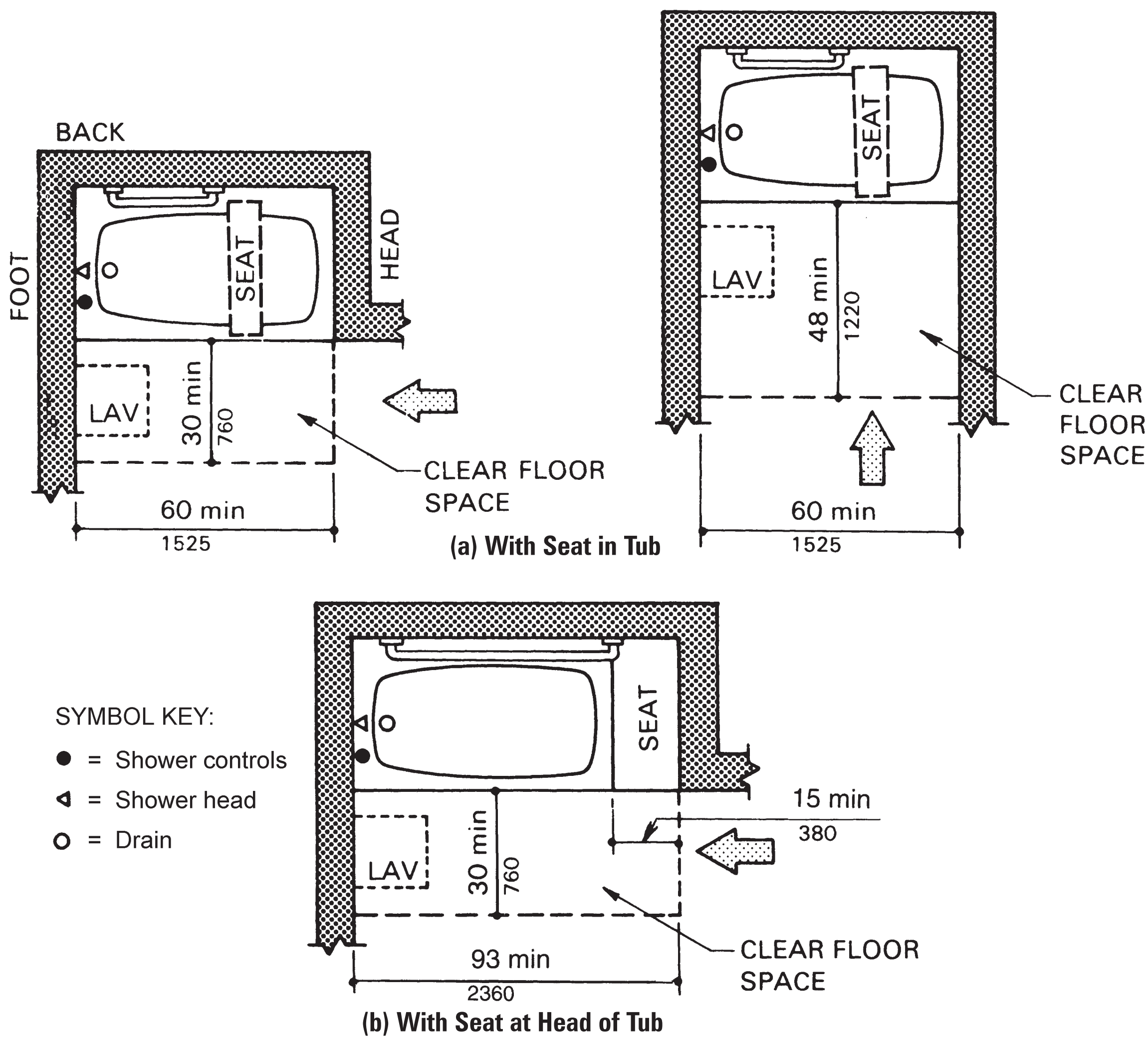

Figure 6-19 Clear Floor Space at Bathtubs

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Due to the probable lack of maneuverability of the user, it is recommended that the plumbing engineer specify a temperature and/or pressure-balanced, water-blending valve with temperature-limit stops.

608 Shower Compartments

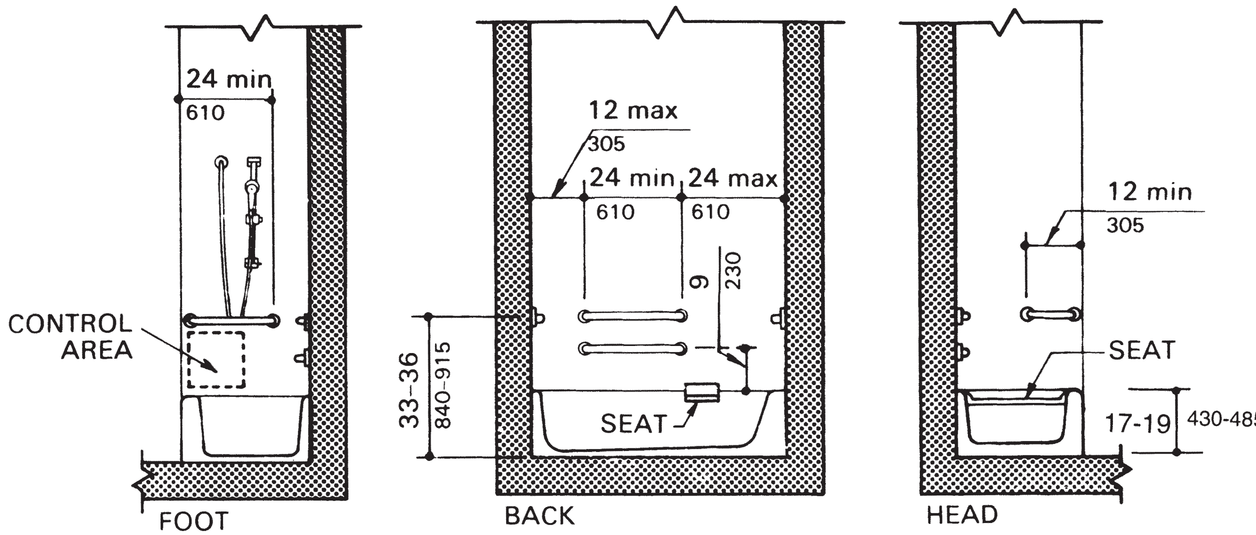
608.1 General Accessible shower compartments shall comply with 608.

608.2 Size and clearances

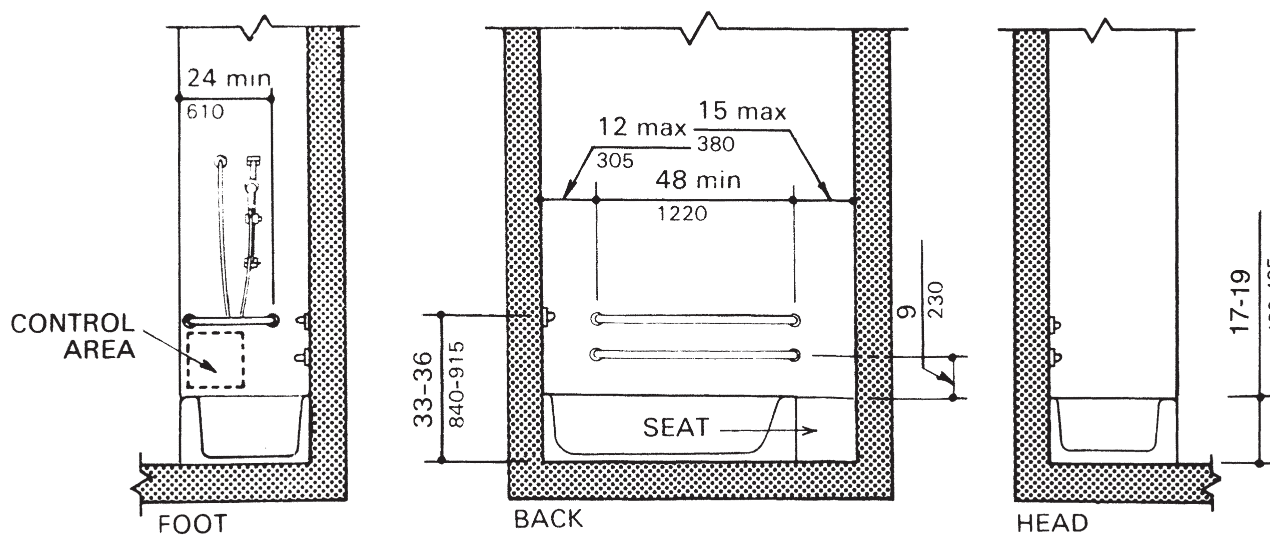
608.2.1 Transfer-type shower compartments Transfer-type shower compartments shall be 36 inches (915 mm) wide by 36 inches (915 mm) deep inside finished dimension, measured at the centerpoint of opposing sides, and shall have a minimum 36 inches (915 mm) wide entry on the face of the shower compartment. The clearance in front of the compartment shall be 48 inches (1220 mm) long minimum measured from the control wall and 36 inches (915 mm) wide minimum. (See Figure 6-21-B4.22.2.1.)

608.2.2 Standard roll-in type shower compartments Roll-in type shower compartments shall be 30 inches (760 mm) wide minimum by 60 inches (1525 mm) deep minimum, clear inside dimension, measured at the centerpoint of opposing sides and shall have a minimum 60 inches (1220 mm) wide entry on the face of the shower. A 30 inches (760 mm) wide minimum by 60 inches (1525 mm) long minimum clearance shall be provided adjacent to the open face of the shower compartment. A lavatory complying with 606 shall be permitted at the end of the clear space, opposite the shower-compartment side where shower controls are positioned. (See Figure 6-22-B4.22.2.2.)

608.2.3 Alternate roll-in type shower compartments Alternate roll-in shower compartments shall



(a) Without Permanent Seat in Tub



(b) With Permanent Seat at Head of Tub

Figure 6-20 Bathtub Accessories

Source: CABO/ANSI A117.1-1992, Reprinted with permission be 36 inches (915 mm) wide and 60 inches (1220 mm) deep minimum. A 36 inches (915 mm) wide minimum entry shall be provided at one end of the long side of the compartment. The shower unit and controls shall be mounted on the end wall farthest from the compartment entry.

608.3 Grab bars Grab bars shall comply with 608.3 and 609 and shall be provided.

608.3.1 Transfer-type showers Grab bars shall be provided across the control wall and on the back wall to a point 18 inches (455 mm) from the control wall. (See Figure 6-23A-B4.22.4A.)

608.3.2 Roll-in type showers Grab bars shall be provided on the three walls of the shower. (See Figure 6-23B-B4.22.4B.) Grab bars shall be 6 inches (150 mm) maximum from the adjacent wall.

EXCEPTIONS:

1. Where a seat is provided in a roll-in shower, grab bars shall not extend over the seat at the control wall and shall not be behind the seat.
2. In alternate roll-in type showers, grab bars shall not be required on the sidewall opposite the control wall and shall not be behind the seat.

608.4 Seats An attachable or integral seat shall be provided in transfer-type shower compartments. Seats shall comply with 610.

608.5 Controls Shower or bathtub/shower facilities shall deliver water that is thermal-shock protected to 120°F (49°C) maximum. Faucets and controls shall comply with 309.4.[2] Controls in roll-in showers shall be above the grab bar but no higher than 48 inches (1220 mm) above the shower floor. (See Figure 6-23B-B4.22.4B.) In transfer type shower compartments, controls, faucets, and the shower unit shall be on the side wall opposite the seat 38 inches (965 mm) minimum and 48 inches (1220 mm) maximum above the shower floor. (See Figure 6-23A-B4.22.4A.)

608.6 Shower unit A shower spray unit shall be provided, with a hose 59 inches (1500 mm) long minimum, that can be used as a fixed shower head and as a hand-held shower. In transfer-type showers, the controls and shower unit shall be on the control wall within 15 inches (380 mm), left or right, of the centerline of the seat. In roll-in type showers, shower spray units mounted on the back wall shall be 27 inches (685 mm) maximum from the side wall. If an adjustable-height shower head mounted on a vertical bar is used, the bar shall not obstruct the use of grab bars.

608.7 Thresholds Shower compartment thresholds shall be ½ inches (13 mm) high maximum and shall comply with 303.[2]

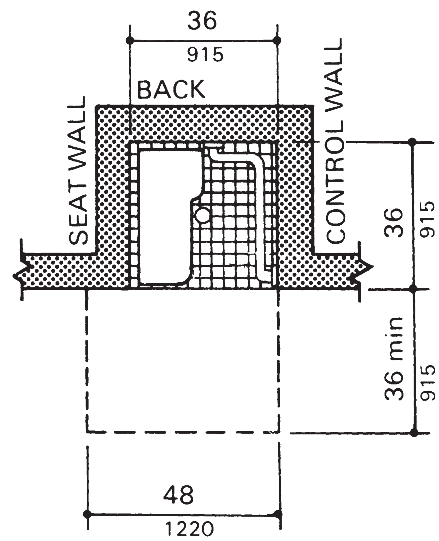


Figure 6-21 Transfer Type Shower Stall
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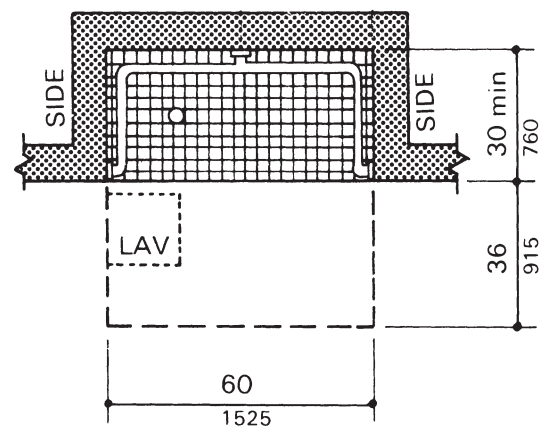

Figure 6-22 Roll-in Type Shower Stall
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608.8 Shower enclosures Shower compartment enclosures for shower compartments shall not obstruct controls or obstruct transfer from wheelchairs onto shower seats.

Shower compartments note:

The recommended shower compartments are for independent use by an individual. Compartments between the two recommended sizes do not effectively serve people with disabilities who wish to use a shower without assistance.

Transfer-type shower compartments that are 36 inches by 36 inches (915 mm by 915 mm) provide additional safety to people who have difficulty maintaining balance because all grab bars and walls are within easy reach. Seated people use the walls of these showers for back support.

The shower compartment with inside finish dimensions of 36 inches by 36 inches (915 mm by 915 mm) has been designated a transfer-type compartment to indicate that wheelchair users can transfer from their chair to the required seat. These dimensions will allow a person of average size to reach and operate the controls without difficulty, while providing reasonable knee space for larger users. A transfer-type shower is also intended to serve persons without disabilities so a folding seat would provide more space for a standing person. Temperature may be limited to 105 to 110°F (40.5 to 43°C), depending on local code requirements.

609 Grab Bars

609.1 General Grab bars in accessible toilet or bathing facilities shall comply with 609.

609.2 Size Grab bars shall have a circular cross section with a diameter of 1¼ in. (32 mm) minimum and 2 inches (51 mm) maximum, or shall provide equivalent grasp ability complying with 505.7.1.[2]

609.2.1 Noncircular cross sections Grab bars with other shapes shall be permitted, provided they have a perimeter dimension of 4 inches (100 mm) minimum and 4.8 inches (160 mm) maximum and edges having an 8 inches (3.2 mm) minimum radius.

609.3 Spacing The space between the wall and the grab bar shall be 1½ inches (38 mm). The space between the grab bar and objects below and at the ends shall be 1½ inches (38 mm) minimum. The space between the grab bar and projecting objects above shall be 15 inches (355 mm) minimum. (See Figure 6-24-B4.24.2.1.)

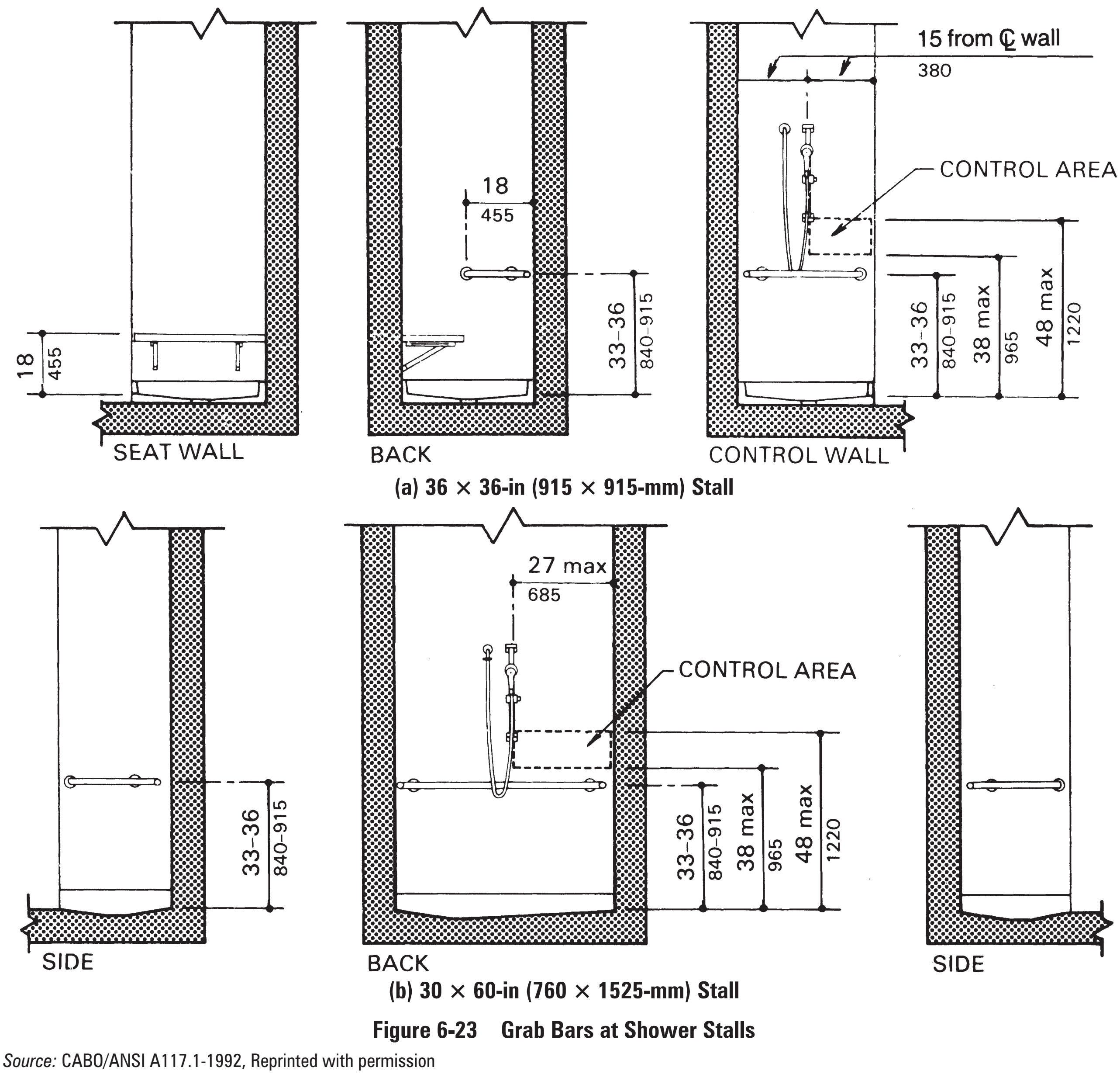

Figure 6-23 Grab Bars at Shower Stalls

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Note: Figure 6-23b: Shower head and control area may be on back wall (as shown) or on either side wall.

EXCEPTION: The space between the grab bars and shower controls, shower fittings, and other grab bars above shall be 1½ inches (38 mm) minimum.

609.4 Position of grab bars Grab bars shall be mounted in a horizontal position, 33 inches (840 mm) minimum and 36 inches (915 mm) maximum above the floor.

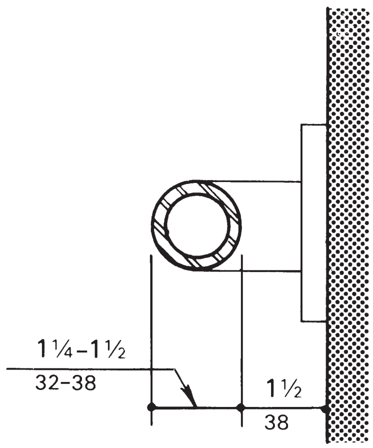

Figure 6-24 Size and Spacing of Grab Bars

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EXCEPTION: Height of grab bars on the back wall of a bathtub shall comply with 607.4.1.1 and 607.4.2.1.

609.5 Surface hazards Grab bars and any wall or other surfaces adjacent to grab bars shall be free of sharp or abrasive elements. Edges shall have a radius of 8 inches (3 mm) minimum.

609.6 Fittings Grab bars shall not rotate within their fittings.

609.7 Installation Grab bars shall be installed in any manner that provides a gripping surface at the locations specified in this standard and that does not obstruct the clear floor space.

609.8 Structural strength Allowable stresses in bending, shear, and tension shall not be exceeded for materials used where a vertical or horizontal force of 250 pounds (113.5 kg) is applied at any point on the grab bar, fastener mounting device, or supporting structure.

Grab bars note:

Many people with disabilities rely heavily upon grab bars to maintain balance and prevent serious falls. Many people brace their forearms between supports and walls to give them more leverage and stability in maintaining balance or for lifting. The grab bars clearance of 1½ inches (38 mm) required in this standard is a safety clearance to prevent injuries from arms slipping through the opening. This clearance also provides a minimum space for gripping.

Grab bars that are wall mounted do not affect the measurement of required clear floor space where the space below the grab bar is clear and does not present a knee space encroachment.

610 Seats

610.1 General Seats in accessible bathtubs and shower compartments shall comply with 610.

610.2 Bathtub seats A removable in-tub seat shall be 15 inches (380 mm) minimum and 16 inches (405 mm) deep maximum, and shall be capable of secure placement. A permanent seat shall be 15 inches (380 mm) deep minimum and be positioned at the head end of the bathtub. The top of the seat shall be 17 inches (430 mm) minimum and 19 inches (485 mm) maximum above the bathroom floor.

610.3 Shower compartment seats Where a seat is provided in a roll-in shower compartment, it shall be a folding type and shall be on the wall adjacent to the controls. Seats shall be L-shaped or rectangular. The top of the seat shall be 17 inches (430 mm) minimum and 19 inches (485 mm) maximum above the bathroom floor. In a transfer-type shower, the seat shall extend from the back wall to a point within 3 inches (75 mm) of the compartment entry. In a roll-in type shower, the seat shall extend from the control wall to a point within 3 inches (75 mm) of the minimum required seat wall width.

610.3.1 Rectangular seats The rear edge of a rectangular seat shall be 2½ inches (64 mm) maximum from the seat wall, and the front edge 15 inches (380 mm) minimum and 16 inches (405 mm) maximum from the seat wall. In a transfer-type shower, the side edge of a rectangular seat shall be 1½ inches (38 mm) maximum. In a roll-in type shower, the side edge of a rectangular seat shall be 1½ inches (38 mm) maximum from the control wall.

610.3.2 L-shaped seats The rear edge of an L-shaped seat shall be 2½ in. (64 mm) maximum from the seat wall, and the front edge 15 inches (380 mm) minimum and 16 inches (405 mm) maximum from the seat wall. The rear edge of the "L" portion of the seat shall be 1½ inches (38 mm) maximum from the wall and the front edge shall be 14 inches (355 mm) minimum and 15 inches. (380 mm) maximum from the wall. The end of the "L" shall be 22 inches (560 mm) minimum and 23 inches (585 mm) maximum from the main seat wall. (See Figure 6-25-B4.22.3.)

610.4 Structural strength Allowable stresses in bending, shear, and tension shall not be exceeded for materials used where a vertical or horizontal force of

250 lb (113.5 kg) is applied at any point on the seat, fastener mounting device, or supporting structure.

Seats note:

The seat in a shower is required to be nearly the full depth of the compartment; it should be as close to the front edge of the seat wall as possible to minimize the distance between the seat and the wheelchair so as to facilitate a transfer. The seat wall must be free of grab bars to allow a person to slide onto the seat, and a portion of the adjacent back wall must be without a grab bar so the person's back can be placed against the walls for support.

611 Laundry Equipment

611.2 Clear floor or ground space A clear floor or ground space complying with 305 positioned for parallel approach shall be provided. The clear floor or ground space shall be centered on the appliance.[2]

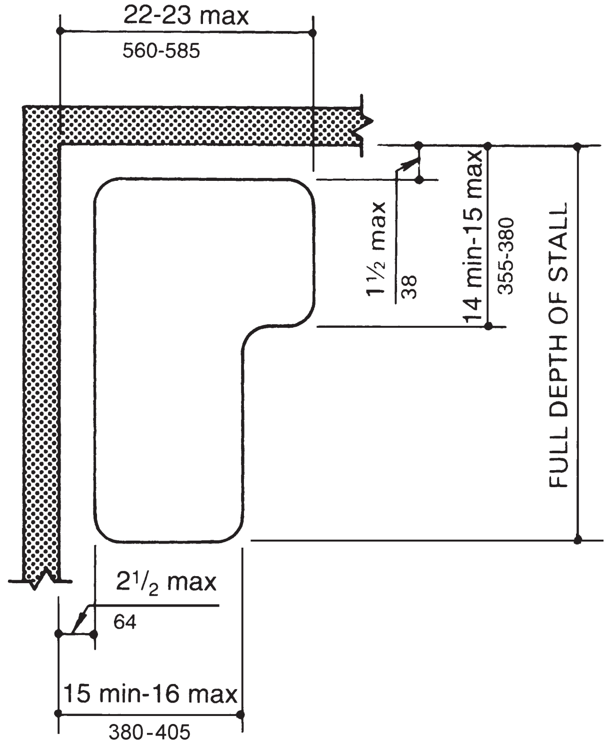

Figure 6-25 Shower Seat Design

Source: CABO/ANSI A117.1-1992, Reprinted with permission

611.3 Operable parts Operable parts, including doors, lint screens, detergent and bleach compartments, shall comply with 309.[2]

611.4 Height Top-loading machines shall have the door to the laundry compartment 34 inches (865 mm) maximum above the floor or ground. Front-loading machines shall have the bottom of the opening to the laundry compartment 15 inches (380 mm) minimum and 34 inches (865 mm) maximum above the floor or ground.

REFERENCES

1. ADAAG Review Federal Advisory Committee. September 30, 1996. Recommendations for a new ADAAG.

2. Council of American Building Officials (CABO)/ International Code Council, Inc. 1998 [1992]. CABO/ANSI A117.1, Accessible and usable buildings and facilities. Falls Church, Va.

7 Energy and Resource Conservation in Plumbing Systems

INTRODUCTION

Prior to the 1973-1974 OPEC oil embargo, energy was considered inexhaustible and expendable. As energy costs grew, society turned its attention toward energy conservation. The Energy Policy and Conservation Act (EPCA) of 1975 was the first major piece of legislation that addressed federal energy management. Additional laws soon followed such as: The Resource Conservation and Recovery Act of 1976, the National Energy Conservation Policy Act of 1978, the Federal Energy Management Improvement Act (FEMIA) of 1988, and the Energy Policy Act (EPACT) of 1992 that expanded upon the EPCA of 1975. Along with the federal government, other sectors of society made strides to reduce energy consumption. The automotive industry, which was heavily impacted by the oil embargo, was quick to adapt by producing smaller, lighter, more fuel-efficient cars. The construction market also made strides by adopting model energy codes, efficiency standards, and alternate fuel sources. One of the highest energy-consuming plumbing systems is domestic hot water, often consuming 2 percent to 4 percent of the total energy used in an office building and 8 percent of residential properties. This plumbing system has a great need for energy-conservation measures.

Just as important as energy conservation is resource conservation. A resource greatly affected by plumbing-system design is water management. Water use in the United States has more than doubled in the past half-century from approximately 180 billion gallons per day in 1950 to more than 400 billion gallons a day in 1995. It has been determined that 39 percent of water use in commercial buildings is for domestic purposes. It is important to note that by reducing hot water use both energy and water is conserved.

This chapter is intended to provide a plumbing engineer with design techniques that conserve both energy and water and assist them in selecting energy and water-efficient equipment and systems. Where the recommendations set forth in this chapter do not meet the minimum provisions of the local code, the code shall apply.

DOMESTIC HOT WATER SYSTEM ENERGY CONSERVATION

Design Techniques

Hot water use can vary from hand washing, showering, and janitorial needs, to cooking, dishwashing, and laundering needs. Design techniques that can be employed to conserve energy when creating hot water are:

1. Eliminate Leaks
2. Reduce Domestic Hot Water Temperature
3. Reduce Fixture Flow Rates
4. Apply Economical Thermal Insulation
5. Limit Water-Heater and Circulation-Pump Operation
6. Consume Off-Peak Power
7. Upgrade to More Efficient Equipment
8. Water Heater Location

1. *Eliminate Leaks*
   One of the first and easiest actions to take to conserve energy is repairing leaky faucets and hot water piping. This will reduce the amount of hot water being wasted and avoid more expensive repairs later due to faucet valve-stem and valve-seat corrosion and water damage from leaky piping.
2. *Reduce Domestic Hot Water Temperature*
   Many domestic water-heating systems are designed to deliver 140°F water based on the anticipated needs of kitchen and janitorial uses, though water for human contact is normally delivered at 105°F. Often 105°F water is produced by blending 140°F hot water with cold water (see ASPE's Plumbing Engineering Design Handbook Chapter *"Domestic Water Heating*

System Fundamentals"). While this reduces the amount of hot water required it does not decrease the energy required to heat the water. Many energy codes and standards for new buildings require the domestic hot water system be set at 110°F under the impression that this will automatically reduce energy in direct proportion to the reduced temperature differential (delta T). It is important to note that setting a water heater below 120°F to avoid blending may allow Legionella bacteria to grow inside the domestic hot water tank. Also, if the building is provided with a kitchen dishwasher requiring 180°F water, a booster heater will need to be sized carefully to adequately function at the increased delta T. This is due to the reduction of the building domestic water-system temperature.

The temperature, after mixing two or more volumes (or flows) of water is calculated using the following equation:

Equation 7-1

$$t_m = \frac{Q_1 \times t_1 + Q_2 \times t_2}{Q_1 + Q_2}$$

where:

t_m = Temperature of mixture
t_1 = Temperature of flow Q_1
t_2 = Temperature of flow Q_2
Q_1 = Cold water, gpm (L/s)
Q_2 = Hot water, gpm (L/s)

Example 7-1

What is the temperature of 45 gpm (2.84 L/s) of 155°F (68.5°C) water mixed with 55 gpm (3.47 L/s) of 75°F (23.9°C) water?

$$\frac{45 \times 155 + 55 \times 75}{45 + 55} = 111°\text{F}$$

in SI units:

$$\left(\frac{2.84 \times 68.5 + 3.47 \times 23.9}{2.84 + 3.47} = 44°\text{C}\right)$$

The ratio (%) of hot water required to be mixed with cold water to provide a mixed water requirement is determined using the following equation:

Equation 7-2

$$\text{Ratio HW} = \frac{t_m - t_1}{t_2 - t_1}$$

Example 7-2

(A) How much hot water is required to provide 80 gph (0.084 L/s) of 110°F (43°C) mixed water with 155°F (68.5°C) hot water and 75°F (23.9°C) cold water?

$$\frac{110 - 75}{155 - 75} = .44 \text{ or } 44\% \text{ hot water}$$

80 gph × 0.44 = 35 gph of 155°F hot water

(0.084 L/s × 0.44 = 0.037 L/s of 68.5°C hot water)

(B) How much hot water is required to provide 80 gph (0.084 L/s) of 110°F (43°C) mixed water with 125°F (51.5°C) hot water and 75°F (23.9°C) cold water?

$$\frac{110 - 75}{125 - 75} = .70 \text{ or } 70\% \text{ hot water}$$

80 gph × 0.70 = 56 gph of 125°F hot water

(0.084 L/s × 0.70 = 0.059 L/s of 51.5°C hot water)

As shown, the reduction in domestic-water temperature, in itself, does not necessarily result in a reduction in energy input related to the water consumed.

3. *Reduce Fixture Flow Rates*

The Energy Policy Act (EPACT) of 1992 set maximum water usages for specific fixtures (e.g. 1.6 gallons per flush for water closets). Reduced flow rates result in less water needing to be pumped and heated, smaller pipe sizes, and less heat loss from piping, consequently saving energy. Fixture flow rates vary depending upon the supply fitting design and water pressure. Manufacturers' test results have shown that flows for lavatories and showers can be quite high, making them prime candidates for fixture-flow reduction. Providing automatic flow-control fittings can reduce fixture flow rates. On lavatories the type of faucet and spout usually dictates the location of these fittings. In showers, the type of head and arm determines the fitting location. After being fitted with a flow-control device, reduced flow rates of one gallon per minute or less are usually seen in lavatories and 3 gallons per minute or less for showers.

Figure 7-1 provides a way to translate fixture flow rate to annual consumption and is useful in determining the most energy efficient design flow rate. By varying the percent of hot water at the fixture, annual energy consumption can be predicted.

Example 7-3

Faucet use at 3.25 gal (12.3 L) of 150°F (66°C) hot water per day with a 100% faucet flow rate equates to an annual energy use of 800×10^3 Btu (844×10^3 kJ) per year. A 67% flow rate reduces energy use to 475×10^3 Btu (507×10^3 kJ) per year, and a 33% flow rate reduces energy use to 225×10^3 Btu (237.4×10^3 kJ) per year or a 62% reduction from full faucet flow rate.

Figure 7-1 can be used as a design tool for many purposes, some of which are to predict energy consumption, anticipated utility costs, and payback calculations for fixture replacement.

Manufacturers of flow-control devices describe in greater detail their design and installation requirements. The installation of this water-

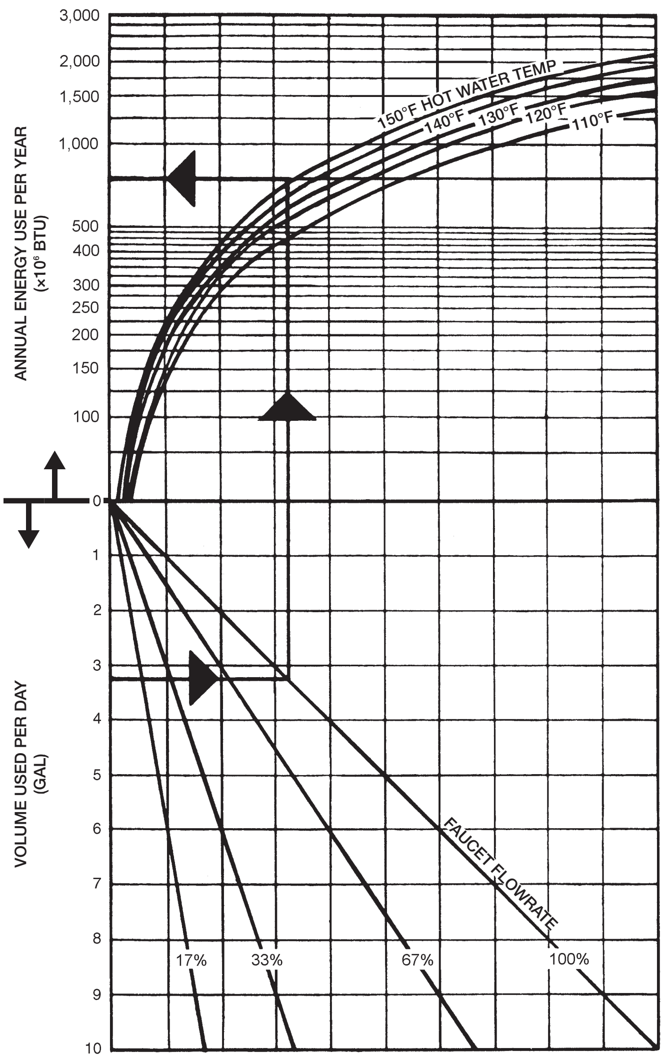

Chart allows user to estimate domestic hot water heating use in terms of water temperature and faucet flow rate.

Figure 7-1 Energy Savings from Reduced Faucet Flow Rates

Source: Cassidy 1982.

conserving device has resulted in the savings of millions of gallons of water per year throughout the country. This reduction in water demand translates into water the local utility company does not have to pump, the purification plant does not have to handle and process, and the waste-treatment plant does not have to treat.

4. *Apply Economical Thermal Insulation*
Economical thermal insulation is the amount of insulation that annually produces the lowest sum of energy lost versus the annual cost of insulation (see the *"Piping Insulation"* chapter of ASPE's Plumbing Engineering Design Handbook for the proper selection criteria). In addition to conserving energy by retarding heat loss, insulation provides such additional benefits as protection against burns, reduction of noise, and control of condensation. The National Insulation Contractors' Association (NICA) is currently using and promoting a computer program called "Economic Thickness of Insulation" (ETI). This program determines the cost-effective insulation thickness for a project and allows the designer to factor in the effects of rising utility costs.

Energy savings, in BTUs, can be determined by the following formula:

Equation 7-3

$$S = g \times L$$

where:

S = Energy savings, Btu/h (kJ/h)
g = Factors taken from Table 7-1 or 7-2 at a particular ΔT, Btu/h/ft (kJ/h/m)
L = System length, ft (m)

Hot water pipes should be continuously insulated from the heater to the end use, while cold water lines should be insulated near the water heater tank to minimize convective losses.

5. *Limit Water-Heater and Circulation-Pump Operation*
Buildings with large hot water distribution systems use circulating loops to ensure hot water is available to all fixtures within a timely manner. By limiting the hours of operation of these pumps and water heaters, substantial savings can be realized. There are 113 hours of "off" time per week in a building if it is occupied 50 hours per week, and the system is brought up to operating temperature one hour prior to the building opening each day. Assuming the domestic hot water system can be shut off for 113 hours per week and the system contains 2,000 gallons of hot water, Table 7-3 indicates the energy saved by limiting the hours of circulation. However, if a fossil-fuel water heater is used, one must take into account the formation of condensation when the system is brought up to temperature.

Table 7-3 The Effect of Stopping Circulation

Operating Temperature, °F (°C)	Piping Insulation Thickness, in. (mm)	Energy Conserved, Btu/yr (kJ/yr)
140 (60)	½ (12.7)	1428×10^6 (1506.5×10^6)
125 (51.5)	½ (12.7)	1153×10^6 (1216×10^6)
110 (43)	½ (12.7)	824×10^6 (869.3×10^6)
140 (60)	1 (25.4)	934×10^6 (985.4×10^6)
125 (51.5)	1 (25.4)	714×10^6 (753.3×10^6)
110 (43)	1 (25.4)	522×10^6 (550.7×10^6)

Time clocks can be used to control the hot water circulating pumps. The energy saved when using time clocks can be calculated as follows:

Table 7-1 Energy Savings Chart for Steel Hot Water Pipes and Tanks

ΔT °F (°C)	Pipe Size, in. (mm)							Hot Water Tanks, Btu/h/ft² (kJ/h/m²)	
	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	w/ Insulation	w/o Insulation
40 (4.4)	14 (48.44)	17 (58.8)	21 (72.7)	26 (90.0)	29 (100.3)	35 (121.1)	42 (145.3)	6 (68.1)	57 (647.3)
45 (7.2)	16 (55.36)	20 (69.2)	24 (83.0)	30 (103.8)	33 (114.2)	41 (141.9)	48 (166.1)	6 (68.1)	65 (738.2)
50 (10.0)	18 (62.28)	22 (76.1)	27 (93.4)	34 (117.6)	38 (131.5)	47 (162.6)	55 (190.3)	7 (79.5)	73 (829.1)
55 (12.8)	20 (69.20)	25 (86.5)	31 (107.3)	38 (131.5)	42 (145.3)	52 (179.9)	62 (214.5)	7 (79.5)	83 (942.6)
60 (13.6)	23 (79.58)	28 (96.9)	35 (121.1)	42 (145.3)	48 (166.1)	58 (200.7)	69 (238.7)	9 (102.2)	92 (1044.8)
65 (18.3)	25 (86.50)	31 (107.3)	38 (131.5)	47 (162.6)	53 (183.4)	65 (224.9)	77 (266.4)	9 (102.2)	102 (1158.4)
70 (21.1)	28 (96.88)	34 (117.6)	42 (145.3)	52 (179.9)	58 (200.7)	71 (245.7)	84 (290.6)	10 (113.6)	112 (1272.0)
75 (23.9)	30 (103.8)	36 (124.6)	46 (159.2)	56 (193.8)	64 (221.4)	78 (269.9)	91 (314.9)	11 (124.9)	122 (1385.6)
80 (26.7)	33 (114.2)	41 (141.9)	50 (173.0)	61 (211.1)	69 (238.7)	84 (290.6)	99 (342.5)	11 (124.9)	132 (1499.1)
85 (28.4)	36 (124.6)	44 (152.2)	54 (186.8)	67 (231.8)	74 (256.0)	91 (314.9)	107 (370.2)	12 (136.3)	142 (1612.7)
90 (32.2)	38 (131.5)	47 (162.6)	58 (200.7)	72 (249.1)	80 (276.8)	98 (339.1)	116 (401.4)	12 (136.3)	154 (1749.0)
95 (35.0)	42 (145.3)	51 (176.5)	62 (214.5)	77 (266.4)	86 (297.6)	105 (363.3)	124 (429.0)	14 (159.0)	164 (1862.5)
100 (37.8)	45 (155.7)	54 (186.8)	66 (228.4)	82 (283.7)	93 (321.8)	113 (391.0)	133 (460.2)	14 (159.0)	175 (1987.5)
105 (38)	47 (162.6)	58 (200.7)	72 (249.1)	87 (301.0)	98 (339.1)	120 (415.2)	141 (487.9)	15 (170.4)	187 (2123.8)
110 (43)	51 (176.5)	62 (214.5)	75 (259.5)	93 (321.8)	104 (359.8)	128 (442.9)	150 (519)	16 (181.7)	198 (2248.7)
115 (46)	54 (186.8)	65 (224.9)	80 (276.8)	98 (339.1)	110 (380.6)	135 (467.1)	159 (550.1)	16 (181.7)	210 (2385.0)
120 (49)	56 (193.8)	69 (238.7)	85 (294.1)	104 (359.8)	117 (404.8)	143 (494.8)	169 (584.7)	17 (193.1)	222 (2521.3)

Source: San Diego Gas & Electric Co.

Notes:

1. Savings are in Btu/h/linear ft. (kJ/h/linear m), unless otherwise indicated.
2. Figures are based on an assumption of 1 in. (25.4 mm) of insulation.
3. $\Delta T = t_o - t_a$ where t_o = Hot water circulating temperature and t_a = Air temperature surrounding piping system.

Table 7-2 Energy Savings Chart for Copper Hot Water Pipes

ΔT °F (°C)	Pipe Size, in. (mm)							
	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	3 (76.2)
40 (4.4)	8 (27.68)	12 (41.5)	14 (48.4)	17 (58.8)	20 (69.2)	25 (86.5)	30 (103.8)	35 (121.1)
45 (7.2)	10 (34.6)	13 (45.0)	16 (55.5)	20 (69.2)	23 (79.6)	29 (100.3)	35 (121.1)	40 (138.4)
50 (10.0)	12 (41.5)	15 (51.9)	19 (65.7)	23 (79.6)	26 (90.0)	33 (114.2)	40 (138.4)	46 (159.2)
55 (12.8)	13 (45.0)	17 (58.8)	21 (72.7)	26 (90.0)	30 (103.8)	38 (131.5)	45 (155.7)	52 (179.9)
60 (13.6)	15 (51.9)	20 (69.2)	24 (83.0)	29 (100.3)	34 (117.6)	42 (145.3)	51 (176.5)	58 (200.7)
65 (18.3)	16 (55.4)	21 (72.7)	27 (93.4)	32 (110.7)	37 (128.0)	47 (162.6)	56 (193.8)	65 (224.9)
70 (21.1)	18 (62.3)	24 (83.0)	30 (103.8)	35 (121.1)	41 (141.9)	52 (180.0)	62 (214.5)	71 (245.7)
75 (23.9)	20 (69.2)	26 (90.0)	33 (114.2)	39 (134.9)	44 (152.2)	56 (193.8)	67 (231.8)	76 (263.0)
80 (26.7)	21 (72.7)	28 (96.7)	35 (121.1)	42 (145.3)	49 (169.5)	61 (211.1)	73 (252.6)	85 (294.1)
85 (29.4)	22 (76.1)	31 (107.3)	38 (131.5)	45 (155.7)	53 (183.4)	66 (228.4)	79 (273.3)	92 (318.3)
90 (32.2)	24 (83.0)	33 (114.2)	41 (141.9)	49 (169.5)	57 (197.2)	71 (245.7)	85 (294.1)	99 (342.5)
95 (35.0)	26 (90.0)	36 (124.6)	44 (152.2)	53 (183.4)	61 (211.1)	76 (263.0)	91 (314.9)	106 (366.7)
100 (37.8)	28 (96.7)	38 (131.5)	48 (166.1)	57 (197.2)	65 (224.9)	82 (283.7)	98 (339.1)	113 (391.0)
105 (38)	30 (103.8)	41 (141.9)	51 (176.5)	60 (207.6)	70 (242.2)	87 (301.0)	104 (359.8)	121 (418.7)
110 (43)	32 (110.7)	43 (148.8)	54 (186.8)	65 (224.9)	74 (256.0)	93 (321.8)	111 (384.1)	128 (442.9)
115 (46)	34 (117.6)	46 (159.2)	57 (197.2)	68 (235.3)	78 (269.9)	98 (339.1)	118 (408.3)	136 (470.6)
120 (49)	36 (124.6)	49 (169.5)	61 (211.1)	72 (249.1)	83 (287.2)	104 (359.8)	125 (432.5)	144 (498.2)

Source: San Diego Gas & Electric Co.

Notes:

1. Savings are in Btu/h/linear ft (kJ/h/linear m).
2. Figures are based on an assumption of 1 in. (25.4 mm) of insulation.
3. $\Delta T = t_o - t_a$ where t_o = Hot water circulating temperature and t_a = Air temperature surrounding piping system.

Equation 7-4

$$\text{Motor kW} \times \text{off hours} \times \text{electric rate (\$/kWh)} = \text{total savings (\$)}$$

6. *Consume Off-Peak Power*

   One of a plumbing engineer's responsibilities is to size the domestic water-heating equipment to meet the needs of the building's occupants in the most energy efficient manner. While using off-peak power to heat and circulate water does not change the number of British thermal units (Btu) required, it does allow the building's owner and tenants to benefit from lower utility costs. Power companies encourage their commercial customers to purchase power during off peak hours in hopes of flattening or evening out the demand on their generating equipment. Some utility companies not only offer lower rates for electricity purchased during off- and semi-peak periods but in many instances have no customer demand charges. The plumbing engineer can obtain electric-rate schedules from the utility serving the site and observe the off-peak periods to program the operation of domestic water-heating equipment. Typically the highest demand for hot water takes place when electrical costs are at their peak. To account for this, the hot water system will maintain the heated water at an elevated temperature, which is blended to achieve the desired temperature levels, saving the system from having to operate during the day. Depending upon the difference in electrical rates, an off-peak powered hot water system can generally pay (in a few years) for the additional equipment required, including the effects of equipment heat losses during periods of standby.

7. *Upgrade to More Efficient Equipment*
   Equipment specifications need to be examined to ensure only hot water heating equipment that meets minimum energy standards is approved for installation. The following factors contribute to the efficiency of gas-fired water heaters and need to be taken into consideration when selecting this equipment: Combustion equipment and its adjustment, tank insulation, heat exchanger effectiveness, firing rate, pickup and demand, and standby stack losses.

8. *Water Heater Location*
   Many hot water heaters are installed in central locations requiring long supply and return piping runs to reach plumbing fixtures. Moving these heaters close to the most-frequent points of use will minimize piping heat loss.

Domestic Hot Water Heating Equipment

There are many different means of generating hot water. Each has its own advantages and disadvantages, and, as plumbing engineers, it is our responsibility to determine which technology is best suited for an application. In addition, the performance efficiency of equipment specified by the plumbing engineer should match the recommendations of the *Domestic Water Heating System Fundamentals* chapter of the "ASPE Plumbing Engineering Design Handbook". The recovery efficiency and standby losses of water-heating equipment should comply with the latest codes and regulations for the manufacturer, e.g. American National Standards Institute (ANSI) C72.1, ANSI Z22.10.3, latest editions. State energy codes also mandate the use of energy-efficient equipment and should be checked by the plumbing engineer prior to the preparation of specifications. Listed below are several hot water heating technologies.

1. Tank-Type Water Heaters
   A. Electric
   B. Gas-Fired
2. Tankless-Type Water Heaters
   A. Electric
   B. Gas-Fired
   C. Condensing
   D. Steam-Fired
   E. Direct-Fired
3. Alternative Resources
   A. Solar Energy
   B. Solid-Waste-Disposal Energy
   C. Geothermal Energy
4. Heat Recovery
   A. Air Conditioning and Commercial Refrigeration
   B Steam Condensate
   C. Cogeneration Plants
   D. Heat Pumps
   E. Drainline Heat Reclaim Systems

1. *Tank-Type Water Heaters*
   Tank-type water heaters are self-contained units that heat and store water within the same storage tank. Insulation is added around the exterior of the tank to prevent heat from escaping. Many older tank-type water heaters were originally supplied with insufficient insulation. Making it energy efficient consisted of either replacing the insulation or the entire unit.

   A. Electric
   The heating element for electric tank-type water heaters is immersed directly into the water, allowing energy to transfer from the element to the water fast and efficiently. They can be used for many applications ranging from commercial and industrial to booster heaters for dishwashing needs.

   B. Gas-Fired
   A gas-fired tank-type water heater uses natural or propane gas to heat stored water. Unlike an electric heater, there are standby losses associated with the heater's flue, which carries the unit's products of combustion to the atmosphere. The flue is internal to the heater and not insulated, acting as a heat exchanger, allowing energy to escape from the heated water.

2. *Tankless-Type Water Heaters*
   Tankless-type water heaters, as their name suggests, do not store water. They are instantaneous heaters that provide hot water only when there is a demand. Because they have no water storage capability, these units eliminate standby heat loss and may reduce the risk of Legionella bacteria growth.

   A. Electric
   Electric tankless-type water heaters consume large amounts of energy when operating. This has relegated their use to remote areas with

low fixture counts and infrequent use. They are usually installed near the point of use to minimize pipe heat loss.

B. *Gas-Fired*
These heaters can be found in commercial, industrial, and residential applications. They have been gaining popularity among new construction and retrofitting of residential properties in warmer climate areas such as California, Florida, Tennessee, and Texas, where the incoming water temperatures are high. There are various models that can produce anywhere from 4 to 10 gallons per minute of hot water at a temperature rise of 77°F. They also can be combined to provide higher flow rates and temperature increases. Similar to electric tankless heaters, these units are typically installed near the point of use but are not recommended for remote areas with low fixture counts that are infrequently used. These applications are better left for the electric type because of the cost associated with the routing of gas piping and its flue.

C. *Condensing*
Condensing gas water heaters recover the heat created by the combustion gases. The recovered heat is referred to as the latent heat of vaporization and is directed back into the water, increasing the unit's efficiency. A condensing water heater operates at approximately 95 percent efficiency compared to 80 percent – 85 percent for a non-condensing water heater. The condensate generated from a condensing unit needs to be drained, but care must be taken to account for its acidic nature. With a pH rating of approximately 5, the condensate is either diluted until it reaches an acceptable pH range or drained to a neutralization tank.

D *Steam-Fired*
Steam-fired tankless-type water heaters generate hot water through the use of a heat exchanger. They are used in hospitals, industrial plants, restaurants, apartment houses, laundries, universities, and hotels among other applications. They can be combined in parallel to meet high flow requirements while requiring less space than comparable tank-type units. The installation of a mixing valve is recommended to ensure that steam does not enter the hot water system in the event of a heat-exchanger breach.

E. *Direct-Fired*
Gas-fired heaters are used in applications where several hundred gallons of hot water are needed per minute. These units use a direct exchange between the water and combustion products produced by the burner assembly. This process eliminates standby losses and can achieve operating efficiencies in excess of 98 percent.

3. *Alternative Resources*
As the consumption of fossil fuels increases so does the need to develop alternative fuel sources. One of these sources is solar energy. Energy from the sun can be converted to operate cars, power lighting, and heat domestic water. Other forms of alternative energy are geothermal and solid wastes, which have been used to heat water while reducing the load placed on mainstream resources. The designer may choose to use alternative energy resources for all or part of the hot water system. This helps to meet restrictions placed upon the domestic water heating systems by energy codes in many parts of the country.

A. *Solar Energy*
Solar water heating is often thought of for warm and sunny climates only; however, an the climate in an area is one of many factors that determine the effectiveness of a solar system. Factors such as the cost of the fuels being replaced, hot water demand, usage patterns, and incoming water temperature help determine the effectiveness of a solar heating system. For most areas of the United States, solar heating can meet the domestic hot water demand during the summer months but often require supplemental heating during the winter. It has been estimated that a solar heating system can meet 40 percent to 80 percent of a building's annual hot water demand. Refer to ASPE's "*Solar Energy System Design*" manual as a source of information in the use and selection of solar heating equipment.

B. *Solid-Waste-Disposal Energy*
Solid-waste collection and disposal systems produce various gases during decomposition. One of these is methane. It can be recovered and burned to produce heat. A second source of methane is leachate evaporation systems in landfill closures. Lastly, solid-waste incineration systems constructed to stringent pollution-control rules and regulations are a source of methane. These systems can potentially provide large volumes of steam and/or domestic hot water. The use of these

alternate energy sources should be within reasonable proximity to the resource. Typical applications include industrial plants with large volumes of burnable materials such as trash, paper, scrap wood, plastics, etc. A solid-waste incinerator system typically consists of a waste-disposal plant with a conveyer, loading system, boiler, ash-disposal equipment, heat exchanger, insulated piping, circulating pump, and controls.

C. *Geothermal Energy*

Geothermal energy is heat from the earth. In states where this form of energy is believed to be available at reasonable depths, the U.S. Department of Energy (DOE) is supporting various state energy commissions in their funding of geothermal assessment programs. The temperature of the available liquid or gas (created when water flows through heated, permeable rock) and the cost of retrieval dictate the viability of geothermal energy. Some geothermal energy uses include steam in the generation of electricity, hot water with a minimum temperature of 150°F for building domestic hot water systems, and industrial parks for space and water heating needs. Three prime areas of concern must be addressed when planning and developing geothermal energy:

1. Competitive Institutional Processes
2. Adequate Temperature and Flow Rate
3. Thermal Loads To Make the System Economically Viable

A geothermal energy system typically consists of production and disposal wells, water-to-water heat exchangers [usually shell-and-tube type, two are required—one for operation while the other is being cleaned of deposits], insulated piping, a circulating pump, and a control system. The plumbing engineer should consult with the state energy office (Department of Energy or the Geothermal Resources Council) for resource information to apply this high-capital, low-operating-cost, alternate energy source.

4. *Heat Recovery*

Heat recovery is the capture and reuse of energy that would normally be lost from a facility. It could be in the form of a liquid or a gas. Common waste heat sources are:

1. Heat rejected from air conditioning and commercial refrigeration processes
2. Heat reclaimed from steam condensate
3. Heat generated by cogeneration plants
4. Heat pumps and heat reclamation systems
5. Heat from wastewater

When considering heat recovery, it is important to determine if the hot water demand justifies the equipment and maintenance costs, and if the heat recovered is sufficient to serve as a heat source. Facilities that typically have the proper blend of demand and waste heat are hospitals, military bases, and industrial facilities.

A. *Air Conditioning and Commercial Refrigeration*

Systems with air- or water-cooled or evaporative condensers reject heat from air conditioning and refrigeration systems that can be reclaimed.

Within the refrigerant cycle there is a condenser that rejects heat while an evaporator creates a cooling effect. For example, for every 1 Btu/h of cooling effect produced by a 40°F evaporator, a 105°F condensing unit rejects 1.15 Btu/h of heat. Systems with an air-cooled or evaporative condensor can be supplemented with a heat exchanger in the compressor's hot gas discharge line to capture the rejected heat. (Refer to Figure 7-2.)

Systems with water-cooled condensers can be supplemented with a heat exchanger in the hot water return line from the condenser to the cooling tower. (Refer to Figure 7-3.) System efficiency can be improved by providing a storage tank with a tube bundle. (Refer to Figure 7-4.)

An advantage of the system shown in Figure 7-4 is that simultaneous use of the domestic water and refrigeration systems does not need to occur for heat recovery. Another advantage of the system shown in Figure 7-4 is when there is an insufficient amount of heat rejected, a backup water heater can be used to bring the water in the storage tank to the proper design temperature. The backup heater can operate on fossil fuel, electricity, steam, or may be fitted with a tube bundle utilizing hot water.

B. *Steam Condensate*

When steam is used as a source for space heating, water heating, or process work there is generally steam condensate. The heat content of the condensate can be captured and reused for heating with the use of a heat exchanger. Laundries are a prime example of facilities where heat reclaimed from steam condensate can be put to use in heat recovery. It is essential to select a system with adequate storage to compensate for fluctuations in

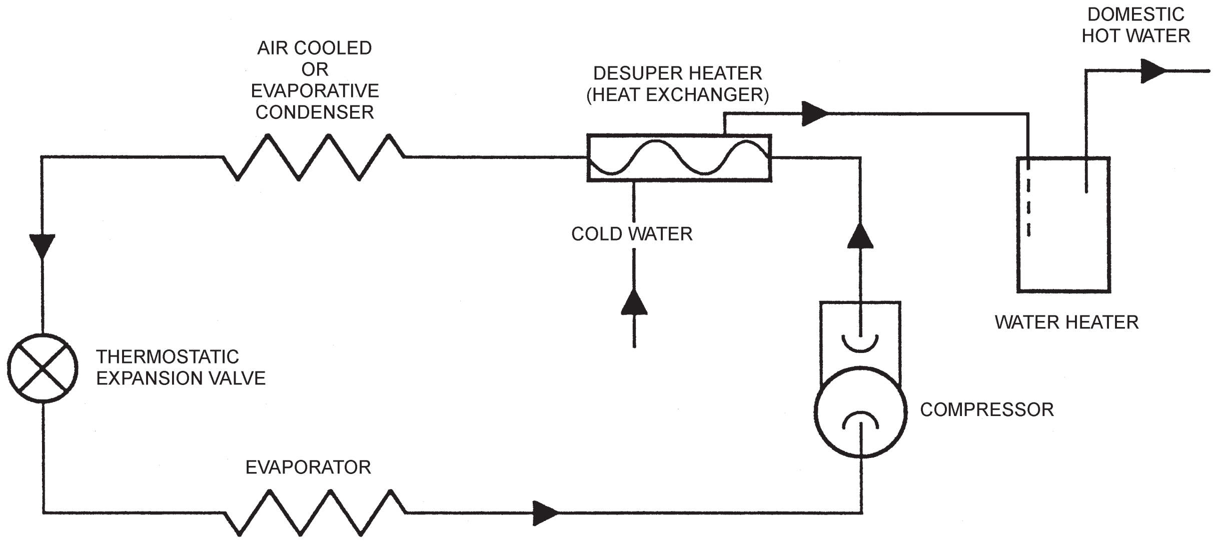

Figure 7-2 Refrigeration Waste-Heat Recovery

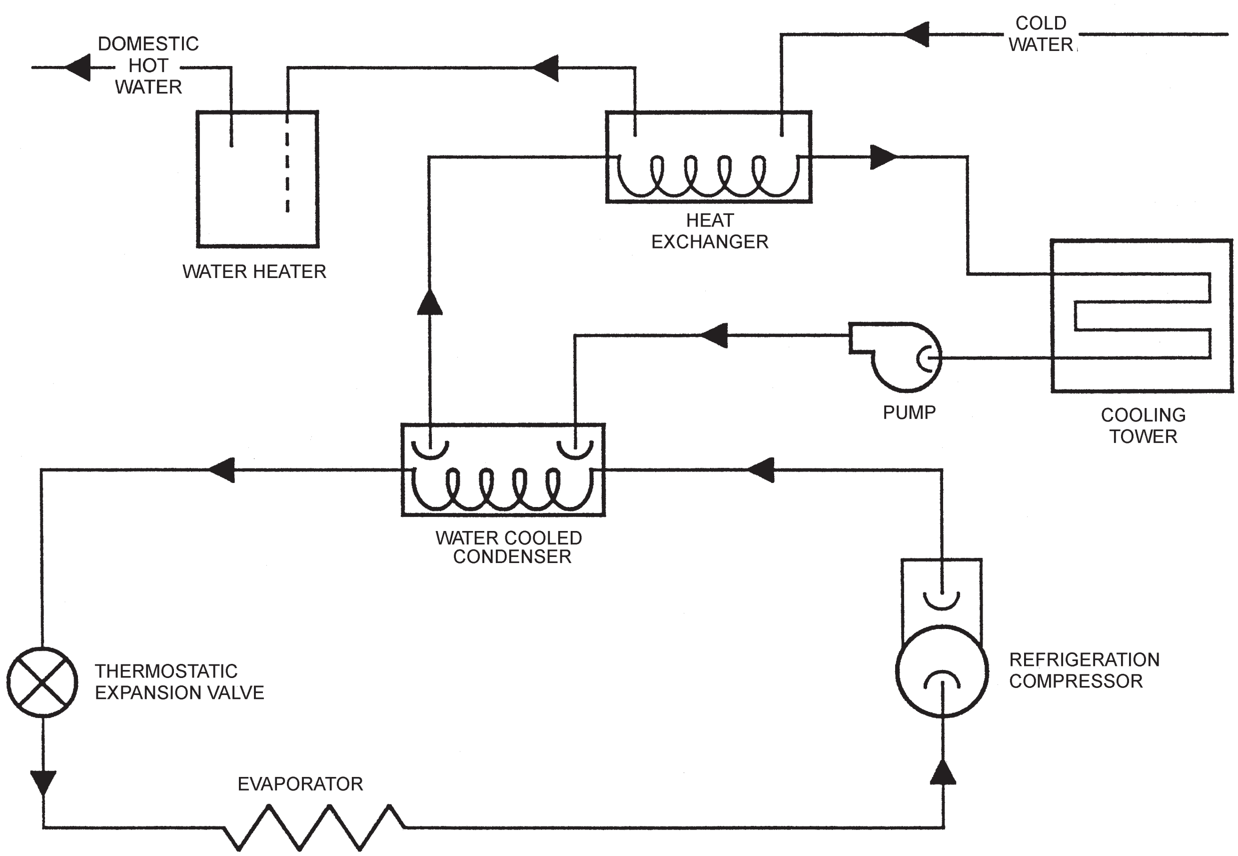

Figure 7-3 Condenser Water Heat Recovery

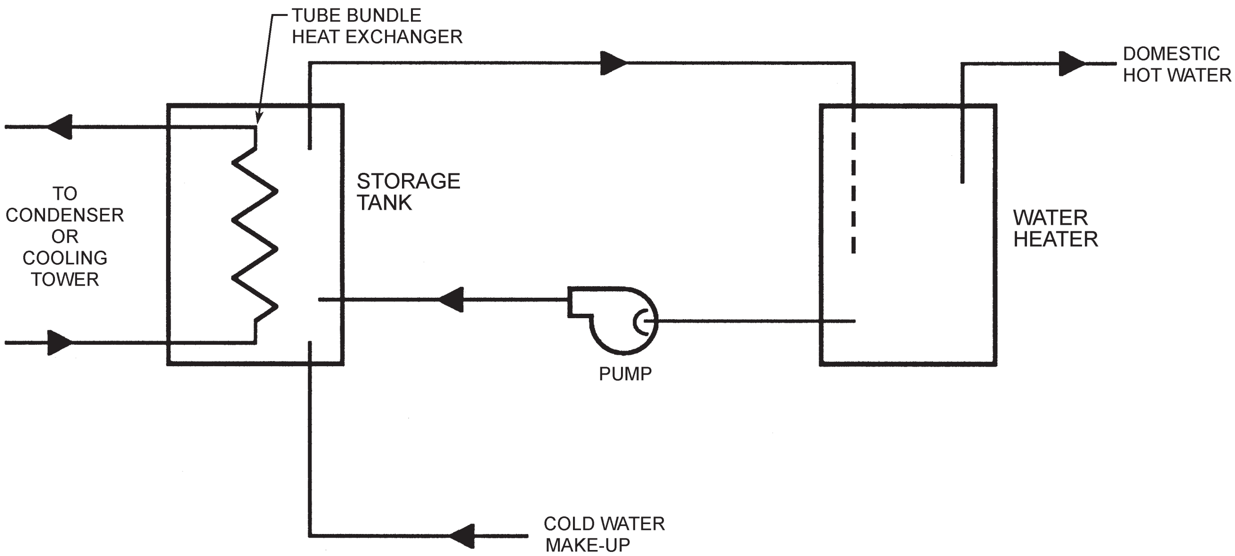

Figure 7-4 Condenser Water Heat Recovery with Storage Tank

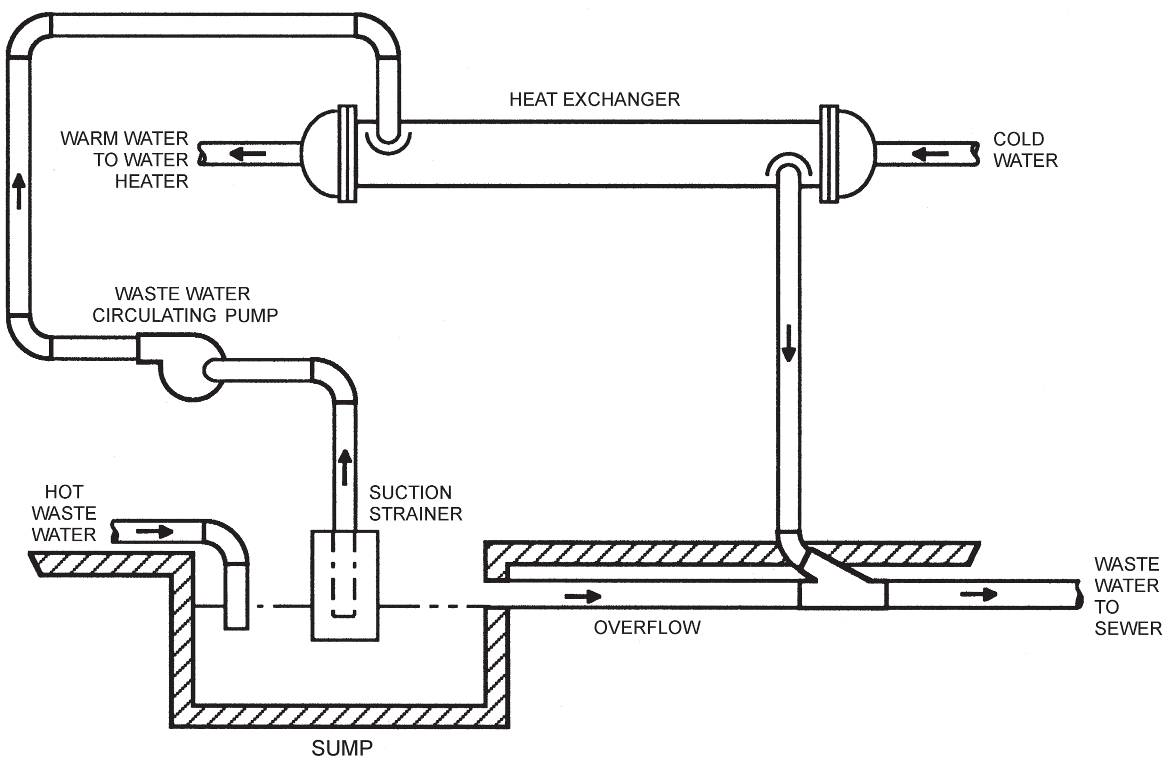

Figure 7-5 Waste Water Heat Recovery

the condensate and domestic water flow. When deciding whether to capture and reuse steam condensate, remember that energy will not be saved if the boiler used to raise the temperature of the returned condensate is less efficient than the primary water heater.

C. *Cogeneration Plants*
The heat produced as a byproduct of generating electricity from reciprocating engines or gas turbines can be reclaimed from the cooling systems and exhaust gases by using a waste heat boiler and heat exchanger. The heat can then be used to produce steam or medium temperature water. To be economically viable, most systems must have a year-round thermal heat load. Reheating makeup water and maintaining temperature in a domestic hot water system are excellent ways to maintain high overall thermal efficiencies.

D. *Heat Pumps*
In today's buildings where computer rooms are continuously generating heat and industrial plants are producing waste heat, heat pumps can be used to transfer this heat to the domestic hot water systems, resulting in energy conservation.

Either direct-expansion or chilled-water-type heat pumps can be used to transfer heat through the refrigeration process from the surrounding air to a water storage tank. The mechanics of this system are to extract heat from a warm environment directly, either through a heat exchanger or cooling coil.

E. *Drainline Heat Reclaim Systems*
It has been estimated that 80 percent to 90 percent of all hot water energy is wasted. The U.S. DOE estimates this amount of energy to be 235 billion kWh a year. One method of recouping some of this energy is using a drainline heat reclaim system. This device can be a passive or active piece of equipment installed in the wastewater drain line of a building. Passive devices use a copper coil wrapped around a vertical portion of a waste line. Domestic water is fed through the copper coil to the hot water heater. As hot water is drained, heat is transferred from the drain line to the incoming domestic water. It has been estimated that these exchangers have an operating efficiency of up to 60 percent and can raise the incoming water temperature by as much as 36°F. Active systems utilize a wastewater circulating pump in conjunction with the heat exchanger. This system is shown in Figure 7-5.

WATER MANAGEMENT

Design Techniques

Conserving water provides benefits to the building's owner and local municipality. The owner saves by having lower utility costs, while the municipality saves resources by having to treat and circulate less water and wastewater. In order to realize these savings, the plumbing engineer must provide designs that reduce water consumption without compromising the fixture's operation. Some design techniques previously mentioned are:

1. Eliminate Faucet and Pipe Leaks
2. Reduce Fixture Flow Rates

Other methods of unique water management are:

3. Alternate Sources of Fresh Water
4. Reclaimed and Graywater

For a water management program to be successful in renovation projects, it is important to first establish the building's current water consumption. The U.S. DOE has developed 8 steps to make a successful water management plan:

1. Gather Information
2. Conduct a Comprehensive Facility Survey
3. Explore and Evaluate Water Management Options
4. Conduct Life Cycle Cost Analysis and Explore Financing Options
5. Develop a Water Management Plan and Work Schedule
6. Inform Building Occupants about Water Management
7. Implement the Water Management Plan
8. Monitor the Water Management Plan

For more information refer to page 135 of the U.S. DOE's *Greening Federal Facilities Guide* second edition.

1. *Eliminate Faucet and Pipe Leaks*
Similar to hot water conservation, this is one of the easiest and first actions that should be taken. Leaks in both the cold and hot water piping should be repaired as well as any leaking faucets. This will reduce the amount of water being wasted and avoid more expensive repairs later.

2. *Reduce Fixture Flow Rates*
Toilets and urinals account for almost half of a typical building's water consumption. Within a group of New York City apartment buildings, 1.3 million toilets were replaced with ultra low flow (ULF) toilets and resulted in a 29 percent

reduction in water consumption. There are many different types of toilets and urinals and each has its own benefits, which will be discussed later in this chapter.

Additional fixtures whose flow rates can be reduced are showers and faucets. In addition to applying flow-restrictor fittings, as previously discussed, metered faucets can be installed which provide water for a pre-determined time and then automatically close. The Americans with Disabilities Act specifies that these faucets must operate for at least 10 seconds.

Electronic sensor controls can be used on toilet and urinal flush valves and faucets. They reduce water consumption and are often used in prisons, military barracks, sporting facilities, and hospitals. Batteries or hard wiring can power these controls. Battery controlled valves and faucets are typically used for renovation projects while new construction is hard wired.

3. *Alternate Sources of Fresh Water*
   Rainwater harvesting is the collection, storage, treatment, and use of rainwater. Harvested water can be used for irrigation, non-potable, and potable uses. A rainwater harvesting system typically starts with a catch area that collects rainwater, usually a building's roof. To ensure potential contaminants and pollutants do not enter the system's storage tank, a wash system is installed which diverts the initial portion of the rainfall away from the storage tank while cleaning the catch area. A screen is usually installed in the catch area to keep out debris. Piping routes the collected rainwater to a storage tank, which can be located indoors, outdoors, aboveground, or underground. It is important to provide a lid on the storage tank to keep light out to discourage algae growth. If the collected water is intended to be the sole source of water for the building, the storage tank should be sized based on a 30-year rainfall event. Water is typically delivered to the building through the use of a domestic water booster pump system, and final water treatment may be needed depending upon the application and quality of water collected.

4. *Reclaimed and Graywater*
   Reclaimed water and graywater collection systems can be used to reduce the amount of domestic water consumed by a building. Wastewater treatment plants provide reclaimed or recycled water to buildings through a second municipal water system where two water lines enter a building. One line is used to deliver potable water for domestic use and a second to provide treated wastewater that can be used for non-potable applications such as landscape irrigation, cooling tower make up, toilet flushing, and fire protection.

   Graywater is typically collected from showers, tubs, lavatories, washing machines, and drinking fountains. It contains a minimal amount of contamination and is reused in certain landscape applications such as subsurface irrigation of lawns, flowers, trees, and shrubs, but should not be used for vegetable gardens because of the potential absorption of cleaning and washing chemicals. Similar to rainwater harvesting, graywater is collected, stored, and filtered prior to use. A graywater storage container should be fitted with overflow protection that is connected to the sanitary sewer system in the event the amount of water collected is more than the amount of water being consumed, a distribution pipe becomes clogged, or collected water is not used in a timely manner. If graywater is stored for extended periods of time it often produces an offensive smell.

Water-Management Equipment

As previously stated, toilets and urinals account for almost half of a typical building's water consumption. The U.S. Environmental Protection Agency (EPA) has determined that 4.8 billion gallons of water are flushed each day. Replacing or retrofitting water closets, urinals, showerheads, and faucets with low flow versions can considerably lower a building's water consumption.

1. *Water Closets and Urinals*
   Ultra low flow (ULF) water closets consume 1.6 gallons per flush (gpf) and are available in three different classifications:
   A. Tank Type
   B. Flush Valve
   C. Specialties

   While the problems associated with ULF toilets when they first became available have been corrected, some low-cost models continue to maintain poor performance.

   A. *Tank Type*
      Water is drained from this water closet by gravity and is most commonly used in residential applications. Prior to ULF models these fixtures consumed 3.5 gpf. A low-cost method of conserving water in these earlier models and in today's ULF is using a refill diverter. When a tank type water closet is flushed, water starts to refill the tank as it is emptying. The time elapsed between the open and closed position of the flapper, allows excess water to flow through the bowl, into

the bowl, and consequently, the drain. While refilling the tank, this water is wasted. A diverter keeps this water in the tank saving one-half to 1 gallon when installed on older toilets and a ¼ gallon on ULF models.

B. Flush Valve
Flush-valve water closets use the building's water pressure to exert a force when operating. They typically require 25 to 40 psig to operate and are most commonly used in commercial buildings. Older, non-ULF models can be retrofitted by adjusting the flush valve, but care must be used to not overly constrain the valve causing it to malfunction. Early closure devices also can be used to cause the flush valve to stop the flow of water sooner than normal, limiting the amount of water discharged.

C. Specialties
Some specialty water closets are pressure-assisted tank-type, dual flush, and composting. Pressure-assist tank-type water closets can be used in applications where it is desired to use a gravity tank-type water closet, but there is a concern about flushing performance. When water conservation beyond ULF is desired, dual flush water closets can be used. These have two flush settings, one for normal operation to flush solids and a second reduced amount for liquids, saving approximately 1 gallon per flush. Composting systems are high capital ventures that require a lot of space and are typically used in unique locations where there is no water supply. They are popular choices in state or county parks, camping facilities, and national parks. Composting toilets are gaining acceptance in other areas of the world for mainstream use in households.

ULF urinals consume 1 gallon per flush, but there are water conservation methods that can go beyond this level. Flush valves that consume a one-half gallon per flush have been employed with success, and waterless urinals that do not consume any water are being used. Waterless urinals use a specially designed trap that uses biodegradable oil. This oil allows waste to pass through while maintaining the trap's seal. Regular maintenance is required to refill the oil, as a small portion of it becomes entrained in the waste when the fixture is used. If routine maintenance is not provided, enough oil could be removed to where it no longer seals the fixture's trap, causing odors to enter the room.

2. Showerheads and Faucets
The 1992 Energy Policy Act set the maximum flow rates for showerheads and faucets at 2.5 gallons per minute. Prior to the Energy Policy Act, showerhead flow rates were between 3 gallons per minute and 7 gallons per minute. Water conserving showerheads incorporate a more narrow spray jet and introduce a greater volume of air when compared to conventional heads. Additional measures that can be taken are temporary stop levers that control the shower valve to reduce or inhibit water flow when used. This feature would be used while a person is soaping or shampooing him or herself. The use of flow restrictors in conventional showerheads is not recommended. They typically restrict the showerhead too much, providing poor water pressure from the head.

Faucets manufactured after 1993 consume no more than 2.5 gallons per minute at 80 psig, meeting the requirements of the 1992 Energy Policy Act. Replacing the faucet's tip with an aerator, which mixes air into the faucet's discharge and reduces its flow rate to 2.5 gpm, can retrofit older faucets, which consume between 3 gallons per minute and 5 gallons per minute. Aerators are typically used in residential faucets and prohibited from health care facilities because of their potential for harboring germs and pathogens. In these applications, low flow tips are used.

GLOSSARY

British thermal unit (Btu) *A heat unit equal to the amount of heat required to raise 1 pound of water 1 degree Fahrenheit.*

Coefficient of performance (COP) *The ratio of the rate of heat removal to the rate of energy input, in consistent units, generally relating to a refrigeration system under designated operating conditions.*

Condenser *A heat exchanger that removes heat from a vapor changing it to its liquid state.*

Delta T (DT) *Temperature differential.*

Domestic-water heating *Supply of hot water for domestic or commercial purposes other than comfort heating.*

Domestic-water heating demand *The maximum design rate of energy withdrawal from a domestic-water heating system in a specified period of time.*

Efficiency, thermal (overall system) *The ratio of useful energy at the point of ultimate use to the energy input.*

Energy *The force required for doing work.*

Energy, nondepletable *Energy derived from incoming solar radiation and phenomena resulting therefrom, including wind, waves, and tides, and lake or pond thermal differences, and energy derived from the internal heat of the earth (geothermal)—including nocturnal thermal exchanges.*

Energy, recovered *A byproduct of energy used in a primary system that would otherwise be wasted from an energy utilization system.*

Heat, latent *The quantity of heat required to effect a change in state.*

Heat, sensible *Heat that results in a temperature change but not a change in state.*

Life-cycle cost *The cost of the equipment over its entire life, including operating and maintenance costs.*

Makeup *Water supplied to a system to replace that lost by blowdown, leakage, evaporation, etc.*

Solar energy source *Source of chemical, thermal, or electrical energy derived from the conversion of incident solar radiation.*

System *An arrangement of components (including controls, accessories, interconnecting means, and terminal elements) by which energy is transformed to perform a specific function.*

Terminal element *The means by which the transformed energy from a system is ultimately delivered.*

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1. Cassidy, Victor M. 1982. Energy saving and the plumbing system. *Specifying Engineering* (February).
2. San Diego Gas & Electric Company. *Commercial Energy Conservation Manual*.
3. U.S. Department of Energy, *Greening Federal Facilities An Energy, Environmental, and Economic Resource. Guide for Federal Facility Managers and Designers* (May 2001)

8 Corrosion

INTRODUCTION

Corrosion is the degradation of a material by its environment. In the case of metals, corrosion is an electrochemical reaction between a metal and its environment. For iron piping, the iron reacts with oxygen to form iron oxide, or rust, which is the basic constituent of the magnetic iron ore (hematite) from which the iron was refined. The many processes necessary to produce iron or steel pipe—from refining through rolling, stamping, and fabricating to finished product—all impart large amounts of energy to the iron. The iron in a finished pipe is in a highly energized state and reacts readily with oxygen in the environment to form rust. Corrosion results from a flow of direct current through an electrolyte (soil or water) from one location on the metal surface to another location on the metal surface. The current flow is caused by a voltage difference between the two locations.

This chapter covers the fundamentals of corrosion as they relate to a building's utility systems, essentially dealing with piping materials for the conveyance of fluids, both liquid and gas. These pipes are installed either under or above ground, thus making the external environment of the pipe earth or air, respectively. The internal environment is the fluid conveyed inside the pipe. There are many environmental conditions that may affect the performance of any given piping material.

FUNDAMENTAL CORROSION CELL

Basic Relations

Corrosion is, in effect, similar to a dry cell. In order for corrosion to occur, there must be four elements, namely: electrolyte, anode, cathode, and a return circuit. The electrolyte is an ionized material, such as earth or water, capable of conducting an electric current.

Figure 8-1 shows the actual corrosion cell. Figure 8-2 (practical case) shows the current flows associated with corrosion:

1. Current flows through electrolyte from the anode to the cathode. It returns to the anode through the return circuit.
2. Corrosion occurs wherever current leaves the metal and enters the electrolyte. The point where current leaves is called the anode. Corrosion, therefore, occurs at the anode.
3. Current is picked up at the cathode. No corrosion occurs here, as the cathode is protected against corrosion (this is the basis of cathodic protection). Polarization (hydrogen film buildup) occurs at the cathode.
4. The flow of the current is caused by a potential (voltage) difference between the anode and the cathode.

Electrochemical Equivalents

Dissimilar metals, when coupled together in a suitable environment, will corrode according to Faraday's law; that is, it will require 26.8 ampere-hours (A-h), or 96,500 coulombs (C), to remove 1 gram-equivalent of the metal. At this rate of attack, the amount of metal that is removed by a current of 1 A flowing for 1 year is shown in Table 8-1.

Table 8-1 Electrochemical Metal Losses of Some Common Metals

Metal	Loss, lb/A-yr (kg/C)
Iron (Fe^{2+})	20.1 (72.4)
Aluminum (Al^{3+})	6.5 (23.4)
Lead (Pb^{2+})	74.5 (268.3)
Copper (Cu^{2+})	45.0 (162.0)
Zinc (Zn^{2+})	23.6 (85.0)
Magnesium (Mg^{2+})	8.8 (31.7)
Nickel (Ni^{2+})	21.1 (76.0)
Tin (Sn^{+})	42.0 (151.2)
Silver (Ag^{+})	77.6 (279.4)
Carbon (C^{4+})	2.2 (7.9)

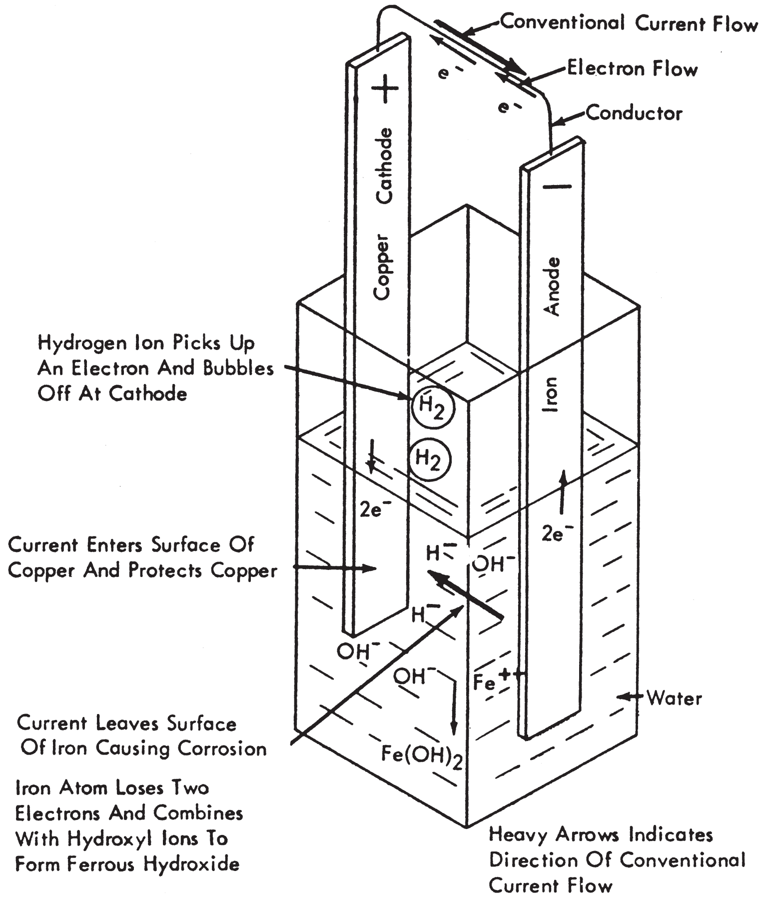


Figure 8-1 Basic Corrosion Cell

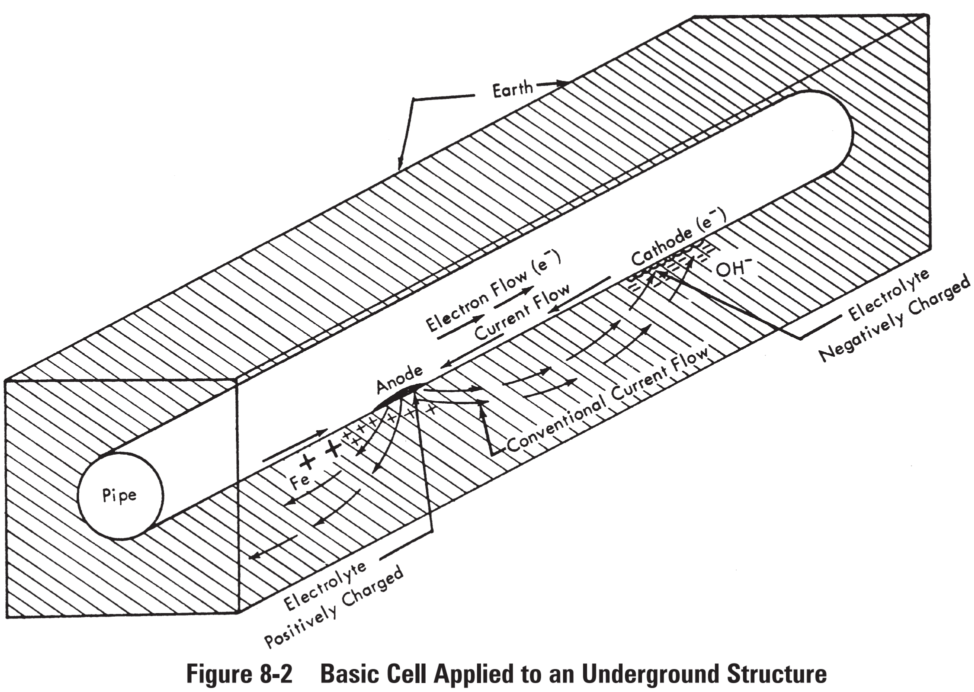


Figure 8-2 Basic Cell Applied to an Underground Structure

COMMON FORMS OF CORROSION

Corrosion occurs in a number of common forms as follows:

Uniform attack (Figure 8-3) Uniform attack is characterized by a general dissolving of the metal wall. The material and its corrosion products are readily dissolved in the corrosive media.

Pitting corrosion (Figure 8-4) Pitting corrosion is usually the result of the localized breakdown of a protective film or layer of corrosion products. Anodic areas form at the breaks in the film and cathodic areas form at the unbroken portion of the film. The result is localized, concentrated corrosion, which forms deep pits.

Galvanic corrosion (Figure 8-5) Galvanic corrosion occurs when two dissimilar metals are in contact with an electrolyte. The example shown is iron and copper in a salt solution, the iron being the anode corroding toward the copper cathode.

Concentration cell attack (Figure 8-6) Concentration cell attack is caused by differences in the concentration of a solution, such as differences in oxygen concentration or metal-ion concentration. These can occur in crevices, as shown in the example, or under mounds of contamination on the metal surface. The area of low oxygen or metal-ion concentration becomes anodic to areas of higher concentration.

Crevice corrosion A form of concentration cell attack (see separate listing).

Impingement attack (Figure 8-7) Impingement attack is the result of turbulent fluid, at high velocity, breaking through protective or corrosion films on a metal surface. There usually is a definite direction to the corrosion formed.

Stress corrosion cracking (Figure 8-8) Stress corrosion cracking results from placing highly stressed parts in corrosive environments. Corrosion causes concentration of the stress, which eventually exceeds the yield strength of the material, and cracking occurs.

Selective attack (Figure 8-9) Selective attack is the corrosive destruction of one element of an alloy. Examples are dezincification of brass and graphitization of cast iron.

Stray current (Figure 8-10) Stray current corrosion is caused by the effects of a direct current source such as a cathodic protection rectifier. Protective current may be picked up on a pipeline or structure that is not part of the protected system. This current follows to the other structure and at some point leaves the other structure and travels through the electrolyte (soil or water) back to the protected structure. This causes severe corrosion at the point of current discharge.

Corrosion by differential environmental conditions (Figure 8-11) Examples of differential environmental cells are shown in Figure 8-11. It should be noted that variations in moisture content, availability of oxygen, change in soil resistivity, or variations of all three may occur in some cases. As in all corrosion phenomena, changes or variations in the environment are a contributing factor.

THE GALVANIC SERIES

The galvanic series of metals, listed in Table 8-2, is useful in predicting the effects of coupling various metals. Metals that are far apart in the series have a greater potential for galvanic corrosion than do metals in the same group or metals close to each other in the series. Metals listed above other metals in the series are generally anodic (corrode) to metals listed below them. The relative area of the metals in the couple must be considered along with the polarization characteristic of each metal.

Table 8-2 Galvanic Series of Metals

Corroded end (anodic)
Magnesium
Magnesium alloys
Zinc
Aluminum 1100
Cadmium
Aluminum 2017 & 2024
Steel or iron
Cast iron
Chromium-iron (active)
Ni-resist irons
18-8 SS (active)
18-8-3 SS (active)
Lead-tin solders
Lead
Tin
Nickel (active)
Inconel (active)
Hastelloy C (active)
Brasses
Copper
Bronzes
Copper-nickel alloys
Monel
Silver solder
Nickel (passive)
Inconel (passive)
Chromium-iron (passive)
18-8 SS (passive)
18-8-3 SS (passive)
Hastelloy C (passive)
Silver
Titanium
Graphite
Gold
Platinum
Protected end (cathode)

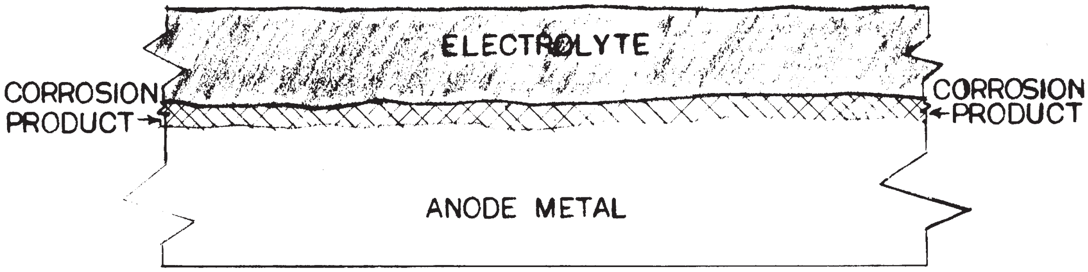


Figure 8-3 Uniform Attack

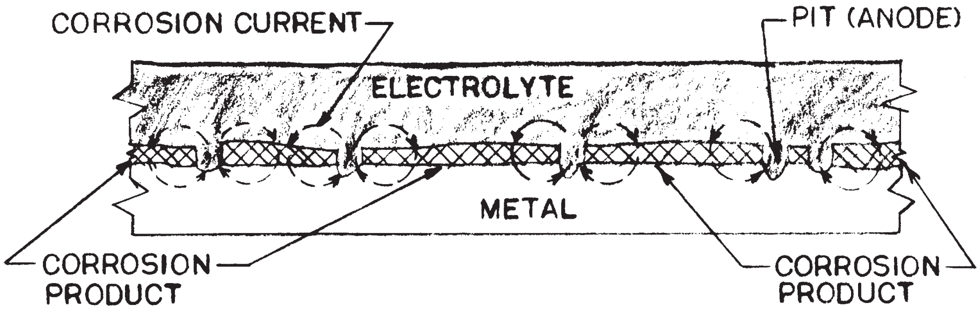


Figure 8-4 Pitting Corrosion

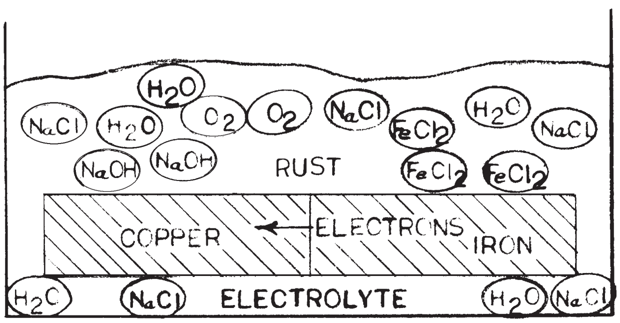


Figure 8-5 Galvanic Corrosion

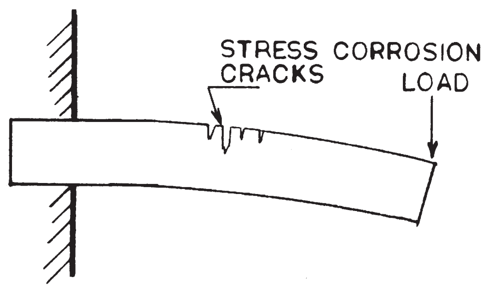


Figure 8-8 Stress Corrosion

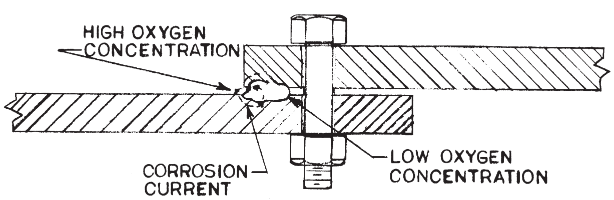
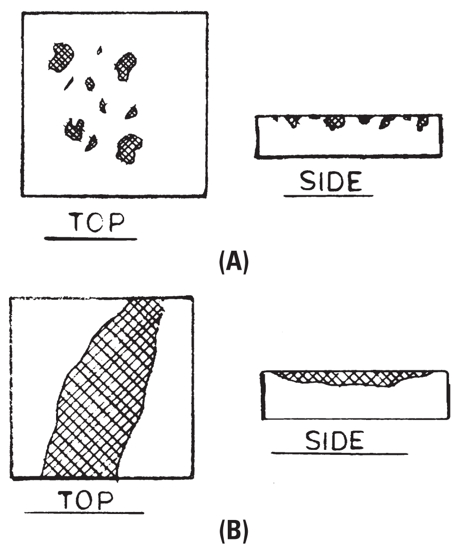


Figure 8-6 Concentration Cells



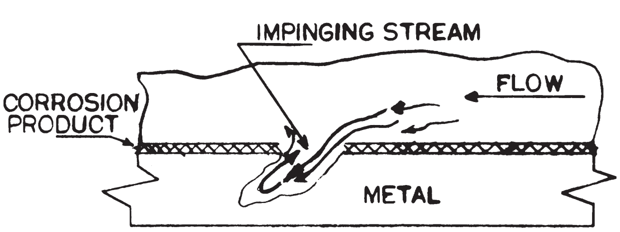


Figure 8-7 Impingement Attack

Figure 8-9 (A) Plug-Type Dezincification
(B) Layer-Type Dezincification

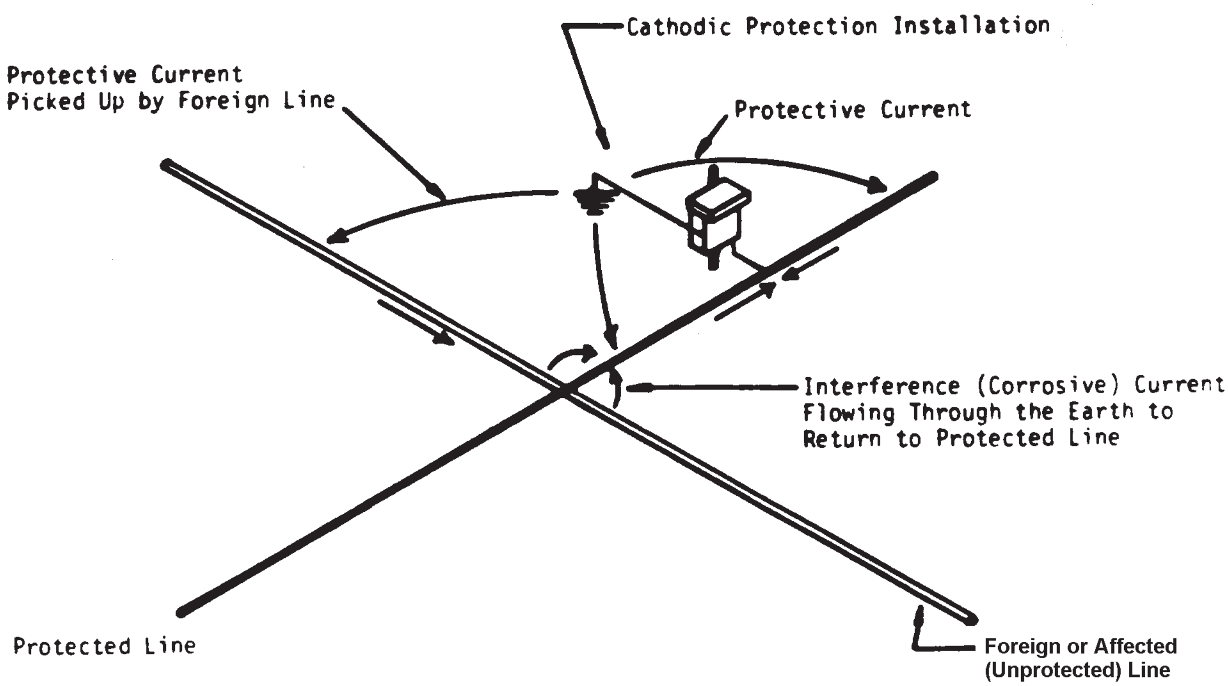


Figure 8-10 Stray Current Corrosion

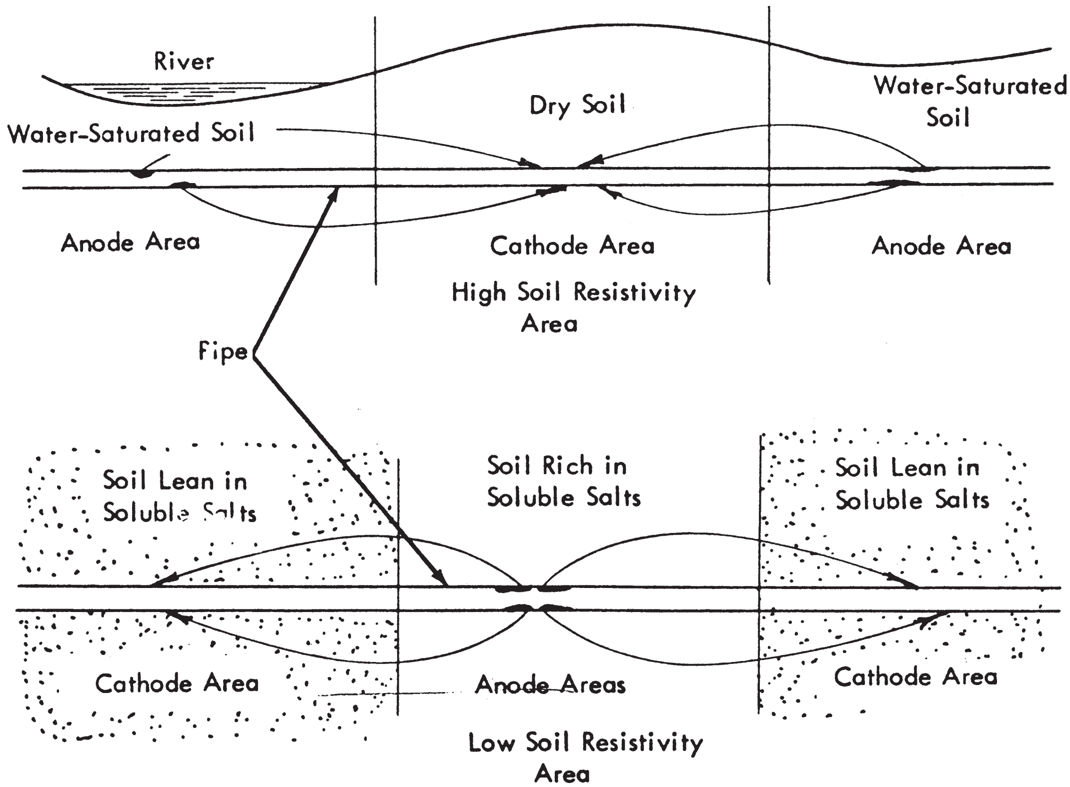


Figure 8-11 Corrosion by Differential Environmental Conditions

ELECTROMOTIVE FORCE SERIES

An "electromotive force" is defined as a force that tends to cause a movement of electrical current through a conductor. Table 8-3, known as the "electromotive force series," lists the metals in their electromotive force order and defines their potential with respect to a saturated copper-copper sulfite half-cell. This list is arranged according to their standard electrode potentials, with positive potentials (greater than 1.0) for elements that are cathodic to a standard hydrogen electrode and negative potentials (less than 1.0) for elements that are anodic to a standard hydrogen electrode. In most cases, any metal in this series will displace the more positive metal from a solution and thus corrode to protect the more positive metal. There are exceptions to this rule because of the effect of ion concentrations in a solution and because of different environments found in practice. This exception usually applies to metals close together in the series, which may suffer reversals of potential. Metals far apart in the series will behave as expected, the more negative will corrode to the more positive. In an electrochemical reaction, the atoms of an element are changed to ions. If an atom loses one or more electrons (e-), it becomes an ion that is positively charged and is called a cation (example: Fe2+). An atom that takes on one or more electrons also becomes an ion, but it is negatively charged and is called an anion (example: OH-). The charges coincide with the valence of the elements.

The arrangement of a list of metals and alloys according to their relative potentials in a given environment is a galvanic series. By definition, a different series could be developed for each environment.

Table 8-3 Electromotive Force Series

	Potential of Metals
Magnesium (galvomag alloy)[a]	1.75
Magnesium (H-I alloy)[a]	1.55
Zinc	1.10
Aluminum	1.01
Cast iron	0.68
Carbon steel	0.68
Stainless steel type 430 (17% Cr)[b]	0.64
Ni-resist cast iron (20% Ni)	0.61
Stainless steel type 304 (18% Cr, 8% Ni)[b]	0.60
Stainless steel type 410 (13% Cr)[b]	0.59
Ni-resist cast iron (30% Ni)	0.56
Ni-resist cast iron (20% Ni$^+$Cu)	0.53
Naval rolled brass	0.47
Yellow brass	0.43
Copper	0.43
Red brass	0.40
Bronze	0.38
Admiralty brass	0.36
90:10 Cu$^-$Ni$^+$ (0.8% Fe)	0.35
70:30 Cu$^-$Ni$^+$ (0.06% Fe)	0.34
70:30 Cu$^-$Ni$^+$ (0.47% Fe)	0.32
Stainless steel type 430 (17% Cr)[b]	0.29
Nickel	0.27
Stainless steel type 316 (18% Cr, 12% Ni, 3% Mo)[b]	0.25
Inconel	0.24
Stainless steel type 410 (13% Cr)[b]	0.22
Titanium (commercial)	0.22
Silver	0.20
Titanium (high purity)	0.20
Stainless steel type 304 (18% Cr, 8% Ni)[b]	0.15
Hastelloy C	0.15
Monel	0.15
Stainless steel type 316 (18% Cr, 12% Ni, 3% Mo)[b]	0.12

Note: Based on potential measurements in sea water, velocity of flow 13 ft/s (3.96 m/s), temperature 77°F (25°C).

a Based on data provided by the Dow Chemical Co.

b The stainless steels, as a class, exhibited erratic potentials depending on the incidence of pitting and corrosion in the crevices formed around the specimen supports. The values listed represent the extremes observed and, due to their erratic nature, should not be considered as establishing an invariable potential relation among the alloys that are covered.

FACTORS AFFECTING THE RATE OF CORROSION

General

The rate of corrosion is directly proportional to the amount of current leaving the anode surface. This current is related to both the potential (voltage) between the anode and cathode and the circuit resistance. Voltage, resistance, and current are governed by Ohm's Law:

Equation 8-1

$$I = \frac{E}{R}$$

where:

I = Current (A or mA)
E = Voltage (V or mV)
R = Resistance (Ω)

Essentially, Ohm's Law states that current is directly proportional to the voltage and inversely proportional to the resistance.

Effect of the Metal Itself

For a given current flow, the rate of corrosion of a metal depends on Faraday's Law.

Equation 8-2

$$w = KIt$$

where:

w = Weight loss
K = Electrochemical equivalent
I = Current
t = Time

For practical purposes, the weight loss is usually expressed in pounds per ampere year (kilograms per coulomb). Loss rates for some common metals are given in Table 8-4.

Table 8-4 Corrosion Rates for Common Metals

Metal	Loss Rate, lb/A-yr (kg/C)
Iron or steel	20 (6.1)
Lead	74 (22.5)
Copper	45 (162.0)
Zinc	23 (7.0)
Aluminum	6.5 (23.4)
Carbon	2.2 (7.9)

This indicates that if 1 ampere is discharged from a steel pipeline over a period of 1 year, 20 pounds (6.1 kilograms) of steel will be lost.

Corrosion of metals in aqueous solutions is also influenced by the following factors: Acidity, oxygen content, film formation, temperature, velocity, and homogeneity of the metal and the electrolyte. These factors are discussed below, since they are factors that can be measured or detected by suitable instruments.

Acidity

The acidity of a solution represents the concentration of hydrogen ions or the pH. In general, low pH (acid) solutions are more corrosive than neutral (7.0 pH) or high pH (alkaline) solutions. Iron or steel, for example, suffers accelerated corrosion in solutions where the pH is 4.5 or less. Exceptions to this rule are amphoteric materials such as aluminum or lead, which corrode more rapidly in alkaline solutions.

Oxygen Content

The oxygen content of aqueous solutions causes corrosion by reacting with hydrogen at the metal surface to depolarize the cathode, resulting in the exposure of additional metal. Iron or steel corrodes at a rate proportional to the oxygen content. Most natural waters originating from rivers, lakes, or streams are saturated with oxygen. Reduction of oxygen is a part of the corrosion process in most of the corrosion found in practice. The possibility of corrosion being influenced by atmospheric oxygen should not be overlooked in design work.

Film Formation

Corrosion and its progress are often controlled by the corrosion products formed on the metal surface. The ability of these films to protect metal depends on how they form when the metal is originally exposed to the environment. Thin, hard, dense, tightly adherent films afford protection, whereas thick, porous, loose films allow corrosion to proceed without providing any protection. As an example, the iron oxide film that usually forms on iron pipe in contact with water is porous and easily washed away to expose more metal to corrosion. The effective use of corrosion inhibitors in many cases depends on the type of film it forms on the surface to be protected.

Temperature

The effect of temperature on corrosion is complex because of its influence on other corrosion factors. Temperature can determine oxygen solubility, content of dissolved gases, and nature of protective-film formation, thereby resulting in variations in the corrosion rate. Generally, in aqueous solutions, higher temperatures increase corrosion rates. In domestic hot water systems, for example, corrosion rates double for each 10°F (6°C) rise above 140°F (60°C) water temperature. Temperature can also reverse potentials, such as in the case of zinc-coated iron at approximately 160°F (71.1°C) water temperature, when the zinc coating can become cathodic to the iron surface, accelerating the corrosion of iron.

Velocity

Velocity of the solution in many cases controls the rate of corrosion. Increasing velocity usually increases corrosion rates. The more rapid movement of the solution causes corrosion chemicals, including oxygen, to be brought into contact with the metal surface at an increased rate. Corrosion products or protective films are carried away from the surface at a faster rate.

Another important effect of high velocity is that turbulence can result in local differential oxygen cells or metal-ion concentration cells causing severe local attack. High velocities also tend to remove protective films causing rapid corrosion of the metal surfaces.

Homogeneity

The homogeneity of the metal and of the electrolyte is extremely important to corrosion rates. In general, nonhomogeneous metals or electrolytes cause local attack or pitting, which occurs at concentrated areas and is, therefore, more serious than the general overall corrosion of a material. Examples include: Concentration cells, galvanic cells, microstructural differences, and differences in temperature and velocity.

CORROSION CONTROL

Corrosion control is the regulation, control, or prevention of a corrosion reaction for a specific goal. This may be accomplished through any one or a combination of the following factors:

1. Materials selection.
2. Design to reduce corrosion.
3. Passivation.
4. Coating.
5. Cathodic protection.
6. Inhibitors (water treatment).

Materials Selection

Corrosion resistance, along with other important properties, must be considered in selecting a material for any given environment. When a material is to be specified, the following steps should be used:

1. Determine the application requirements.
2. Evaluate possible material choices that meet the requirements.
3. Specify the most economical method.

Factors to be considered include:

1. Material cost.
2. Corrosion-resistance data.
3. Ability to be formed or joined by welding or soldering.
4. Fabricating characteristics (bending, stamping, cutting, etc.).
5. Mechanical properties (tensile and yield strength, impact resistance, hardness, ductility, etc.).
6. Availability of material.
7. Electrical or thermal properties.
8. Compatibility with other materials in system.
9. Specific properties, such as nuclear-radiation absorption, low or high-temperature properties.

Initial cost is an important consideration, but the life cost as applied to the system, as a whole, is more important. For example, if an inexpensive part must be periodically replaced, the cost of downtime and labor to install it may make the inexpensive part the most expensive part when all factors are considered.

Design to Reduce Corrosion

Corrosion can be eliminated or substantially reduced by incorporating some basic design suggestions in the system design. The following five design suggestions can minimize corrosive attack:

1. *Provide dielectric insulation between dissimilar metals*, when dissimilar metals such as copper and steel are connected together, e.g., at a water heater. In a pipeline, for example, dielectric insulation should be installed to prevent contact of the two metals. Without such insulation, the metal higher in the galvanic series (steel) will suffer accelerated corrosion because of the galvanic cell between copper and steel. When designing systems requiring dissimilar metals, the need for dielectric insulation should be investigated.
2. *Avoid surface damage or marking.* Areas on surfaces that have been damaged or marked can initiate corrosion. These areas usually become anodic to the adjacent untouched areas and can lead to failures. The designer, therefore, should consider this when there is a need for machining or fabrication so that unnecessary damage does not occur.
3. *Do not use excessive welding or soldering heat.* Areas that are heated excessively during welding or soldering can result in changes to the metals' microstructure. Large grain growth can result in accelerated corrosion. The grain growth changes the physical properties of the metal and results in nonhomogeneity of the metal wall. Designs can minimize this effect by using heavier wall thicknesses in areas to be welded.
4. *Crevices should be avoided.* Concentration cells usually form in crevices and can cause premature failures. Regardless of the amount of force applied in bolting two plates together, it is not possible to prevent gradual penetration of liquid into the crevice between the plates. This forms concentration cells where the fluid in the crevices is depleted and forms anodic areas. The most practical way of avoiding crevices is to design welded connections in place of mechanical fasteners.
5. *Other design suggestions*: Corrosion can be minimized if heat or chemicals near metal walls are avoided. Condensation of moisture from the air on cold metal surfaces can cause extensive corrosion if not prevented. The cold metal surface should be thermally insulated if possible. Any beams, angles, etc., should be installed so they drain easily and cannot collect moisture, or drain holes must be provided.

Passivation

Passivation is the accelerated formation of a protective coating on metal pipe (primarily stainless steel) by contact with a chemical specifically developed for this purpose.A thin, protective film is formed when reacting and bonding to the metal. This occurs at the point of potential metal loss (corrosion).

Passivation prevents corrosion in the remaining pits left from free machining and the residual that gets trapped therein. Sulfides and iron particles act as initiation sites to corrosion. It is not a scale removal method, thus, surface cutting tool contaminates need to be removed prior to the passivation process. The use of citric acid for passivation is an alternate to using nitric acid in the stainless steel industry. Due to it being safe, organic, and easy to use, citric acid has gained popularity. Care must be taken to ensure the balance of time, temperature, and concentrations to avoid "flash attack".

Flash attacks are caused by contaminated passivating solutions containing high levels of chlorides. A heavily etched, dark surface rather than an oxide film occurs. Passivating solutions should be free of contaminants to prevent this from happening.

New methods are being discovered and tested to protect other material surfaces such as aluminum. Periodic testing after passivation ensures the metal surfaces is maintained.

Coating

Materials exposed to the atmosphere that do not have the ability to form natural protective coatings, such as nickel and aluminum, are best protected by the application of artificial protective coatings. The coating is applied to keep the corroding material from the surface at all times.

One of the most important considerations in coating application is surface preparation. The surface must be properly cleaned, free of scale, rust, grease, and dirt to allow the coating to bond properly to the surface. The best coating in the world will give unsatisfactory results if the surface is poorly prepared. The surface may require pickling, sandblasting, scratch brushing, or flame cleaning to properly prepare it for application of a coating.

The actual coating that is applied depends on the application and may be either a metallic (such as galvanizing) or nonmetallic, organic (such as vinyl or epoxy) coating. The coating may actually be a coating system, such as primer, intermediate coat (to bond primer and top coat), and finish or top coat. Coating manufacturers' literature should be consulted regarding coating performance, surface preparatory application, handling of coated surfaces, etc.

For atmospheric exposure, coatings alone are relied on to provide protection in many applications. Coatings by themselves, however, are not considered adequate for corrosion control of buried or submerged structures because there is no such thing as a perfect coating. All coatings have inherent holes or holidays. Often the coating is damaged during installation or adjacent construction. Concentrated corrosion at coating breaks often causes failures sooner on coated structures than on bare ones. In stray current areas, severe damage occurs frequently on coated pipe because of the high density of discharge current at coating faults.

The most important function of coating is in its relation to cathodic protection. Cathodic protection current requirements, and hence operating costs, are proportional to the amount of bare surface exposed to soil. When structures are coated, it is necessary only to protect the small areas of coating faults. Careful applications of coating and careful handling of coated structures lead to maximum coating effectiveness, thus minimizing protective current requirements and costs. Also, lower current usage generally means less chance of stray current effects on other structures.

Cathodic Protection

Cathodic protection is an effective tool to control corrosion of metallic structures, such as water lines and tanks, buried or immersed in a continuous electrolyte by making the metal structure the cathode and applying direct current from an anode source. By making the entire structure the cathode, all anode areas from the local corrosion cells are eliminated, and DC current is prevented from leaving the structure, thereby stopping further corrosion.

The most common sacrificial anode is made of magnesium. Magnesium has the highest natural potential of the metals listed in the electromotive series and, therefore, the greatest current-producing capacity of the series. Zinc anodes are sometimes used in very low-resistivity soils where current-producing capacity such as that of magnesium is not required.

The two proven methods of applying cathodic protection are with (1) galvanic anodes and (2) impressed current systems. The basic difference between the two types of protection is as follows: The galvanic anode system depends on the voltage difference generated between the anode material and the structure material to cause a flow of DC current to the structure. The impressed current system utilizes an AC/DC rectifier to provide current to relatively inert anodes and can be adjusted to provide the necessary voltage to drive the required current to the structure surfaces. Choice of the proper system depends on a number of factors. Each has its advantages, which are discussed below.

Galvanic anodes Galvanic anodes are used most advantageously on coated structures in low soil resistivity where current requirements are low. Some advantages and disadvantages of galvanic anodes are as follows:

Advantages:

1. Relatively low installation cost.
2. Do not require external power source.
3. Low maintenance requirements.
4. Usually do not cause adverse effects on foreign structures.
5. Can be installed with pipe, minimizing right-of-way cost.

Disadvantages:

1. Driving voltage is low (approximately 0.15 V).
2. Current output is limited by soil resistivity.
3. Not applicable for large current requirements.

The galvanic anode system of an active metal anode, such as magnesium or zinc, is placed in the electrolyte (soil or water) near the structure and connected to it with a wire. This is illustrated in Figures 8-12 and 8-13. Cathodic protection is achieved by current flow due to the potential difference between the anode (metal) and the cathode (structure). A corrosion cell or battery is created, and current flows from the corroding anode material through the soil to the cathode or protected structure. Hence the galvanic anode is deliberately caused to waste itself to prevent corrosion of the protected structure. Because the galvanic anode system relies on the difference in voltage between two metals, which in most cases is limited to 1.0 V or less, the current generated by the anodes is usually low (approximately 0.1 to 0.5 A per anode).

Galvanic anode systems are usually used for structures having small current requirements, such as well-coated, small-diameter pipes; water heaters; sewage lift stations; some offshore structures; and structures in congested areas where currents must be kept low to avoid detrimental effects on other structures. Galvanic anodes may be installed in banks at specific locations. They are, however, usually distributed around protected structures because of their limited current output.

As an example, considering a pipe-to-soil potential of 0.85 V as protection for a steel pipeline, the driving potential of zinc anodes is 0.25 V and for magnesium is 500 A-h/lb (1795 C/kg). The actual life of anodes of a given weight at a known current output can be calculated using the following formulas:

Equation 8-3

$$LM = \frac{57.08 \times w}{i}$$

Equation 8-4

$$Lz = \frac{38.2 \times w}{i}$$

where:

LM = Life of magnesium anode (yr)
Lz = Life of zinc anode (yr)
w = Weight of anode, lb (kg)
i = Output of anode (mA)

The controlling factor for current output of zinc and magnesium anodes is soil resistivity. When soil resistivity is known or determined, then the current output of variously sized anodes for either magnesium or zinc can be estimated as follows:

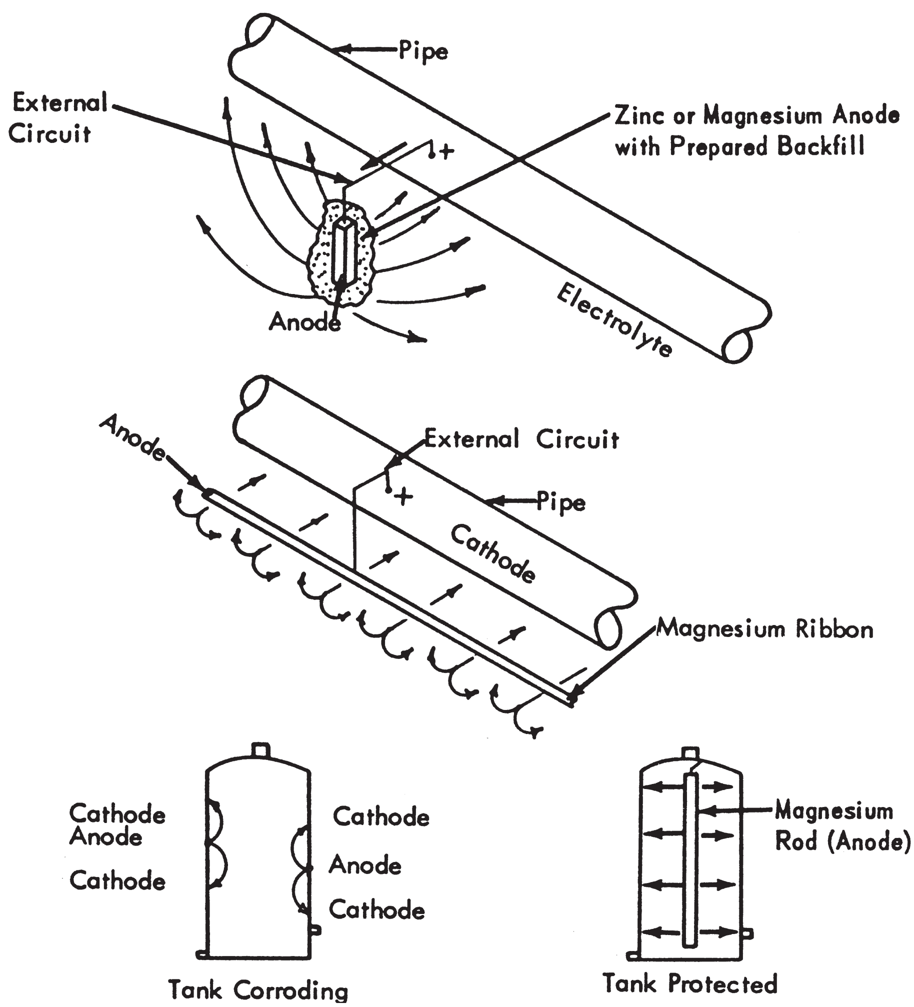


Figure 8-12 Cathodic Protection by the Sacrificial Anode Method

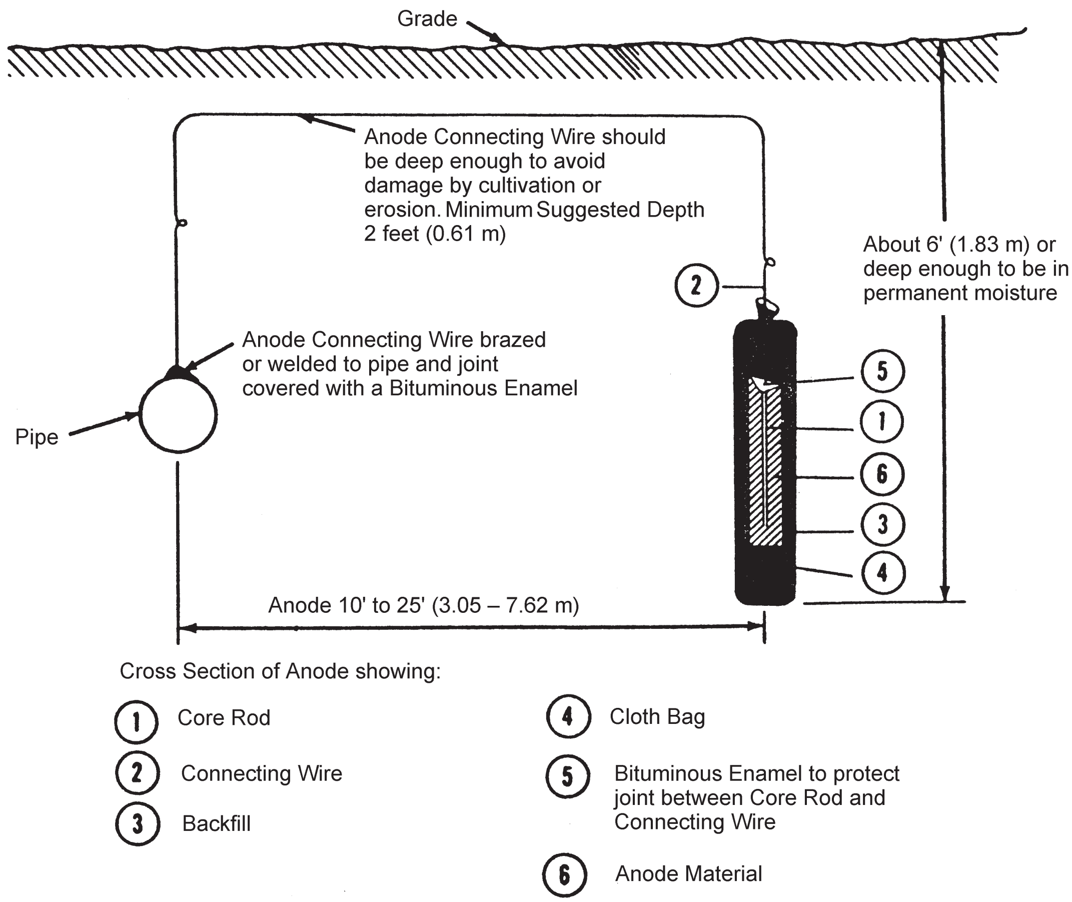


Figure 8-13 Typical Sacrificial Anode Installation

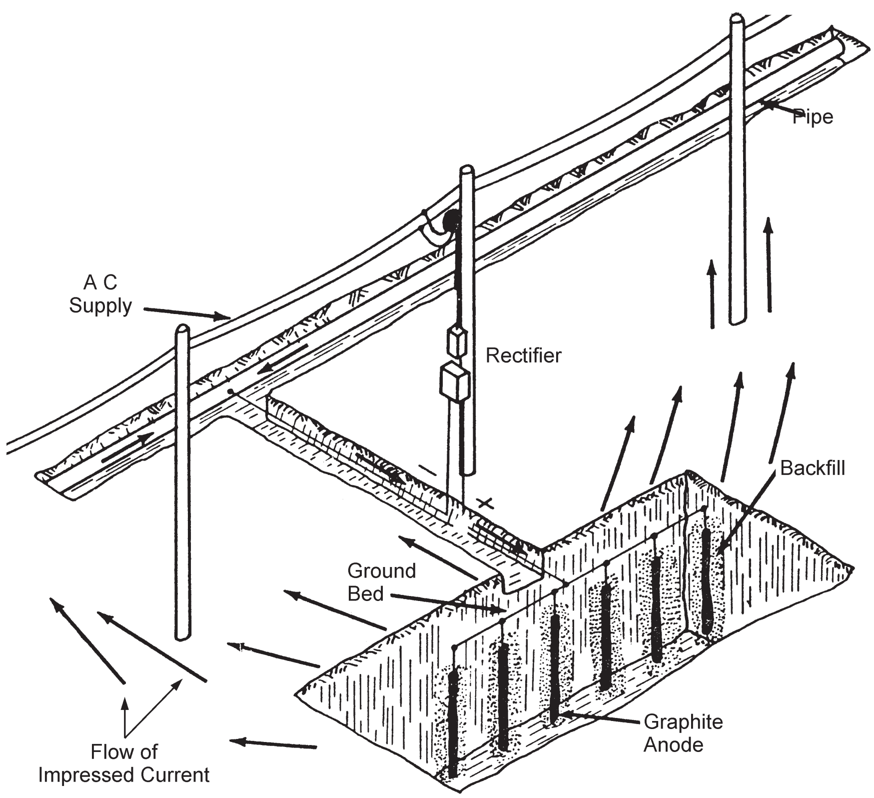


Figure 8-14 Cathodic Protection by the Impressed Current Method

Equation 8-5

$$iM = \frac{150{,}000 \times f}{p}$$

Equation 8-6

$$iZ = \frac{150{,}000 \times f \times 0.27}{p}$$

where:

iM = Current output of magnesium (mA)
iZ = Current output of zinc (mA)
p = Soil resistivity (Ω-cm)
f = Anode size factor

Cost of galvanic cathodic protection generally favors the use of zinc anodes over magnesium at soil resistances below 1500 Ω-cm and the use of magnesium at soil resistances over 1500 Ω-cm.

Impressed current The impressed current system, illustrated in Figure 8-14, differs substantially from the galvanic anode system in that it is externally powered, usually by an AC-DC rectifier, which allows great freedom in adjustment of current output. Current requirements of several hundred amperes can be handled by impressed current systems. The impressed current system usually consists of graphite or high-silicon iron anodes connected to an AC-DC rectifier, which, in turn, is wired to the structure being protected. Current output is determined by adjustment of the rectifier voltage to provide current as required. The system is not limited by potential difference between metals, and voltage can be adjusted to provide adequate driving force to emit the necessary current. Impressed current systems are used for structures having large current requirements, such as bare pipe; tank farms; large-diameter, cross-country pipe lines; cast-iron water lines; and many offshore facilities.

Impressed current cathodic protection has the following advantages and disadvantages:

Advantages:

1. Large current output.
2. Voltage adjustment over a wide range.
3. Can be used with a high soil resistivity environment.
4. Can protect uncoated structures.
5. Can be used to protect larger structures.

Disadvantages:

1. Higher installation and maintenance cost.
2. Power costs.
3. Can cause adverse effects (stray current) with foreign structures.

When designing impressed current cathodic protection systems, the engineer must determine the type and condition of the structure. Obtaining knowledge of the presence or lack of coating, size of structure, electrical continuity, and location is a necessary first step. Next, the availability of power and ease of installing the ground bed are required. After all of the above are satisfactorily done, it is generally necessary to perform a current-requirement test utilizing a portable DC generator or storage batteries. This defines an apparent DC current requirement to protect the structure. Tests to determine any adverse effects should also be conducted on foreign structures at this time. Any current drained to foreign structures should be added to the current requirements. After the total current requirement is known, the ground bed is designed so that the circuit resistance is relatively low. Actual ground-bed design is dependent on soil resistivity. A number of empirical formulas are available to determine the number of parallel anodes required for a certain circuit resistance.

Cathodic protection criteria Criteria for determining adequate cathodic protection have been established by The National Association of Corrosion Engineers (NACE). These criteria are based on measuring structure-to-electrode potentials with a copper-sulfate reference electrode. The criteria are listed for various metals, such as steel, cast iron, aluminum, and copper, and may be found in NACE Standard RP-01.

Cathodic protection serves its purpose best, and is by far the most economical, when it is properly coordinated with the other methods of corrosion control, especially coating. In general, the least expensive, easiest to maintain, and most practical system is to apply a good-quality coating to a new structure and then use cathodic protection to eliminate corrosion at the inevitable breaks in the coating. The reason for this is that it takes much more current and anodes to protect bare metal than it does to protect coated metal. The amount of protective current required is proportional to the area of metal exposed to the electrolyte.

In addition to using coatings, it is necessary to assure continuity of the structures to provide protection of the whole structure. This also prevents undesirable accelerated stray current corrosion to the parts of the structure that are not electrically continuous. Therefore, all noncontinuous joints, such as mechanical, push-on, or screwed joints in pipelines, must be bonded. All tanks in a tank farm or piles on a wharf must be bonded together to ensure electrical continuity.

Other important components used in effective cathodic protection systems are dielectric insulation and test stations. Dielectric insulation is sometimes used to isolate underground protected structures from above-ground structures to reduce the amount of cathodic protection current required. Care must be taken to avoid short-circuiting (bypassing) the insulation, or protection can be destroyed. Test stations are wires attached to the underground structure (pipeline or tank) to provide electrical contact for the purpose of determining protection effectiveness. Test stations are also used to make bonds or connections between structures when required to mitigate stray-current effects.

Costs of cathodic protection Corrosion of underground, ferrous metal structures can be economically controlled by cathodic protection. Cathodic protection costs are added to the initial investment since they are a capital expense. To be economically sound, the spending of the funds must yield a fair return over the expected life of the facility.

To protect a new facility requires an initial increase of perhaps 10% in capital investment. Payout time is usually 10 to 15 years; thereafter, appreciable savings accrue due to this investment, which prevents or reduces the frequency of leaks. Effective corrosion control through the application of cathodic protection reduces the leak frequency for a structure to the minimum with minimum cost.

Cathodic protection systems must be properly maintained. Rectifier outputs must be checked monthly. Changes or additions to the protected structure must be considered to see if changes or additions to the cathodic protection system are required. Annual inspections by a corrosion engineer are required to ensure that all malfunctions are corrected, and cathodic protection continues unhampered.

Inhibitors (Water Treatment)

Plant utility services such as boiler feed water, condensate, refrigerants, and cooling water require the addition of inhibitors or water treatment. Boiler feed water must be treated to maintain proper pH control, dissolved solid levels, and oxygen content. Condensate requires treatment to control corrosion by oxygen and carbon dioxide. Brine refrigerants and cooling water in closed-loop circulating systems require proper inhibitors to prevent corrosion.

Water treatment may consist of a simple adjustment of water hardness to produce naturally forming carbonate films. This carbonate film, if properly adjusted, will form to a controlled thickness just sufficient to prevent corrosion by keeping water from contacting the metal surface. In cooling water, where hardness control is not practical, inhibitors or film-forming compounds may be required.

Sodium silicate and sodium hexameta-phosphate are examples of film-forming additives in potable water treatment. A tight, thin, continuous film of silica (water glass) or phosphate adheres to the metal surface, preventing pipe contact with the water. (Phosphate additives to potable water are limited or prohibited in some jurisdictions.)

In closed-loop cooling systems, and systems involving heat-exchange surfaces, it may not be possible to use film-forming treatment because of detrimental effects on heat transfer. In these cases, inhibitors are used; these control corrosion by increasing polarization of anodic or cathodic surfaces and are called "anodic" or "cathodic inhibitors," respectively. The anodic or cathodic surfaces are covered, preventing completion of the corrosion cell by elimination of either the anode or cathode.

When water treatment or inhibitors are used, a testing program must be established to ensure that proper additive levels are maintained. In some cases, continuous monitoring is required. Also, environmental considerations in local areas must be determined before additives are used or before any treated water is discharged to the sanitary sewer or storm drainage system.

GLOSSARY

Active The state in which a metal is in the process of corroding.

Active potential The capability of a metal corroding based on a transfer of electrical current.

Aeration cell An oxygen concentration cell– an electrolytic cell resulting from differences in the quantity of dissolved oxygen at two points.

Amphoteric corrosion Corrosion usually caused by a chemical reaction resulting from a concentration of alkaline products formed by the electrochemical process. Amphoteric materials are those materials that are subject to attack from both acidic and alkaline environments. Aluminum and lead, commonly used in construction, are subject to amphoteric corrosion in highly alkaline environments. The use of cathodic protection in highly alkaline environments, therefore, intensifies the formation of alkaline byproducts.

Anaerobic Free of air or uncombined oxygen.

Anion A negatively charged ion of an electrolyte that migrates toward the anode under the influence of a potential gradient.

Anode Negative in relation to the electrochemical process. The electrode at which oxidation or corrosion occurs.

Anodic protection An appreciable reduction in corrosion by making a metal an anode and maintaining this highly polarized condition with very little current flow.

Cathode Positive in relation to the electrochemical process. The electrode where reduction (and practically no corrosion) occurs.

Cathodic corrosion An unusual condition in which corrosion is accelerated at the cathode because cathodic reaction creates an alkaline condition corrosive to certain metals, such as aluminum, zinc, and lead.

Cathodic protection Reduction or elimination of corrosion by making the metal a cathode by means of an impressed DC current or attachment to a sacrificial anode.

Cathodic The electrolyte of an electrolytic cell adjacent to the cathode.

Cation A positively charged ion of an electrolyte that migrates toward the cathode under the influence of a potential gradient.

Caustic embrittlement Weakening of a metal resulting from contact with an alkaline solution.

Cavitation Formation and sudden collapse of vapor bubbles in a liquid, usually resulting from local low pressures, such as on the trailing edge of an impeller. This condition develops momentary high local pressure which can mechanically destroy a portion of the surface on which the bubbles collapse.

Cavitation-corrosion Corrosion damage resulting from cavitation and corrosion: metal corrodes, pressure develops from collapse of the cavity and removes the corrosion product, exposing bare metal to repeated corrosion.

Cell A circuit consisting of an anode and a cathode in electrical contact in a solid or liquid electrolyte.

Concentration cell A cell involving an electrolyte and two identical electrodes, with the potential resulting from differences in the chemistry of the environments adjacent to the two electrodes.

Concentration polarization That portion of the polarization of an electrolytic cell produced by concentration changes resulting from passage of electric current through the electrolyte.

Contact corrosion Corrosion of a metal at an area where contact is made with a (usually nonmetallic) material.

Corrosion Degradation of a metal by chemical or electrochemical reaction with its environment.

Corrosion fatigue Reduction of fatigue durability by a corrosive environment.

Corrosion fatigue limit The maximum repeated stress endured by a metal without failure in a stated number of stress applications under defined conditions of corrosion and stressing.

Corrosion mitigation The reduction of metal loss or damage through use of protective methods and devices.

Corrosion prevention The halting or elimination of metal damage through use of corrosion-resisting materials, protective methods, and protective devices.

Corrosion potential The potential that a corroding metal exhibits under specific conditions of concentration, time, temperature, aeration, velocity, etc.

Couple A cell developed in an electrolyte resulting from electrical contact between two dissimilar metals.

Cracking Separation in a brittle manner along a single or branched path.

Crevice corrosion Localized corrosion resulting from the formation of a concentration cell in a crack formed between a metal and a nonmetal, or between two metal surfaces.

Deactivation The process of prior removal of the active corrosion constituents, usually oxygen, from a corrosive liquid by controlled corrosion of expendable metal or by other chemical means.

Dealloying The selective leaching or corrosion of a specific constituent from an alloy.

Decomposition potential (or voltage) The practical minimum potential difference necessary to decompose the electrolyte of a cell at a continuous rate.

Depolarization The elimination or reduction of polarization by physical or chemical means; depolarization results in increased corrosion.

Deposit attack (deposition corrosion) Pitting corrosion resulting from accumulations on a metal surface that cause concentration cells.

Differential aeration cell An oxygen concentration cell resulting from a potential difference caused by different amounts of oxygen dissolved at two locations.

Drainage Conduction of current (positive electricity) from an underground metallic structure by means of a metallic conductor.

Electrode A metal in contact with an electrolyte that serves as a site where an electrical current enters the metal or leaves the metal to enter the solution.

Electrolyte An ionic conductor (usually in aqueous solution).

Electromotive force series (e.m.f. series) A list of elements arranged according to their standard electrode potentials, the sign being positive for elements having potentials that are cathodic to hydrogen and negative for elements having potentials that are anodic to hydrogen. (This convention of sign, historically and currently used in European literature, has been adopted by the Electrochemical Society and the National Bureau of Standards; it is employed in this publication. The opposite convention of G. N. Lewis has been adopted by the American Chemical Society.)

Electronegative potential A potential corresponding in sign to those of the active or anodic members of the e.m.f. series. Because of the existing confusion of sign in the literature, it is suggested that "anodic potential" be used whenever "electronegative potential" is implied. (See "electromotive force series.")

Electropositive potential A potential corresponding in sign to potentials of the noble or cathodic members of the e.m.f. series. It is suggested that "cathodic potential" be used whenever "electropositive potential" is implied. (See "electromotive force series.")

Flash attack A heavily etched, dark surface resulting from contaminated passivating solutions with high chloride levels.

Forced drainage Drainage applied to underground metallic structures by means of an applied e.m.f. or sacrificial anode.

Galvanic cell A cell consisting of two dissimilar conductors in contact with an electrolyte, or two singular conductors in contact with dissimilar electrolytes. More generally, a galvanic cell converts energy liberated by a spontaneous chemical reaction directly into electrical energy.

Galvanic corrosion Corrosion that is increased because of the current caused by a galvanic cell (sometimes called "couple action").

Galvanic series A list of metals arranged according to their relative corrosion potential in some specific environment; sea water is often used.

General corrosion Corrosion in a uniform manner.

Graphitization (graphitic corrosion) Corrosion of gray cast iron in which the metallic constituents are converted to corrosion products, leaving the graphite flakes intact. Graphitization is also used in a metallurgical sense to mean the decomposition of iron carbide to form iron and graphite.

Hydrogen embrittlement Hydrogen embrittlement causes a weakening of the metal by the entrance of hydrogen into the metal through, for example, pickling or cathodic polarization.

Hydrogen overvoltage A higher than expected difference in potential associated with the liberation of hydrogen gas.

Impingement attack Localized erosion-corrosion caused by turbulence or impinging flow at certain points.

Inhibitor A substance that, when added in small amounts to water, acid, or other liquids, sharply reduces corrosion.

Ion An electrically charged atom or group of atoms known as "radicals."

Natural drainage Drainage from an underground metallic structure to a more negative structure, such as the negative bus of a trolley substation.

Noble potential A potential substantially cathodic compared to the standard hydrogen potential.

Open-circuit potential The measured potential of a cell during which no significant current flows in the external circuit.

Overvoltage The difference between the potential of an electrode at which a reaction is actively taking place and another electrode at equilibrium for the same reaction.

Oxidation Loss of electrons, as when a metal goes from the metallic state to the corroded state. Thus, when a metal reacts with oxygen, sulfur, etc., to form a compound as oxide, sulfide, etc., it is oxidized.

Oxygen concentration cell A galvanic cell caused by a difference in oxygen concentration at two points on a metal surface.

Passive The state of a metal when its behavior is much more noble (resists corrosion) than its position in the e.m.f. series would predict. This is a surface phenomenon.

pH A measure of the acidity or alkalinity of a solution (from 0 to 14). A value of seven (7) is neutral; low numbers (0-6) are acidic, large numbers (8-14) are alkaline.

Pitting Localized light corrosion resulting in deep penetration at a small number of points.

Polarization The shift in electrode potential resulting from the effects of current flow, measured with respect to the "zero-flow" (reversible) potential, i.e., the counter-e.m.f. caused by the products formed or concentration changes in the electrode.

Protective potential A term sometimes used in cathodic protection to define the minimum potential required to suppress corrosion. For steel in sea water, this is claimed to be about 0.85 V as measured against a saturated calomel cell.

Remote electrode (remote earth) Remote earth is any location away from the structure at which the potential gradient of the structure to earth is constant. The potential of a structure-to-earth will change rapidly near the structure and if remote earth is reached, there will be little or no variation in the voltage.

Resistivity The specific opposition of a material. Measured in ohms (Ω) to the flow of electricity.

Rusting Corrosion of iron or an iron-base alloy to form a reddish-brown product that is primarily hydrated ferric oxide.

Stray current corrosion Corrosion that is caused by stray currents from some external source.

Stress corrosion/stress-accelerated corrosion Corrosion that is accelerated by stress.

Stress corrosion cracking Cracking that results from stress corrosion.

Tuberculation Localized corrosion at scattered locations resulting in knob-like mounds.

Under-film corrosion Corrosion that occurs under lacquers and similar organic films in the form of randomly distributed hairlines (most common) or spots.

Weld decay Corrosion, notably at specific zones away from a weld.

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9 Seismic Protection of Plumbing Equipment

INTRODUCTION

Every structure is designed for vertical, or gravity, loads. In the case of pipes, gravity loads include the weight of the pipe and its contents, and the direction of the loading is downward. Seismic loads are the horizontal forces exerted on a structure during an earthquake. Earthquake forces can be in any direction. The ordinary supports designed for gravity loads generally take care of the vertical loads during an earthquake. Therefore, the primary emphasis in seismic design is on lateral, or horizontal, forces.

Study of seismic risk maps, Figures 9-1 and 9-2, indicates that the potential for damaging earthquake motion is far more pervasive than is commonly known. Complete seismic design requirements, including construction of nonstructural elements (piping, ductwork, conduit, etc.), are in effect in only a small fraction of the areas that could be rated as having a high or moderate risk. Seismic design requirements for nonstructural elements, except for heavy cladding panels, are seldom enforced even in California, which is considered the innovator in state building code requirements related to seismic movement. However, the nonstructural damage resulting from recent small earthquakes and the large United States and Japanese shocks shows that the major advancements in building structural design, by themselves, may not have produced an acceptable level of overall seismic protection. Now that—at least for modern structures designed and built in accordance with current seismic codes—the potential for collapse or other direct, life-endangering structural behavior is quite small, attention has shifted to nonstructural life safety hazards, continued functionality, and economic issues. The cost of an interruption in a building's ability to function—which could cause a loss of rent,

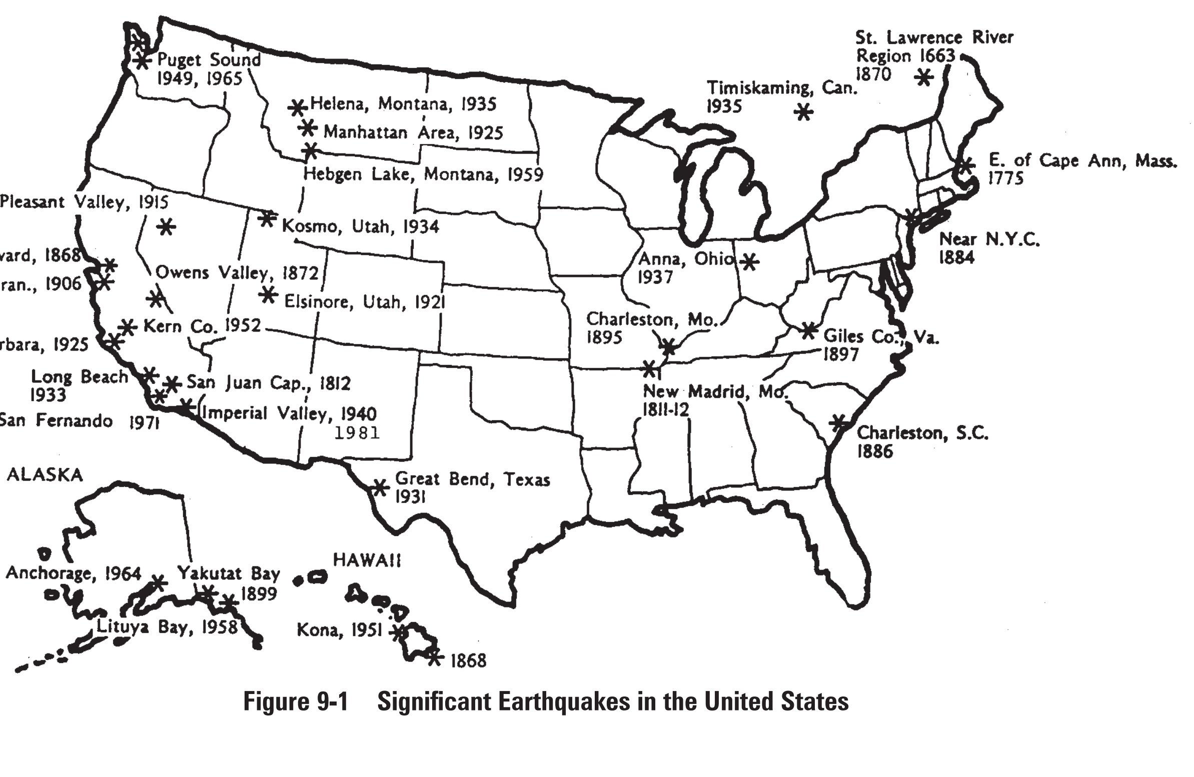


Figure 9-1 Significant Earthquakes in the United States

disruption of normal business affairs, or curtailment of production—is coming more into focus.

The costs of seismic protection of plumbing components and equipment range from small—such as those to anchor small tanks—to a considerable percentage of installation costs—such as those for complete pipe bracing systems. Beyond protection of life, the purpose or cost-benefit relationship of seismic protection must be clearly understood before the appropriate response to the risk can be made. The design professional responsible for any given element or system in a building is in the best position to provide that response. Seldom, however, can rational seismic protection be supplied solely by a single discipline. Building systems are interdependent in both design and function, and good seismic protection, like good overall building design, is best provided by employing a cooperative, interdisciplinary approach.

This chapter is intended to provide a basic understanding of the mechanisms of seismic damage and the particular vulnerabilities of plumbing systems and equipment. It is desirable that the professional sufficiently understand the problem in order to select the appropriate seismic protection in any situation, based on a ranking of the damage susceptibility and a knowledge of the scope of mitigation techniques.

The seismic-protection techniques currently in use for buildings are described in general. Although specific seismic-protection details for some situations are discussed, it is suggested that structural-design assistance be obtained from a professional of that discipline. Care should be taken in the design of seismic control systems. Proper design may require assistance from an engineer experienced in these systems. In all cases, the current local building code requirements for seismic movement should be consulted and used as minimum standards.

The detailed analysis and design techniques used for nuclear power plants and other heavy industrial applications, while similar in nature to those discussed here, are considered inappropriate for most buildings and are beyond the scope of this chapter. References are given throughout the text for additional study in specific areas of interest.

CAUSES AND EFFECTS OF EARTHQUAKES

Plate Tectonics and Faults

All seismic activity on the earth's surface, including earthquakes and volcanoes, are now understood to be caused by the relative movement of pieces of the earth's crust. Ten of the largest pieces, called plates, and their prevailing motions, are shown in Figure 9-3. The edges of these plates make up the world's primary fault systems, along which 90% of all earthquakes occur. The balance of earthquakes occur on countless additional, smaller faults that lie within plate boundaries. The causes and exact mechanisms of these intraplate earthquakes, which affect much

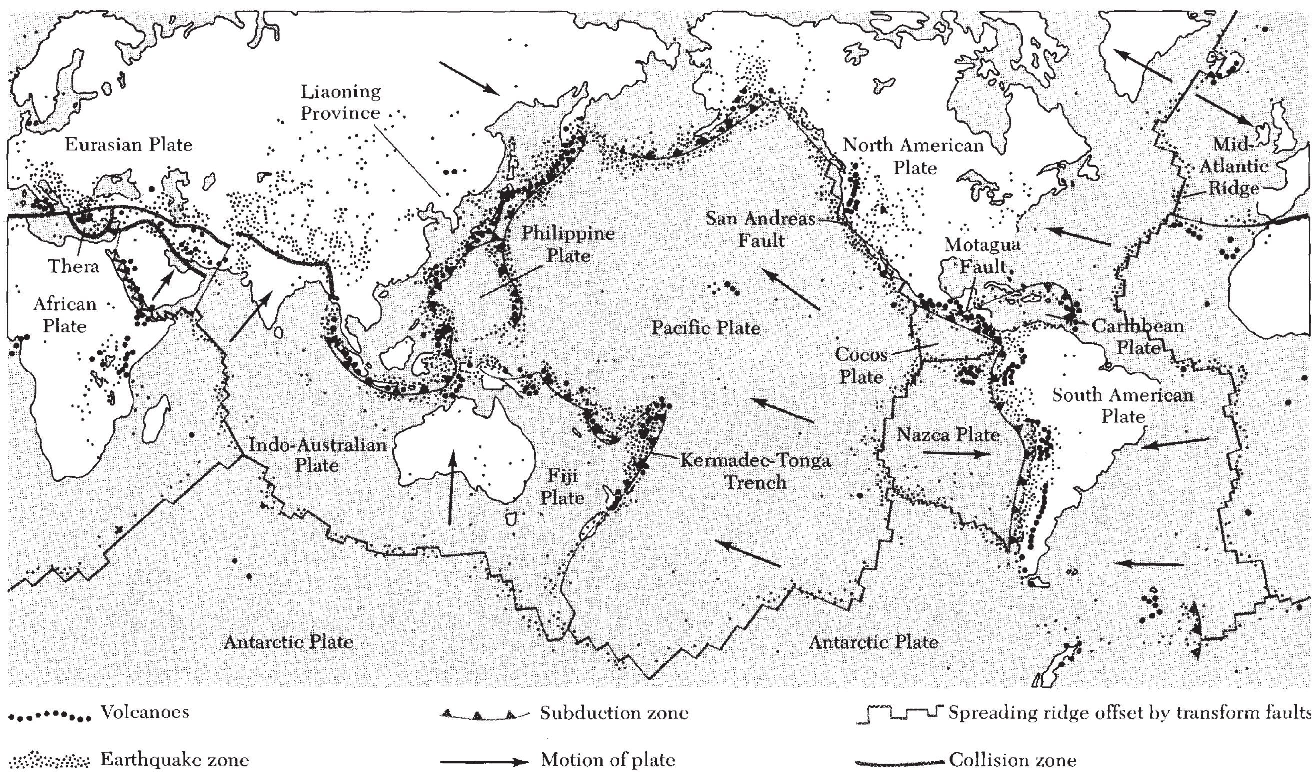


Figure 9-3 World Map Showing Relation Between the Major Tectonic Plates and Recent Earthquakes and Volcanoes.

Note: Earthquake epicenters are denoted by small dots, volcanoes by large dots.

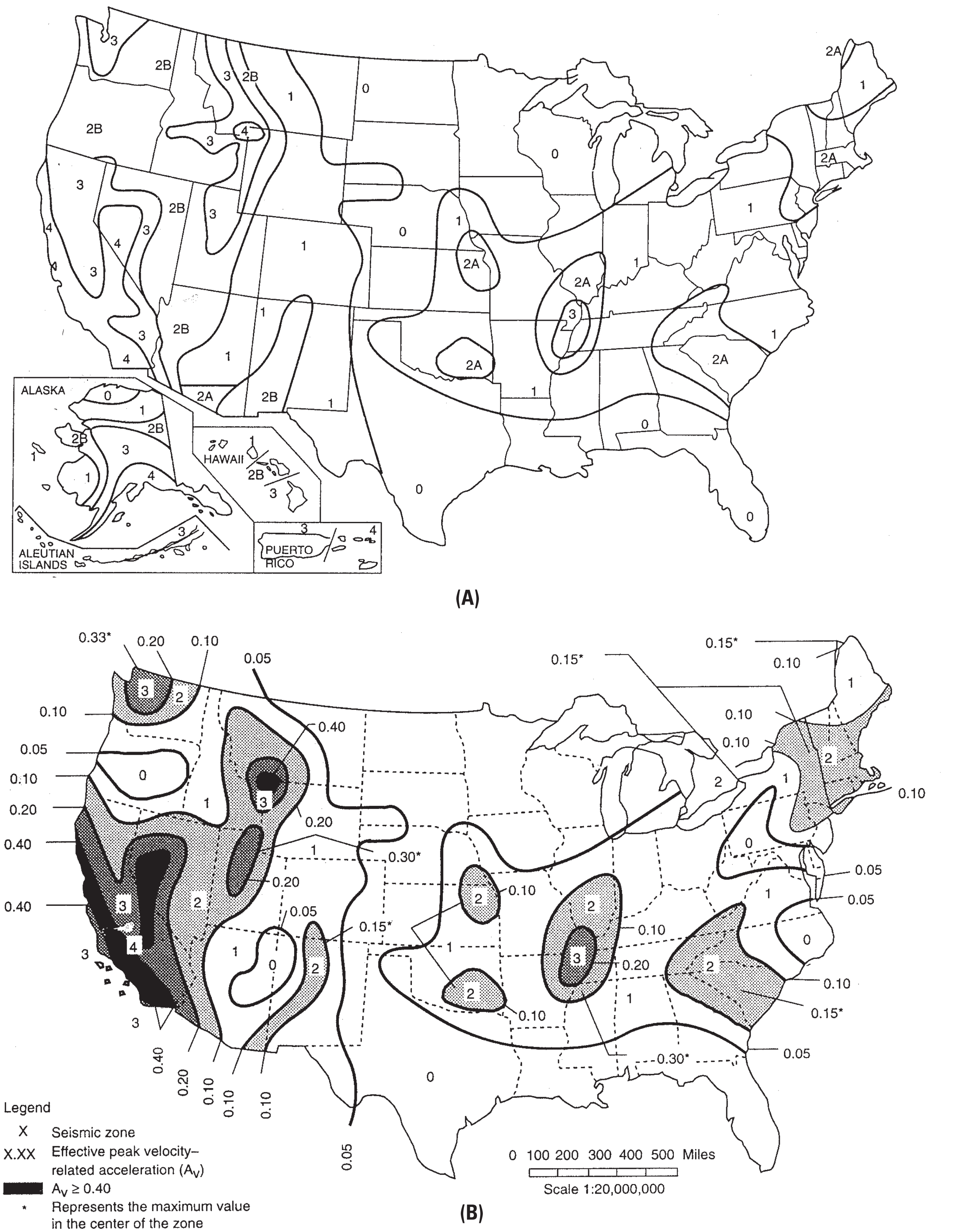


Figure 9-2 (A) Seismic Zone Map of the United States; (B) Map of Seismic Zones and Effective, Peak-Velocity-Related Acceleration (Av) for Contiguous 48 States.

Note: Linear interpolation between contours is acceptable.

of the middle and eastern United States, are not well understood.

The relative movement at plate boundaries is often a sliding action, such as occurs along the San Andreas Fault along the west coast of North America. The plates can also converge, when one plate slides beneath another, or diverge, when molten rock from below rises to fill the voids that gradually form. Although overall plate movement is extremely slow, properly measured only in a geologic time frame, the local relative movement directly at the fault plane can occur either gradually (creep) or suddenly, when tremendous energy is released into the surrounding mass.

The most common mechanism used to describe earthquakes is the “elastic rebound theory,” wherein a length of fault that is locked together by friction is strained to its capacity by the continuing plate movement, and both sides spring back to their original positions (See Figure 9-4). Waves in a variety of patterns emanate from this fault movement and spread in every direction. These waves change throughout the duration of the earthquake, add to one another, and result in extremely complicated wave motions and vibrations. At any site away from the fault, the three-dimensional movement of the surface, which is caused by combinations of direct, reflected, and refracted waves, is known simply as “ground shaking.” Energy content or intensity of the ground shaking decreases with distance from the causative fault, although because certain structures can be tuned into the motion, this is not always apparent. The horizontal, vertical, and rotational forces on structures are unpredictable in direction, strength, and duration. The structural load is proportional to the intensity of shaking and to the weight of the supported elements.

By combining knowledge of known fault locations with historical and instrumented ground motion records, seismologists can construct maps showing zones of varying expected ground motion. Figure 9-2 shows such maps, which were used to develop design criteria zoning for a national seismic code.

Damage from Earthquakes

Four separate phenomena created by earthquakes can cause damage:

1. Surface fault slip (ground rupture).
2. Wave action in water created by seismic movement (called tsunamis in open bodies of water, seiches in closed bodies of water).
3. Ground shaking.
4. Ground failure, such as a sudden change to liquid characteristics in certain sands caused by increased pore water pressure called "liquefaction" and "landslides."

It is accepted that buildings and their contents are not designed to withstand ground rupture caused by seismic events. Protection from this is obtained by avoiding potentially dangerous sites. Underground piping can be severely damaged by either fault rupture or ground failure, and frequently pipe lines must cross areas with these potential problems. Seismic design provisions for underground systems in these cases consist of special provisions for the considerable distortion expected in the ground or redundant systems and valving, such that local damage can be accepted without serious consequences.

EARTHQUAKE MEASUREMENT AND SEISMIC DESIGN

Ground Shaking and Dynamic Response

The primary thrust of seismic design, as it relates to buildings, is to protect against the effects of ground shaking. Although recently there has been concern that surface waves may damage structures by pure distortion, virtually all design is done assuming the entire ground surface beneath a structure moves as a unit, producing a shaking or random motion whose

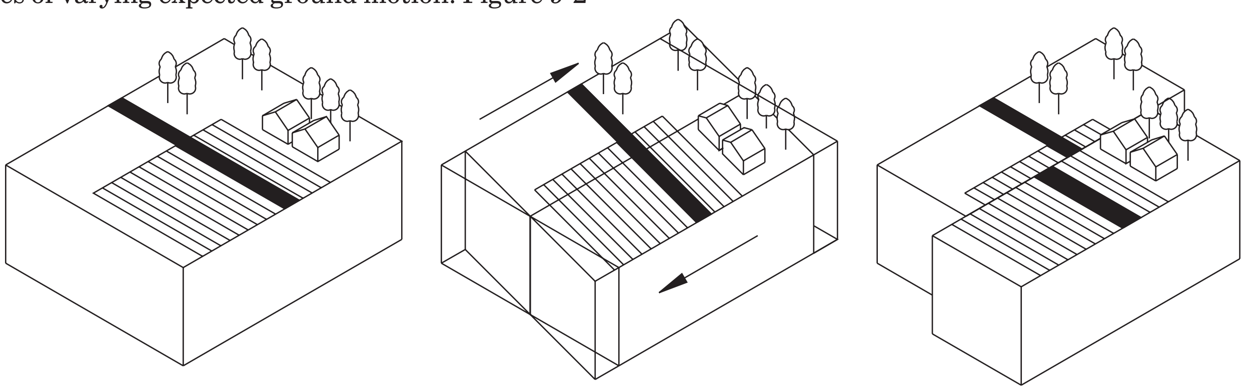


Figure 9-4 Elastic Rebound Theory of Earthquake Movement

According to the Elastic Rebound Theory, a fault is incapable of movement until strain has built up in the rocks on either side. As this strain accumulates, the earth’s crust gradually shifts (at a rate of about 2 inches a year along the San Andreas Fault). Rocks become distorted but hold their original positions. When the accumulated stress finally overcomes the resistance of the rocks, the earth snaps back into an unrestrained position. The “fling” of the rocks past each other creates the shock waves we know as earthquakes.

unidirectional components can be studied mathematically and whose effects on structures can be analyzed using structural dynamics and modeling. The movement of the ground mass under a building during an earthquake is measured and recorded using the normal parameters of motion, displacement, velocity, and acceleration. Two orthogonal plan components and one vertical component are used to completely describe the motion. The effect of each orthogonal plan component on the structure under design is considered separately.

The amplitude of displacement, velocity, and acceleration at any moment are, of course, related, as each measures the change in the other over time. Given the record of how one parameter has changed over time (time history), the other two can be calculated. However, due to the direct relationship of force to acceleration (F-Ma) and also because acceleration is easiest to instrumentally measure, acceleration has become the standard measurement parameter. The characteristically spiked and jagged shape of the acceleration time history (accelergram, Figure 9-5) is universally recognized as being associated with earthquakes.

When any nonrigid structure, such as the pendulum or cart and spring of Figure 9-6(A) is subjected to a time history of base motion, the movement (D) of the mass (M) can be measured over time, and this record of motions becomes the dynamic response (K). The dynamic response will be different than the input motion because of the inertial lag of the mass behind the base and the resultant energy stored by distorting the connecting structure. The dynamic response to any input motion, then, will depend on the size of the mass and the stiffness of the supporting structure.

The Response Spectrum

Because of the difficulty of measuring all the variations of distortion in a normal structure at each moment of time, a shorthand measure of maximum response is often used. The maximum response of a

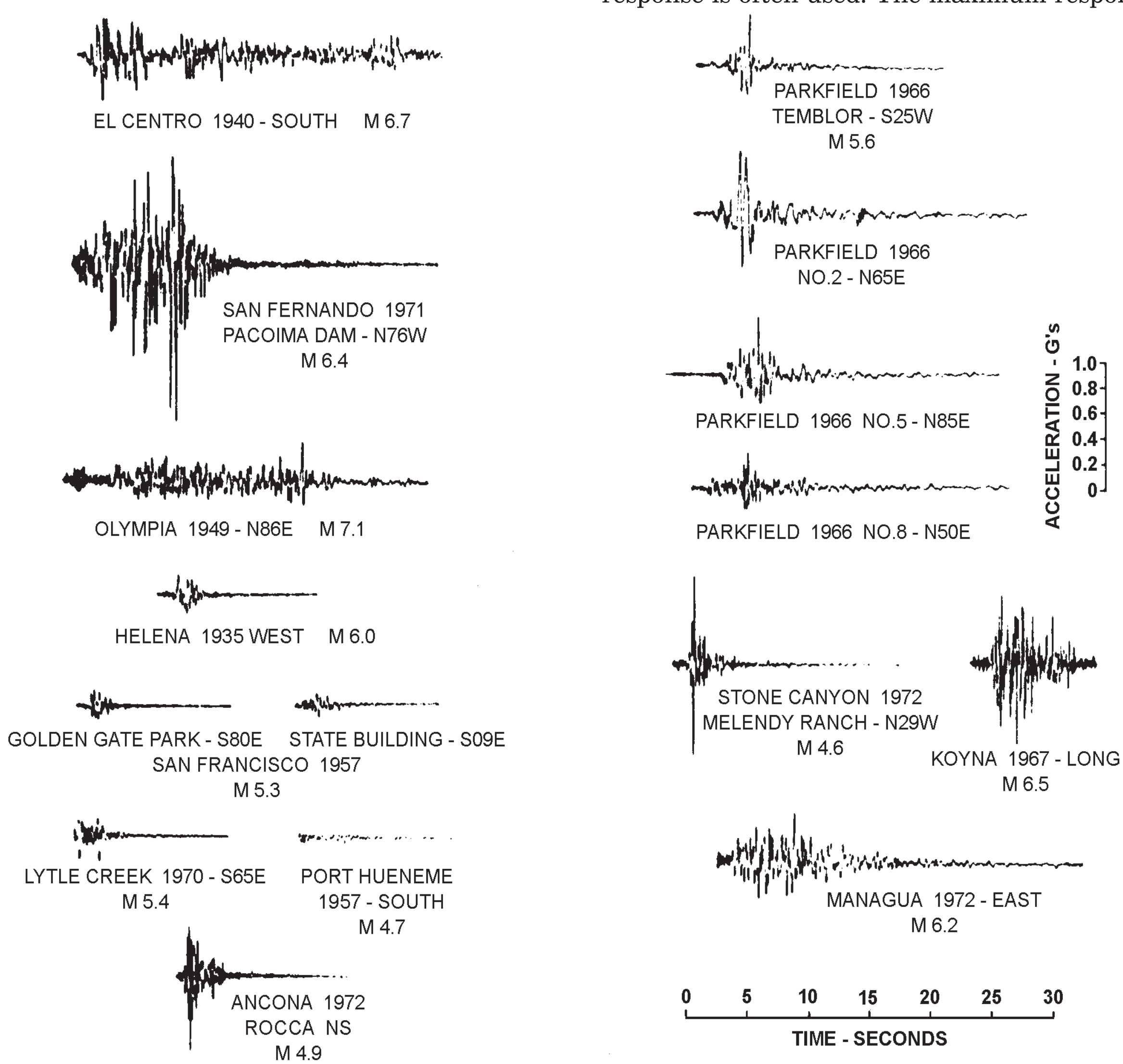


Figure 9-5 Earthquake Ground Accelerations in Epicentral Regions

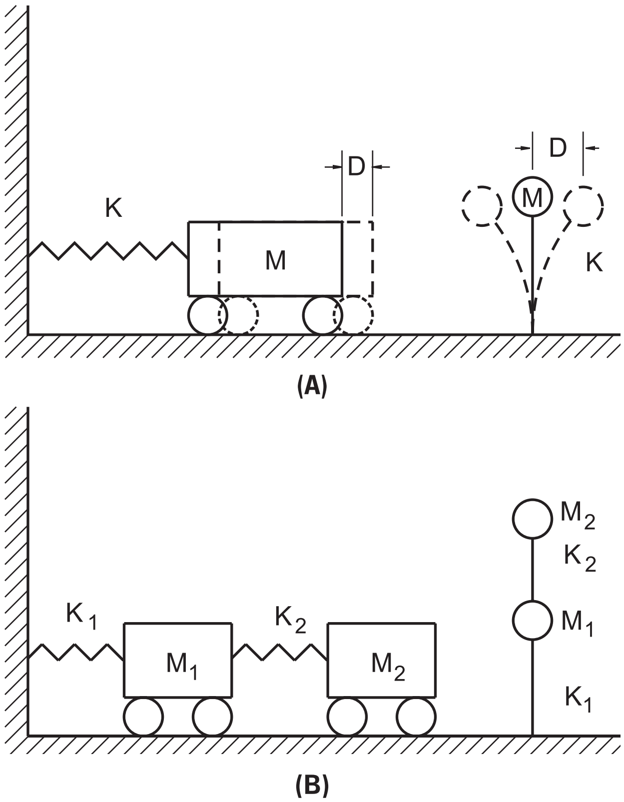


Figure 9-6 Undamped Mechanical Systems: (A) Single-Degree-of-Freedom Systems; (B) Multiple-Degree-of-Freedom Systems.

series of simple pendulums (single-degree-of-freedom system) to a given time history of motion is calculated, and the resulting set of maximums is known as a "response spectrum." (See Figure 9-7.) The response parameter could be displacement, velocity, or acceleration, although acceleration is most often used. The variation in dynamic characteristics of each pendulum in the infinite set is measured by the natural period of vibration. The natural period of any system is dependent on stiffness and mass and measures the length of one complete cycle of free (natural) vibration. Frequency, or the inverse of the period, is also often used in place of the period.

If the input motion (or forcing function) for a structure is of constant frequency and matches the natural frequency, resonance occurs, and the response is theoretically infinite. Damping that occurs to some degree in all real systems prevents infinite response, and the amplitude of the actual response will be proportional to the damping present. Damping is normally measured as a percentage of the amount of damping that would create zero response; that is, the pendulum when set in motion would simply return to its at-rest position. The damping in most structures is between 2 and 10 percent. For any input motion, the response would depend on the amount of damping present, and, therefore, responses (and response spectra) are often presented as families of similar curves, each corresponding to a different damping value. (Refer to Figure 9-7.)

By the response-spectrum technique, the maximum single response to a given base motion of a structure with a known period and damping can be predicted. It must be remembered that the response spectra eliminates the time element from consideration because the maximums plotted for each period are likely to have occurred at different times during the time history. Every ground motion will have its own distinct response spectrum, which will show on a gross basis which vibratory frequencies were predominant in motion. Since ground motions vary not only between earthquakes but between sites during the same earthquake, an infinite variety of response spectra must be considered possible. Fortunately, characteristics of wave transmission and physical properties of soil place upper bounds on spectral shapes. Using statistical analysis of many motions and curve fitting techniques, it is possible to create a design spectrum of energy stored by distorting the connecting structure. The spectrum that is theoretically most appropriate for a dynamic response to any input motion, then, will depend upon the region or even the given site.

With such a design spectrum for acceleration, measured in units of the acceleration of gravity (e.g., the maximum horizontal force in single degree of freedom), systems can be closely approximated using the ordinate as a percentage of the system.

Just as the response of a structure on the ground can be calculated by consideration of the ground motion time history, the response of a system on any floor of a building can similarly be calculated if the time history of the floor motion is known. Using computers, it is possible to calculate such floor motions in structures using base ground motion as input. Response spectra can then be calculated for each floor that would be appropriate for building contents or equipment. The vibratory response of the building is generally far more coherent than rock or soil, as the motion of floors is focused into the natural periods of the building. Floor response spectra are, therefore, often highly peaked around one or two frequencies, so responses nearer to theoretical resonance are more likely than they are on the ground. Responses 25 times greater than input acceleration can be calculated in such circumstances where response spectra for ground motion usually show response multiples of 25. (See US Department of Defense 1973.) These extreme responses are unlikely and are not considered in design, however, due to the many non-linearities in real structures and the low possibility of near-perfect resonance.

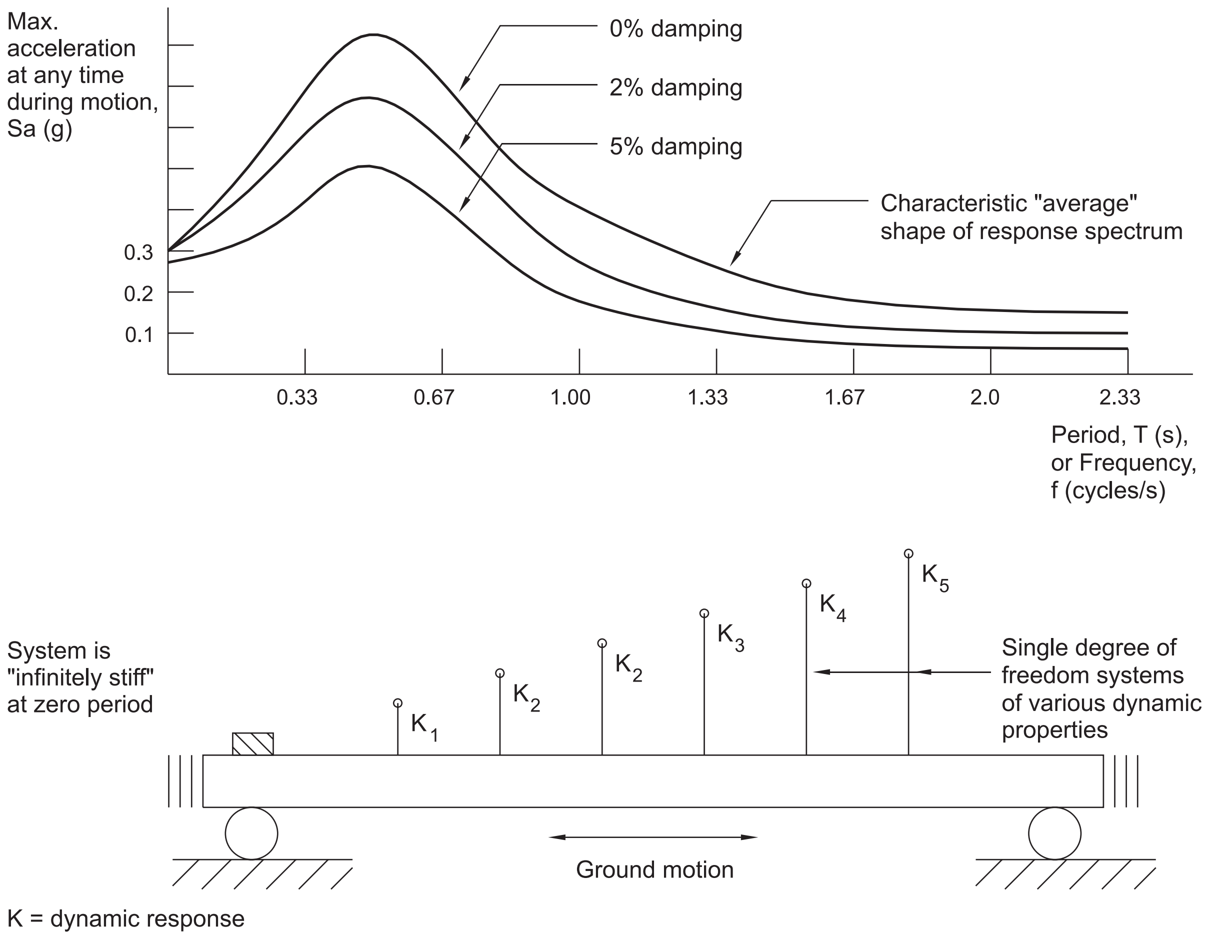


Figure 9-7 Response Spectrum

The response of multidegree-of-freedom systems [Figure 9-6(B)] cannot be simply calculated from a response spectrum, but spectra are often used to quickly approximate the upper limit of the total lateral force on the system. A "pseudo-dynamic elastic analysis" can be done on any system using response spectra to obtain a close approximation of maximum forces or distortions. These analyses are typically done by an experienced engineer using a computer, as they can be labor intensive if performed manually.

LEARNING FROM PAST EARTHQUAKES

Damage to Plumbing Equipment

Damage to plumbing equipment or systems in earthquakes occurs in two ways:

1. Failure due to forces on the element resulting from dynamic response to ground or floor shaking. The most common example is the sliding or overturning of tanks.
2. Failure due to forced distortions on the element caused by differential movement of two or more supports. This can occur at underground utility entrances to buildings, at building expansion or seismic joints, or, on rare occasions, even between floors at a structure due to interstory drift.

An obvious method of determining failure modes and isolation elements susceptible to damage is to study the experience of past earthquakes.

Particularly useful are the following summaries.[1] (Concerning piping, it should be pointed out that both reports indicate that damage was light on an overall basis; the scattered damage found was as described below.)

The 1964 Alaska Earthquake

Damage summary

1. Most pipe failures occurred at fittings. Most brazed or soldered joints were undamaged, many screwed joints failed, and a few caulked joints were pulled apart or twisted.
2. Failures in screwed joints often occurred where long unbraced horizontal runs of pipe joined short vertical risers or were connected to equipment. Small branch lines that were clamped tightly to the building were torn from large horizontal mains if these were unbraced and allowed to sway.

1. Ayres, Sun, et al. 1973 and Ayres and Sun 1973.

3. Joints were loosened or pulled apart in long horizontal runs of unbraced cast-iron pipe, and hangers were bent, shifted, or broken.
4. Pipes crossing seismic joints were damaged if provisions were not made for the relative movements between structural units of buildings.
5. Thermal expansion loops and joints were damaged when the pipes were not properly guided.
6. Fire-sprinkler piping was practically undamaged because it was provided with lateral bracing.
7. Sand filter, water softener, domestic hot water, heating-hot-water expansion and cold-water-storage tanks shifted, toppled, or rolled over when they were not firmly anchored to buildings.
8. Hundreds of small, gas-fired and electric domestic water heaters fell over. Many of the legs on which heaters stood collapsed, and vent connectors were damaged.
9. Some plumbing fixtures were damaged by falling debris.
10. Vertical plumbing stacks in tall buildings were practically undamaged.

The 1971 San Fernando Earthquake

Damage summary

1. Unanchored heavy equipment and tanks moved and damaged the connected piping.
2. Heavy equipment installed with vibration isolation mounts moved excessively, often destroyed the isolators, and damaged the connected piping.
3. Cast-iron supports for heavy cast-iron boilers failed.
4. Pipes failed at threaded connections to screwed fittings. Some cast-iron fittings were fractured.
5. Pipes were damaged when crossing separations between buildings.
6. Screwed pipe legs under heavy tanks failed, and angle iron legs were deformed.
7. Plumbing fixtures were loosened from mounts, and enamel was chipped.
8. Domestic water heater legs were bent or collapsed.

The overall recommendations applicable to plumbing equipment from the Alaska report, made primarily as a response to observed damage, are worth relating:

1. Pipelines should be tied to only one structural system. Where structural systems change, and relative deflections are anticipated, movable joints should be installed in the piping to allow for the same amount of movement.
2. Suspended piping systems should have consistent freedom throughout; for example, branch lines should not be anchored to structural elements if the main line is allowed to sway.
3. If the piping system is allowed to sway, movable joints should be installed at equipment connections.
4. Pipes leading to thermal expansion loops or flexible pipe connections should be guided to confine the degree of pipe movement.
5. Whenever possible, pipes should not cross seismic joints. Where they must cross seismic joints, appropriate allowance for differential movements must be provided. The crossing should be made at the lowest floor possible, and all pipe deflections and stresses induced by the deflections should be carefully evaluated. Standards of the National Fire Protection Association (NFPA) for earthquake protection to fire-sprinkler systems should be referred to for successful, field-tested, installation details that are applicable to any piping system. The latest revision to FM data sheet 2-8 for sprinkler systems is also valuable as a reference guide.
6. Supports for tanks and heavy equipment should be designed to withstand earthquake forces and should be anchored to the floor or otherwise secured.
7. Suspended tanks should be strapped to their hanger systems and provided with lateral bracing.
8. Pipe sleeves through walls or floors should be large enough to allow for the anticipated movement of the pipes and ducts.
9. Domestic water heaters should be provided with legs that can withstand earthquake forces, and the legs should be anchored to the floor and/or strapped to a structurally sound wall.
10. Earthquake-sensitive shut-off valves on gas-service lines should be provided where maximum protection from gas leaks is required.
11. Vibrating and noisy equipment should, if possible, be located far from critical occupancies, so that the equipment can be anchored to the structure, and vibration isolation is not required.

    Avoid mounting heavy mechanical equipment on the top or upper floors of tall buildings unless all vibration-isolation mounts and supports are carefully analyzed for earthquake-resistant design.

    When equipment and the attached piping must be isolated from the structure by vibration isolators, constraints should be used.

SEISMIC PROTECTION TECHNIQUES

General

Assuming that the building in which the piping systems are supported is designed to perform safely in response to earthquake forces, the piping systems must be designed to resist the seismic forces through the strength of the building attachments.

The design professional must consider local, state, and federal seismic requirements, as applicable, in the area of consideration. Only those engineers with seismic experience should design the supports required for seismic zones. Close coordination with the structural engineer is required to ensure the structural system properly supports the mechanical systems and equipment.

Equipment

Seismic protection of equipment in buildings, as controlled by the design professional, consists of preventing excessive movement that would either damage the equipment directly or break the connected services. Equipment certification is required in the International Building Code (IBC) 2000 for equipment with importance factor of 1.5. Also, piping systems with importance factor of 1.5 must be completely designed and detailed on the plans including supports and restraints. These are major issues.

Other than meeting the requirements set forth in IBC 2000, the ability of the equipment housing or working parts to withstand earthquake vibration is generally not formally considered for one or more of the following reasons:

1. Such failure would not endanger life.
2. Continued functioning is not always required.
3. Most equipment will experience transportation shocks or working vibrations that are similar to earthquake motions, and the housing and internal parts are therefore considered adequate.
4. The design professional has little control over the manufacturing process. Competitively priced equipment specially qualified to resist earthquake motion is not available.
5. Because of a lack of performance data for equipment that is anchored, the extent of the problem is unknown.

Movement to be prevented is essentially overturning and sliding, although these effects can take place with a variety of characteristics:

1. Overturning (moment).
   - A. Overturn of equipment.
   - B. Failure in tension or compression of perimeter legs, vibration isolators, hangers, or their supports.
   - C. Excessive foundation rotation.
2. Sliding (shear).
   - A. Sliding of floor-mounted equipment.
   - B. Swinging of hung equipment.
   - C. Excessive sideways failure of legs, stands, tank mounts, vibration isolators, or other supports. Although these failures are often described as local overturning of the support structure, they are categorized as a shear or sliding failure because they are caused by the straight lateral movement of the equipment rather than the tendency to overturn.

Prevention of overturning and sliding effects can best be discussed by considering the categories of mounting equipment, such as fixed or vibration-isolated, and floor-mounted or hung.

Fixed, floor-mounted equipment This group includes tanks, water heaters, boilers, and other equipment that can rest directly on the floor. Although anchoring the base of such equipment to the floor is obvious, simple, and inexpensive, it is commonly omitted. Universal base anchorage of equipment undoubtedly would be the single largest improvement and would yield the largest cost-benefit ratio in the entire field of seismic protection of plumbing equipment. This anchoring is almost always to concrete and is accomplished by cast-in-place anchor bolts or other inserts, or by drilled or shot-in concrete anchors. The connection to the equipment base is totally configuration dependent and may require angles or other hardware to supplement the manufactured base. For elements that have a high center of gravity, it may be most efficient to resist overturning by bracing at the top, either diagonally down to the floor, to the structure above, or to adjacent structural walls. Vertical steel beams, or "strongbacks," can also be added on either side of tall equipment to span from floor to floor; a vertical slip joint connection should be placed at the top of such beams to avoid unexpected interaction between the floor structures.

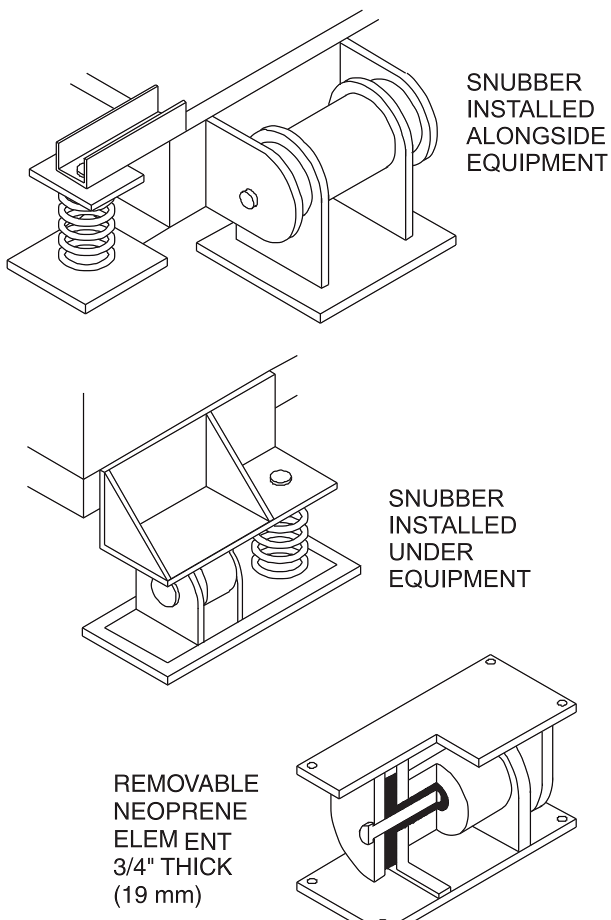
Tanks supported on cast-iron legs or threaded pipes have proven to be particularly susceptible to support failure. These types of legs should be avoided or have supplemental bracing.

The horizontal earthquake loads from equipment mounted on or within concrete stands or steel frames should be braced from the equipment through the support structure and out the base. Concrete tank saddles often are not attached to the tank, are of inadequate strength (particularly in the longitudinal direction), are not anchored to the floor foundation, or have inadequate provisions for earthquake-generated forces in the floor or foundation. Steel equipment frames often have similar problems, some of which can be solved by diagonal bracing between legs.

Fixed, suspended equipment The most common element in this group is the suspended tank. Seldom are these heavy elements laterally braced. The best solution is to install the tank tightly against the structural member above, thus eliminating the need for bracing. However, even these tanks should be secured to the suspension system to prevent slipping. Where the element is suspended below the supporting member, cross-bracing should be installed in all directions to provide lateral stability. Where a tank is suspended near a structural wall, struts to the wall may prove to be simpler and more effective than diagonal bracing.

Vibration-isolated, floor-mounted equipment This group includes units containing internal moving parts, such as pumps, motors, compressors, and engines. The entire concept of vibratory isolation by flotation on a nontransmitting material (spring, neoprene, cork, etc.), although necessary for equipment-operating movement, is at cross-purposes with seismic anchorage. The isolation material generally has poor lateral, force-carrying capacity in itself, plus the housing devices are prone to overturning. It is, therefore, necessary to either supplement conventional isolators with separate snubbing devices (Figure 9-8), or to install specially designed isolators that have built-in restraints and overturning resistance (Figure 9-9). Isolators with minimal lateral-force resistance used in exterior applications to resist wind are usually inadequate for large seismic forces and are also commonly made of brittle cast iron. The possibility of complete isolator unloading and ensuing tension forces due to overturning or vertical acceleration also must be considered. Manufacturers' ratings of lateral loads for isolators should be carefully examined, for often the capacity is limited by the anchorage of the isolators themselves, which is normally unspecified.

The containment surfaces in these devices must be hard connections to the equipment or its base to avoid vibratory short circuits. Because this requirement for complete operational clearance allows a small, ¼-d" (6.4-9.5 mm), movement before restraint



(A)

Figure 9-8 Snubbing Devices:
(A) Three-Dimensional Cylinder Snubber

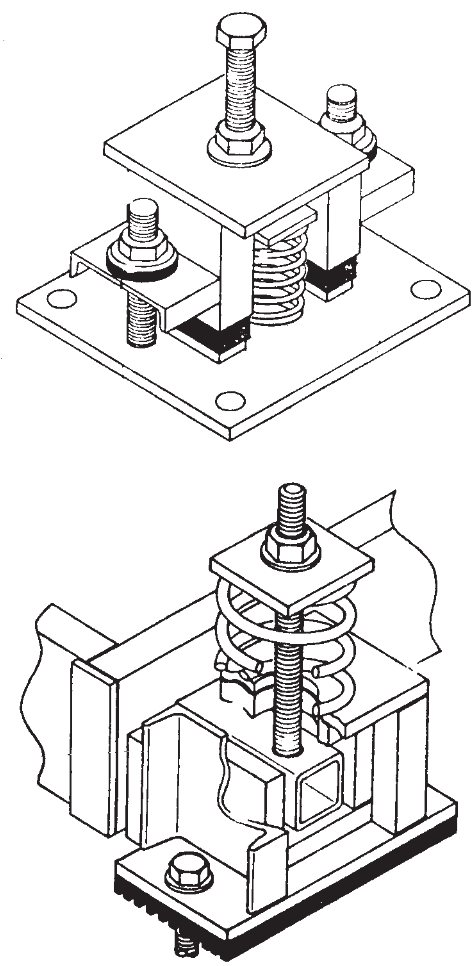
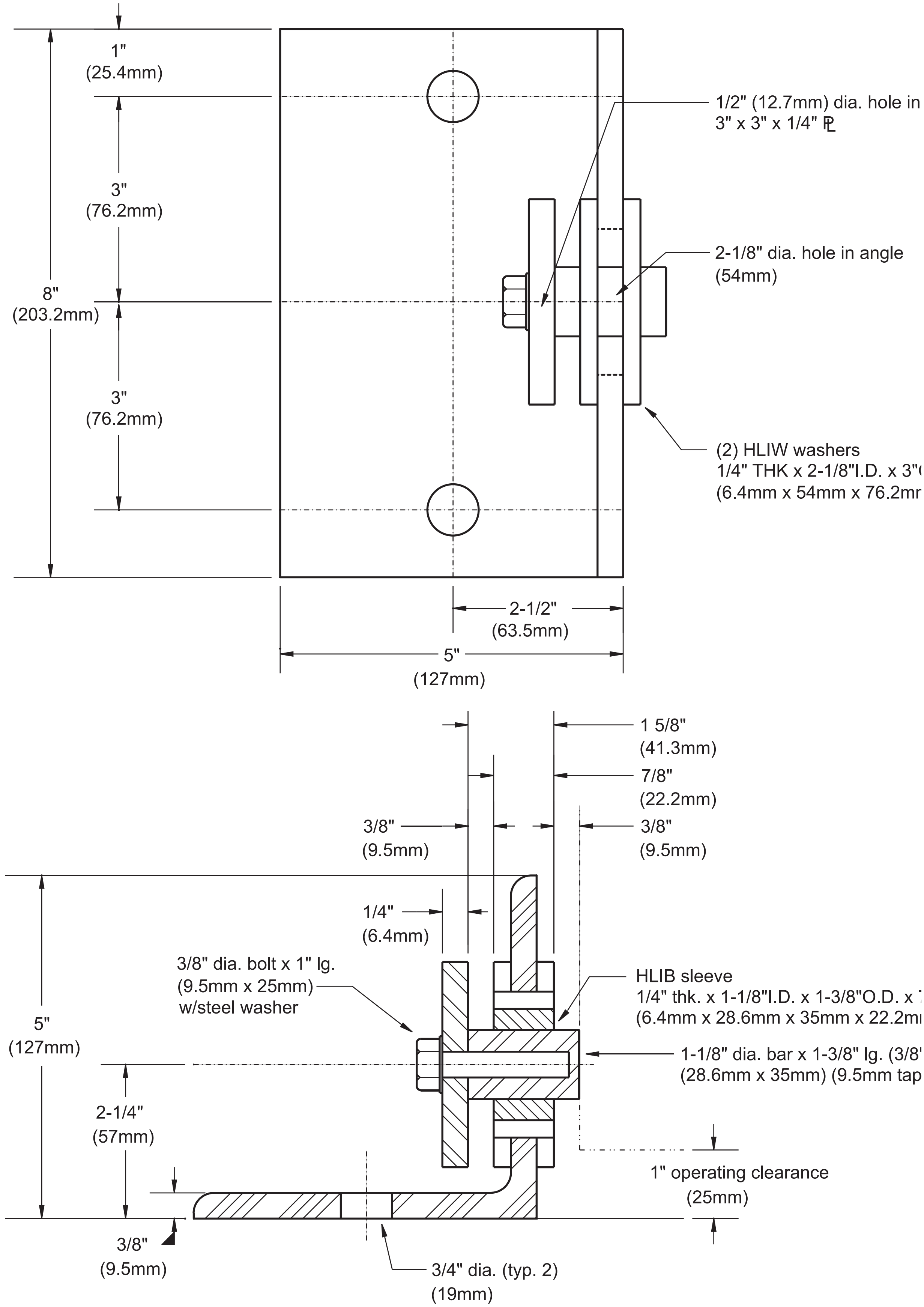


Figure 9-9 Isolators with Built-In Seismic Restraint



(B)

Figure 9-8 Snubbing Devices: (B) Three-Directional Angle Snubbers

begins, resilient pads are added to ease the shock load that could be caused by impact.

Because of the stored energy in isolation springs, it is more efficient to anchor the assembly, as restraint is built into the isolator rather than being a separate unit. In retrofit applications, or occasionally due to dimensional limitations, separate snubbers are preferable. Once snubbers are decided upon, those that restrain in three dimensions are preferred because that minimizes the number required. Although some unconfirmed rubber-in-shear isolators are intended to resist loads in several directions, there is little data to indicate adequacy to resist the concurrent large amplitude dynamic loading that could occur in an earthquake. Unless such isolators are considered for real earthquake loading (as opposed to code requirements) with a suitable safety factor, additional snubbing is recommended. Rubin-in-shear isolators with metal housing are more likely to have the overload capacity that may be needed to resist seismic loading, but unless they are specifically tested and rated for this loading, ultimate capacities should be compared with expected real seismic loads.

Vibration-isolated, suspended equipment This is by far the most difficult type of equipment to restrain, particularly if only a small movement can be tolerated. The best method is to place an independent, laterally stable frame around the equipment with proper operating gaps padded with resilient material, similar to a snubber. However, this frame and its support system can be elaborate and awkward. An alternate method is to provide a self-contained, laterally stable, suspended platform upon which conventional seismic isolators or snubbers can be mounted.

Smaller equipment bolted or welded directly to the structure doesn't need restraints, but the bolts or welds must be designed for seismic loads. However, equipment suspended close to the structure requires restraints. Isolators within hangers should always be installed tight against the supporting structural member. When hanger rods are used to lower the unit, cross bracing or diagonal bracing should be installed.

Cable that is installed taut, but allowed to sag under its own weight will allow vibration isolation to function. Additional slack is not required and should not be allowed. Use of neoprene grommets or bushings is not required. The cable sag and cable flexibility provide adequate cushioning.

Piping Systems

Normally, piping suspended by hangers less than 12 inches (305 mm) in length, as measured from the top of the pipe to the bottom of the support where the hanger is attached, do not require bracing. The following piping shall be braced:

1. Fuel oil, gas, medical gas, and compressed air piping 1-inch (25.4-mm) nominal diameter and larger.
2. Piping in boiler rooms, mechanical rooms, and refrigeration mechanical rooms 1¼-inch (31.8-mm) nominal diameter and larger.
3. All piping 2½-inches (63.5-mm) nominal diameter and larger.

Conventionally installed piping systems have survived earthquakes with minimal damage. Fitting failures generally occur at or near equipment connectors where equipment is allowed to move, or where a main is forced to move and small branches connected to the main are clamped to the structural elements. In theory, then, a few well-placed pipe restraints in the problem areas could provide adequate seismic protection. In practice, however, the exact configuration of piping is seldom known to the designer, and even if it was, the key brace locations are not easy to determine. Often, partial restraint in the wrong location is worse than no restraint at all. Correct practice is therefore to provide complete restraint when seismic protection of piping systems is advisable. This restraint can be applied throughout the system or in local, well-defined areas such as mechanical or service rooms.

Although there are many variables to consider when restraining pipe against seismic movement, the techniques to do so are simple and similar to those used for hanging equipment. Fixing pipe directly to structural slabs, beams, columns, or walls is, of course, the simplest method. Many codes and guidelines consider hangers of less than 12 inches (305 mm) as being equivalent to direct attachment. For pipes suspended more than 12 inches (305 mm), diagonal braces to the structure above or horizontal struts to an adjacent structure are normally installed at vertical hanger locations. Vertical suspension hardware is usually incorporated into braces, both for efficiency and because it is readily available.

Connection to the pipe at transverse braces is accomplished by bearing the pipe or insulation on the pipe clamp or hanger. Attachment to the pipe at longitudinal brace points is not as simple. For small loads, tight-fitting clamps (such as riser clamps) dependent on friction are often used. For larger loadings, details commonly used for anchor points in high-temperature systems with welded or brazed direct connections to the piping may be necessary. Welding should be done by certified welders in accordance with American Welding Society (AWS) D 1.1 and shall use either the shielded or submerged arc method.

Transverse bracing shall be at 40 feet (12.2 m) maximum spacing, except that fuel oil and gas piping shall be at 20 feet (6.1 m) maximum spacing. Longitudinal bracing shall be at 80 feet (24.4 m) maximum spacing, except that fuel oil and gas piping shall be at 40 feet (12.2) maximum spacing.

The many parameters that must be considered before the exact details and layout of a pipe bracing system can be completed are shown schematically in Figure 9-10. These parameters are discussed in more detail below:

1. *Weight of pipe and contents* Since the motion being restrained is a dynamic response, the forces that must be resisted in each brace are proportional to the tributary weight.
2. *Location of pipe* The strength of structural members, particularly compression members, is sensitive to length, so a pipe that must run far from a structural support may require more or longer braces. In boiler service rooms, a horizontal grid of structural beams has sometimes been placed at an intermediate height to facilitate bracing of pipes.
3. *Type of structure* The connection of hangers and braces to the structure is an important factor in determining a bracing system, as demonstrated by the following considerations: Many light roof-deck systems cannot accept point loads except at beam locations; pipe locations and brace layout are thereby severely limited unless costly cross beams are placed at every brace. Other roof and floor systems have significant limitations on the magnitude of point loads, which limit brace spacing.

   It is often unacceptable to have anchors drilled or shot into the underneath of prestressed concrete floors. Limitations on depth and location also exist in the bottom flange of steel or reinforced concrete beams and in the bottom chord of joists.

   Many steel floor-deck styles have down flutes 1½ in. (38.1 mm) or less in width; the strength of drilled or shot-in anchors installed in these locations is questionable.

   The structures of buildings that employ interstitial space may have the capacity to brace pipe to either the top or the bottom of the space, which greatly increases bracing layout flexibility.
4. *Piping material* The strength and ductility of the material will affect brace spacing. The stiffness will affect dynamic response and therefore loading.
5. *Joint type* The joint has proven to be the element most likely to be damaged in piping systems; threaded and bell-and-spigot joints have been particularly susceptible. The joint type also determines, in conjunction with the pipe material, the length of the span between braces. Brazed and soldered joints perform acceptably. Most no-hub joints, however, have virtually no stiffness; effective bracing of such systems is nearly impossible. Mechanical joints exhibit the most complex behavior, with spring-like flexibility (when pressurized) within a certain rotation and then rigidity. In addition, the behavior of such systems under earthquake conditions, which cause axial loadings necessary to transmit forces to longitudinal braces, is unknown. As a minimum, cast iron and glass pipe, and any other pipe joined

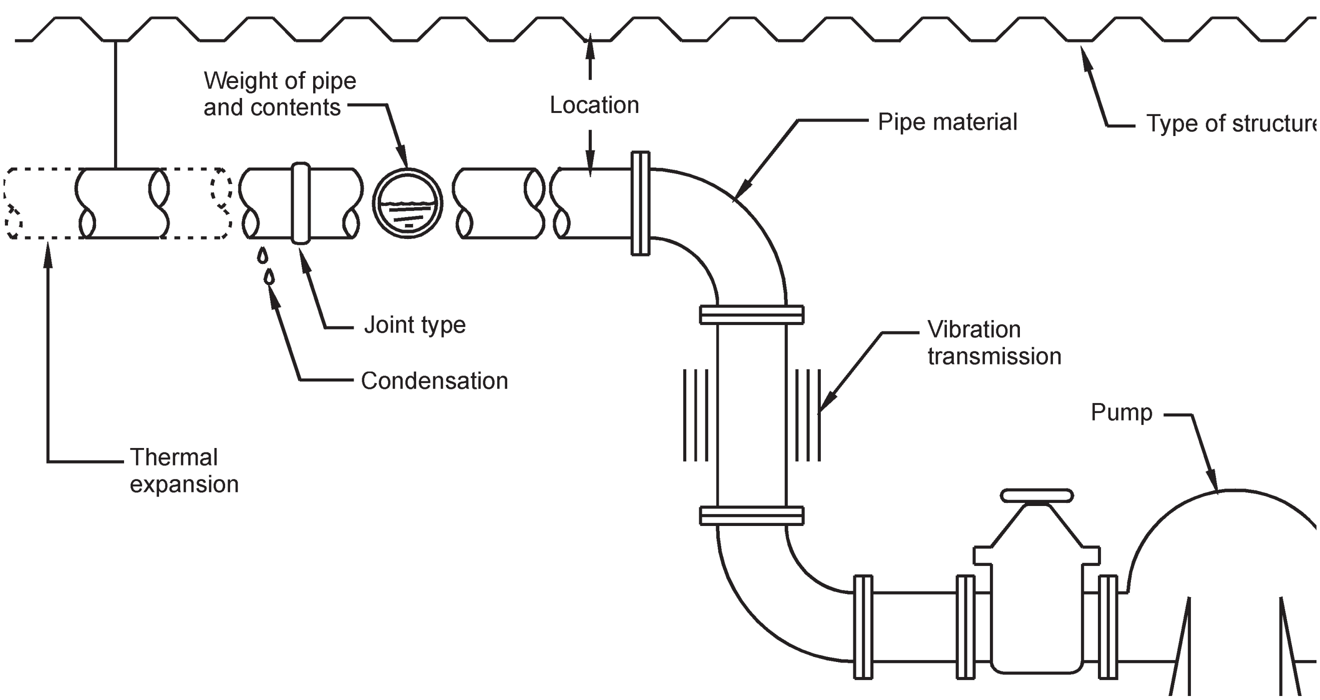


Figure 9-10 Parameters to be Considered for Pipe Bracing

with a shield-and-clamp assembly, where the top of the pipe exceeds 12 inches (305 mm) from the supporting structure, shall be braced on each side of a change of direction of 90 degrees or more. Riser joints shall be braced or stabilized between floors. For hubless, pipe-riser joints unsupported between floors, additional bracing is required. All pipe vertical risers shall be laterally supported with a riser clamp at each floor.

6. *Vibration* Traditionally, unbraced pipe systems seldom cause vibration transmission problems because of their inherent flexibility. Many engineers are concerned that completely braced "tight" piping systems could cause unpredictable sound and vibration problems.

7. *Temperature movement* Pipe anchors and guides used in high-temperature piping systems must be considered and integrated into a seismic bracing system. A misplaced longitudinal brace can become an unwanted anchor and cause severe damage. Thermal forces at anchor points, unless released after the system is operational, are additive to tributary seismic forces. Potential interference between seismic and thermal support systems is particularly high near pipe bends where a transverse brace can become an anchor for the perpendicular pipe run.

8. *Condensation* The need to thermally insulate high-temperature and chilled water lines from hanging hardware makes longitudinal brace attachment difficult. In some configurations of short runs with bends, transverse braces can be utilized near elbows to brace the system in both directions. Friction connections, using wax-impregnated oak or calcium-silicate sleeves as insulators, have been used.

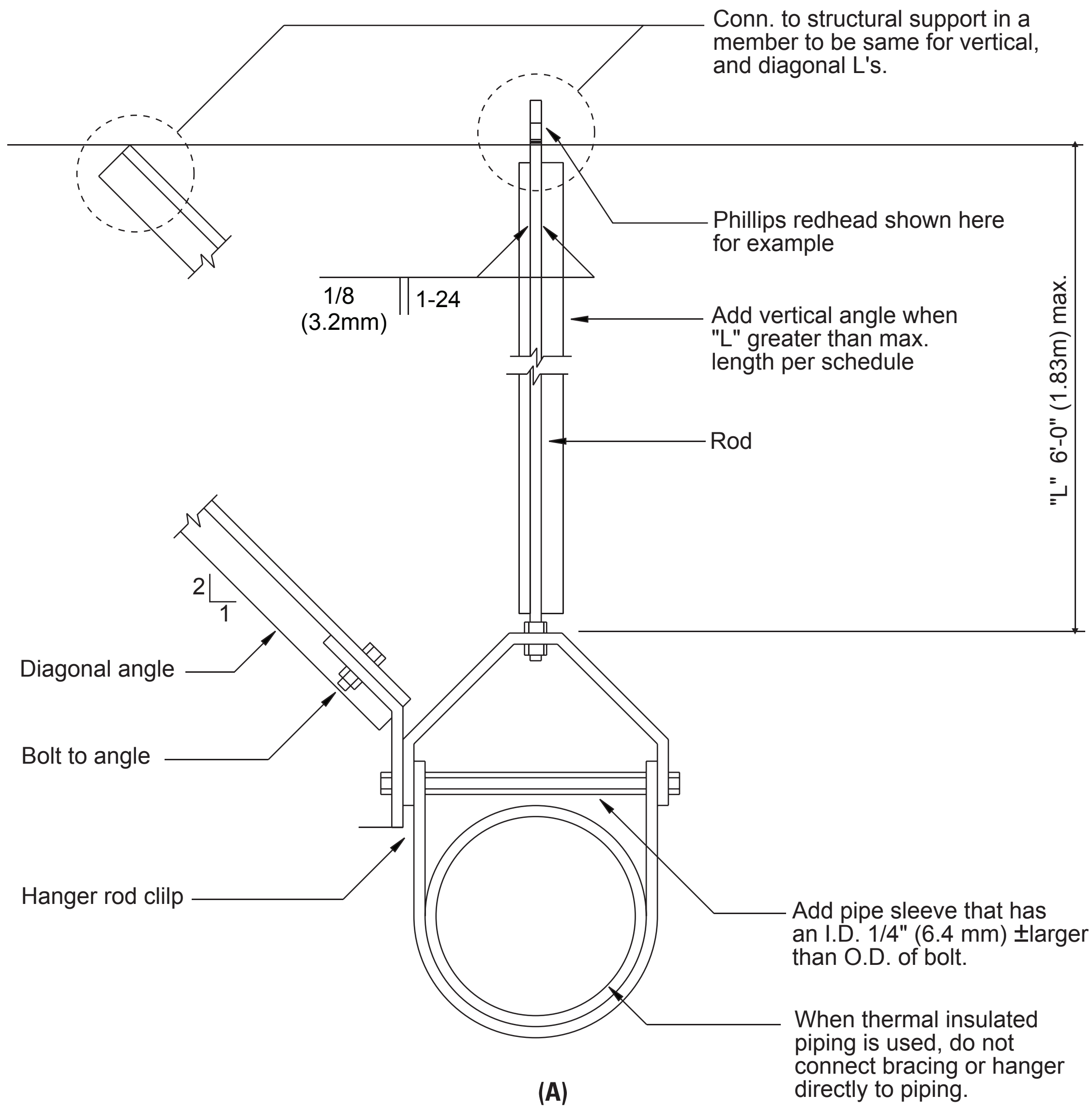
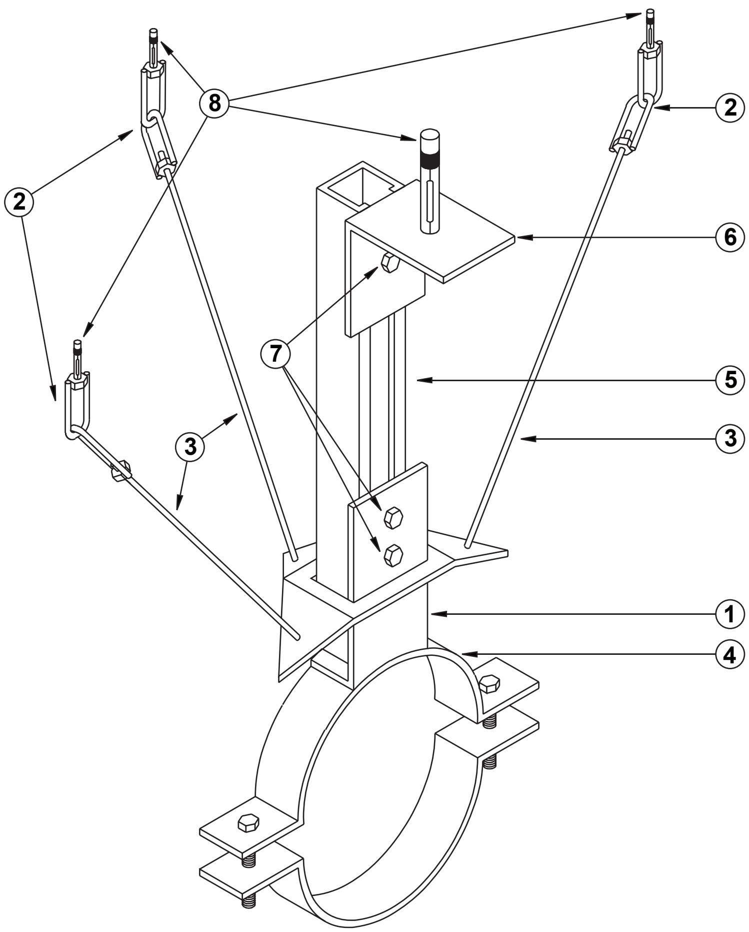
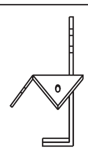
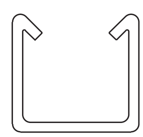
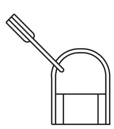
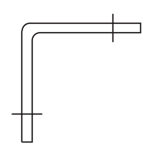
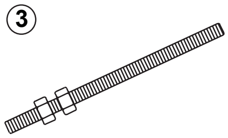
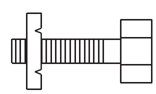
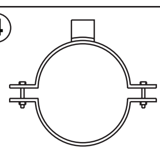
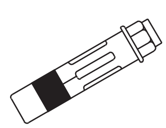


Figure 9-11 Pipe Bracing Systems: (A) Typical Pipe Bracing

Source: SMACNA



1 	Triangle Plate 1/4" Plate 1/4"X1-1/4" Flat Bar	5 	1-1/4"x1-1/4"x12 Ga. Channel Length Varies (Not Included)
2 	1/2" Flexible Connector	6 	1/4" Angle Clip
3 	1/2" All-Thread Rod (Not Included) Length Varies With Nylon Lock Nut	7 	1/4" Dia Mach. Bolt with Clamp Nut 30 Ft # Torque
4 	Pipe Hanger Size and Type Can Vary	8 	Phillips Sleeve Anchor

(B)

Figure 9-11 Pipe Bracing Systems: (B) Tension 360

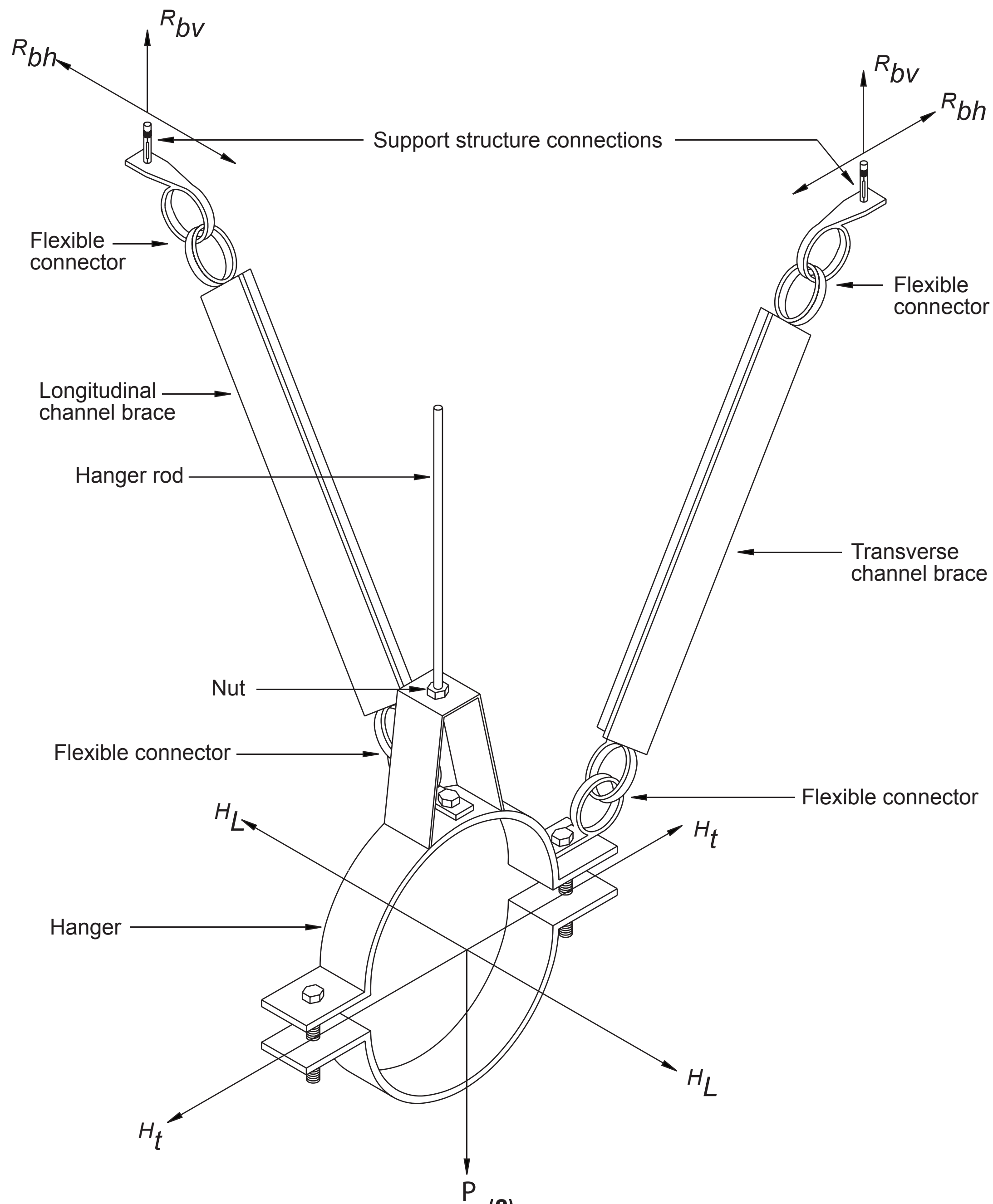


Figure 9-11 Pipe Bracing Systems: (C) Superstrut.

Several bracing systems have been developed that contain some realistic and safe details governing a wide range of loading conditions and configurations. For example, SMACNA (Sheet Metal and Air Conditioning Contractors' National Association) and PPIC (Plumbing and Piping Industry Council) have prepared some guidelines on bracing systems for use by engineers, architects, contractors, and approving authorities. Some of these details for construction of seismic restraints are seen in Figures 9-11 and 9-12.

The guidelines set forth by SMACNA and PPIC utilize three pipe-bracing methods:

1. The structural angle.
2. The structural channel.
3. The aircraft cable method. (See Figure 9-12.)

Several manufacturers have developed their own seismic bracing methods. (See Figures 9-13 and 9-14.)

Whatever method is used, one should determine the adequacy of the supporting structure by properly applying acceptable engineering procedures.

Pipe risers seldom pose a problem because they are normally clamped at each floor and movement due to temperature changes are routinely considered. Very large or stiff configurations, which could be affected by interstory drift, or situations where long, free-hanging horizontal runs could be inadvertently "braced" by a riser, are possible exceptions. The effect of mid-span couplings with less strength or rigidity than the pipe itself must also be considered.

The techniques for handling the possible differential movement at locations of utility entrances to buildings or at building expansion joints are well developed because of the similarity to nonseismic problems of settlement, temperature movement, and wind drift. Expansion loops or combinations of mechanically flexible joints are normally employed. For threaded piping, flexibility may be provided by the installation of swing joints. For manufactured ball joints, the length of piping offset should be calculated using seismic drift of 0.015 feet per foot (0.0046 meter per meter) of height above the base where seismic separation occurs. The primary consideration in seismic applications is to recognize the possibility of repeated, large differential movements.

CODES

Design Philosophy

The process of the seismic design for buildings has had a reasonably long time to mature. Beginning in the 1920s, after engineers observed heavy building damage from earthquakes, they began to consider lateral forces on buildings in this country and Japan. Today's procedures are based on analytical results as well as considerable design experience and observed performance in earthquakes of varying characteristics. Lateral forces for buildings specified in most codes are much lower than could be calculated from structural dynamics for a variety of reasons, including:

1. Observed acceptable performance at low design levels.
2. Expected ductile action of building systems (ability to continue to withstand force and distort after yielding). Redundancy of resisting elements in most systems.
3. High damping as distortions increase, which creates a self-limiting characteristic on response.

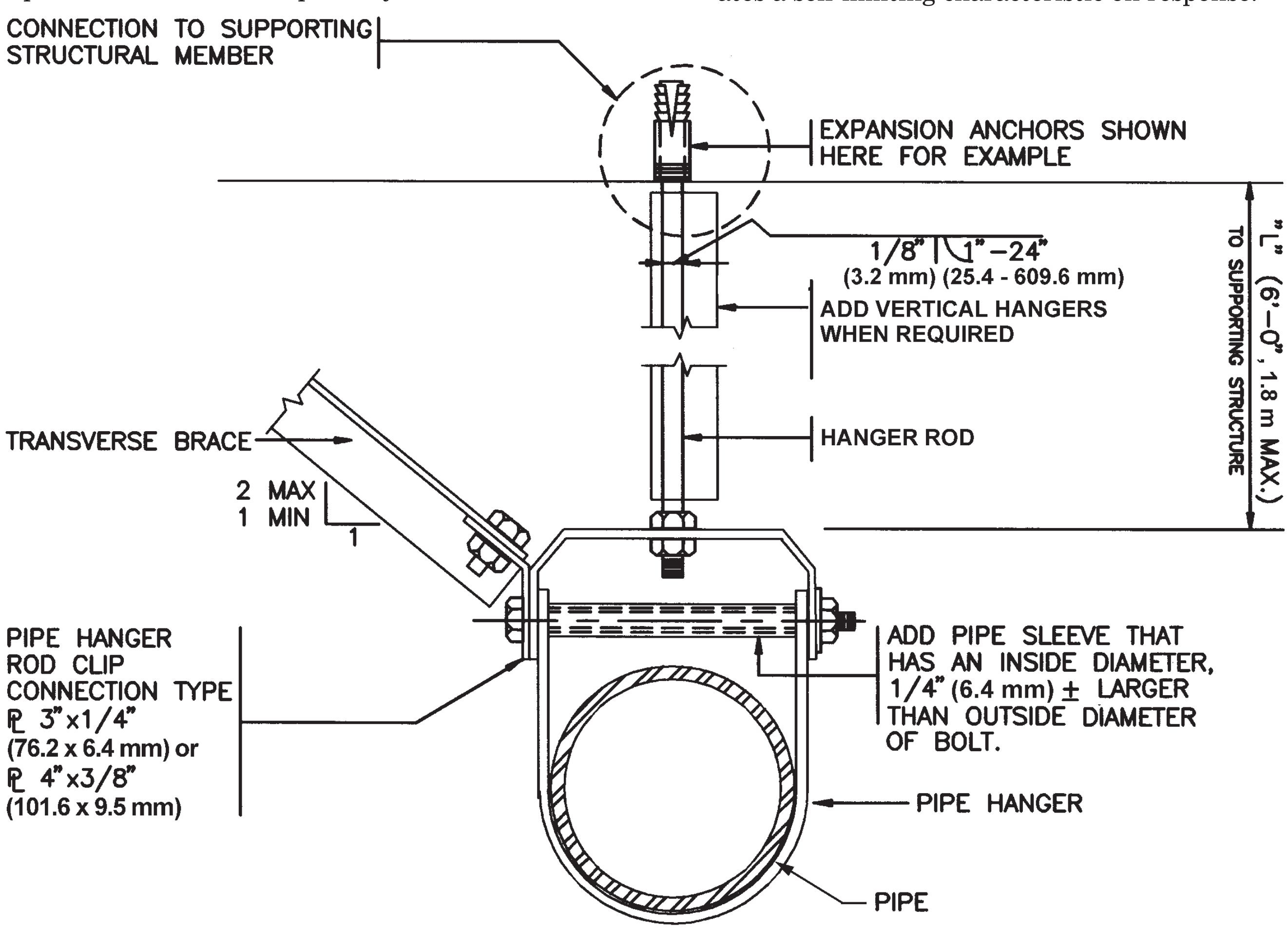
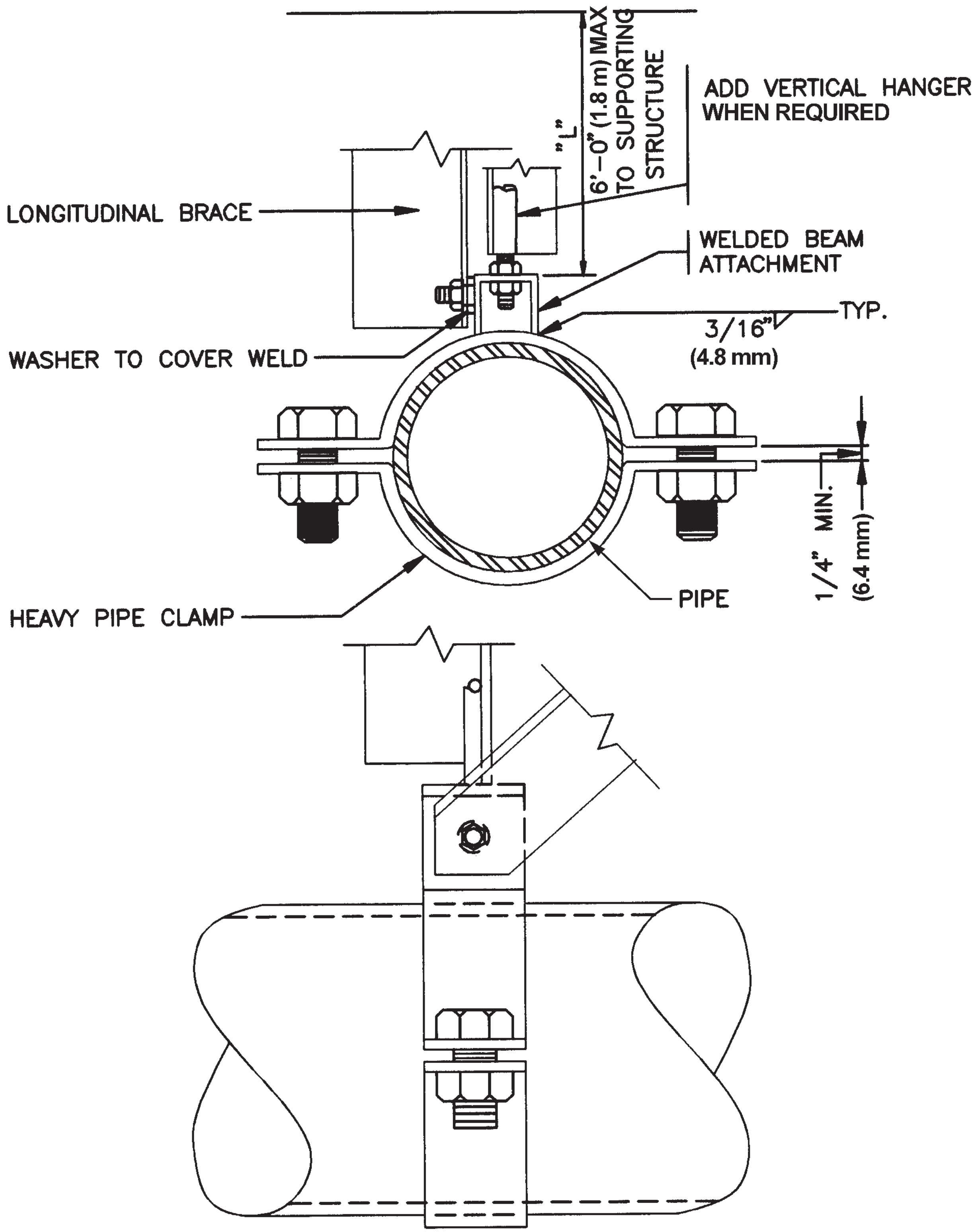


Figure 9-12 Construction Details of Seismic Protection for Pipes: (A) Transverse Bracing for Pipes

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.

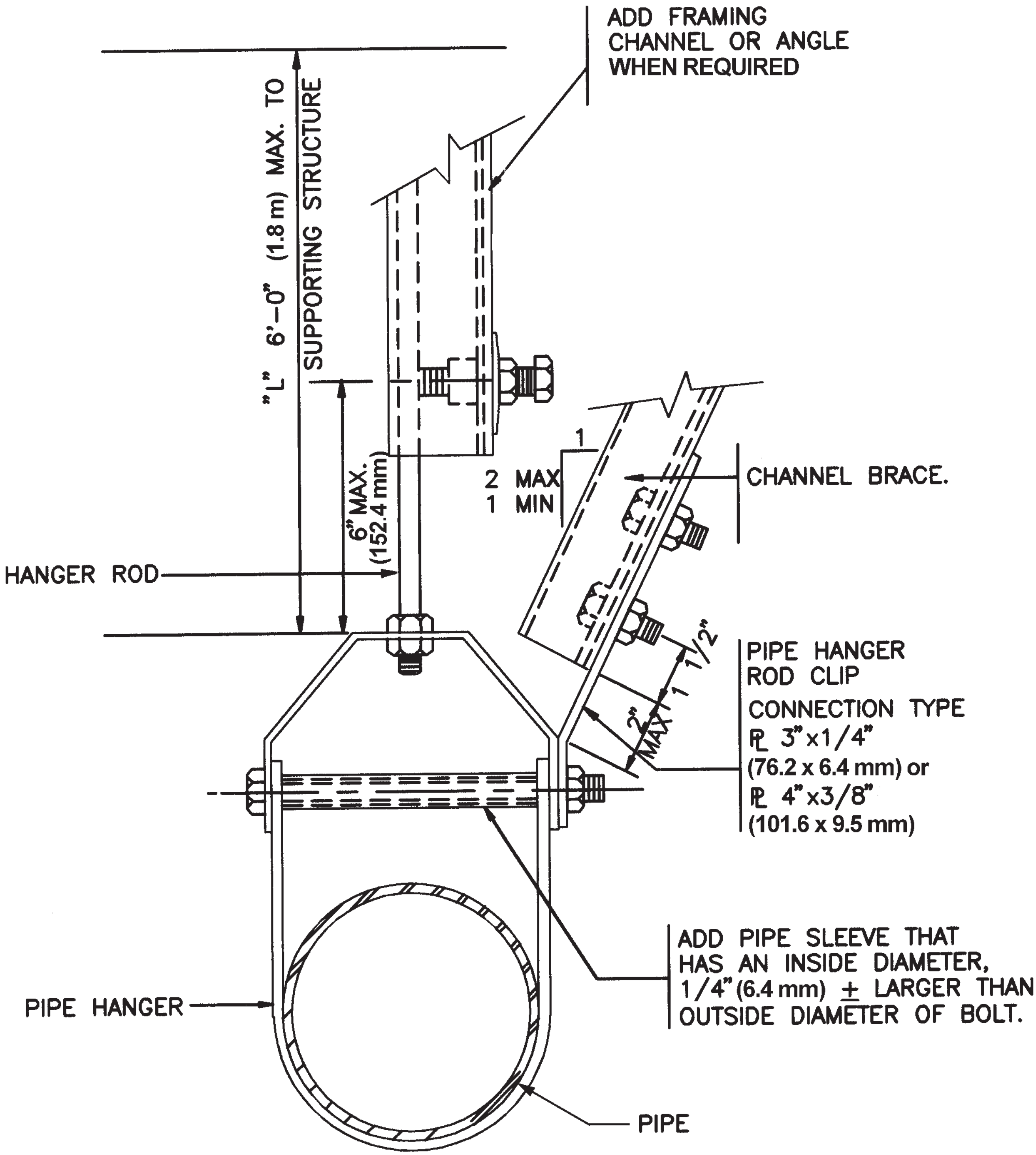


(B)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (B) Longitudinal Bracing for Pipes

Note: Movement due to temperature has been neglected in this example.

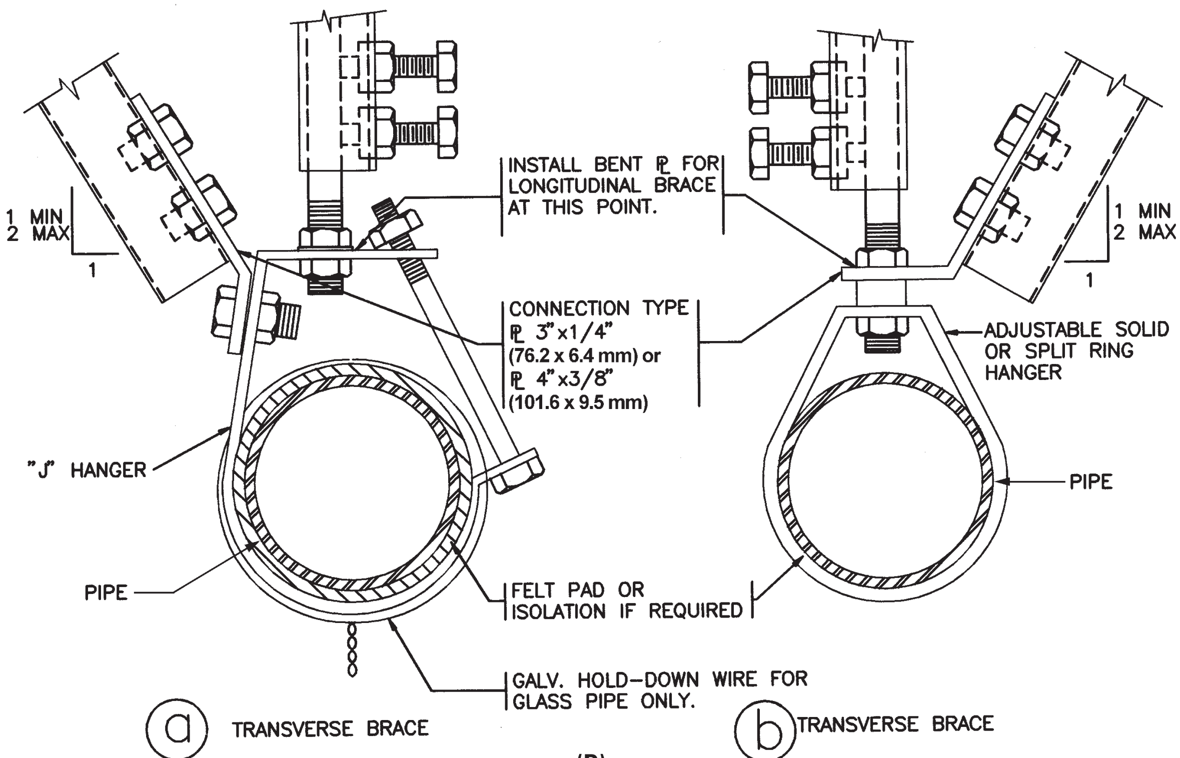
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(C)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (C) Strut Bracing for Pipes

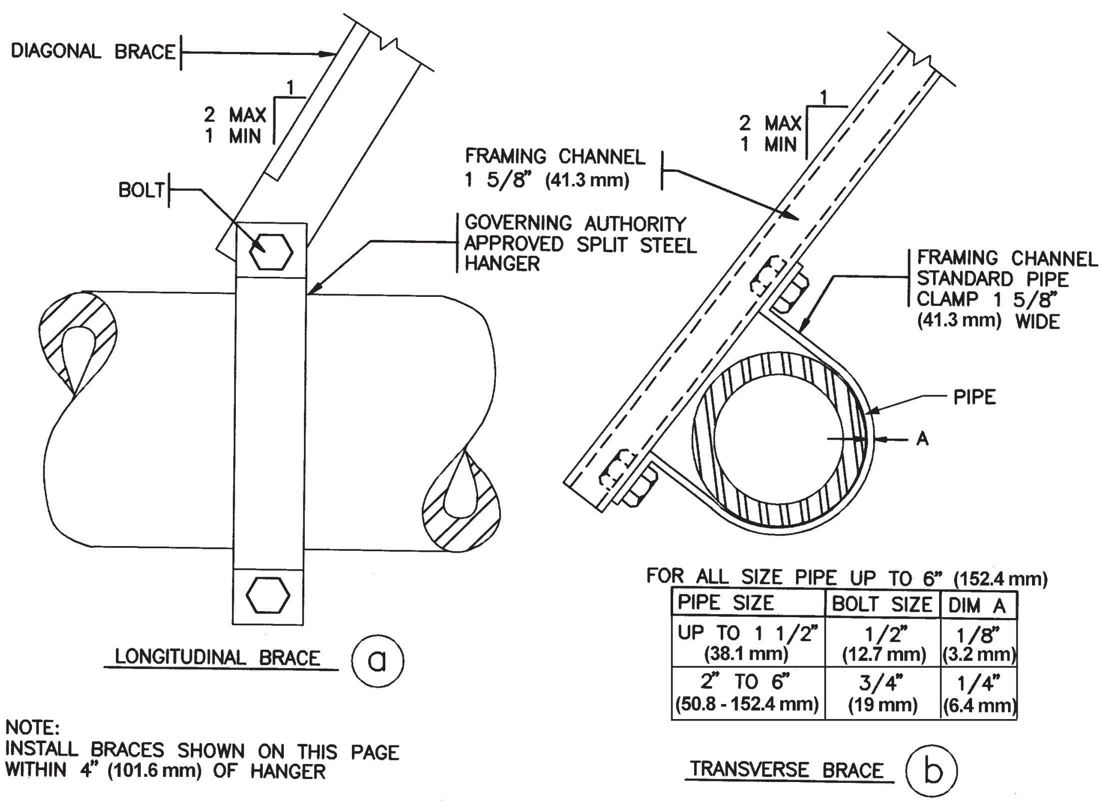
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(D)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (D) Alternate Attachment to Hanger for Pipe Bracing

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



FOR ALL SIZE PIPE UP TO 6" (152.4 mm)

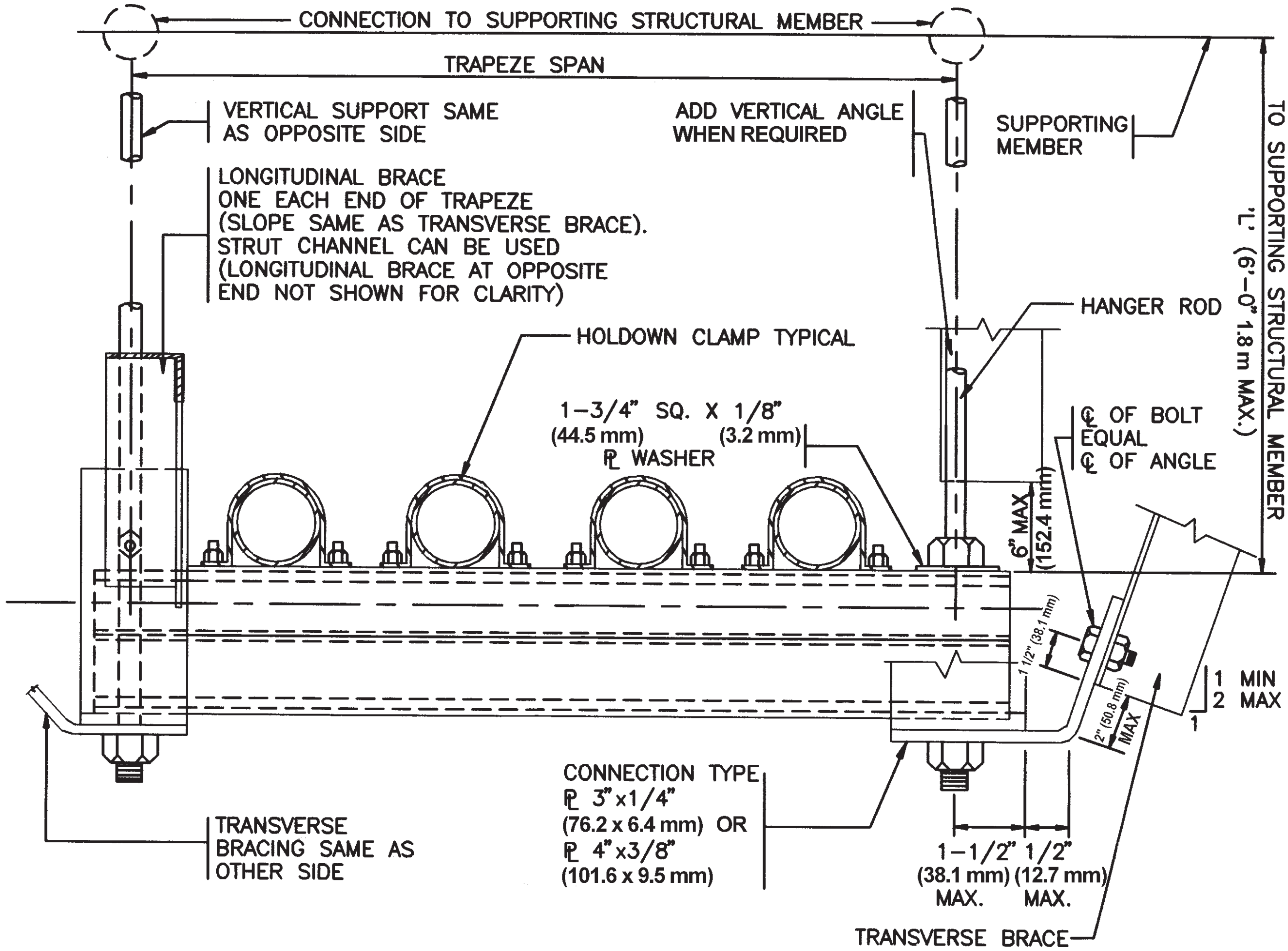
PIPE SIZE	BOLT SIZE	DIM A
UP TO 1 1/2" (38.1 mm)	1/2" (12.7 mm)	1/8" (3.2 mm)
2" TO 6" (50.8 - 152.4 mm)	3/4" (19 mm)	1/4" (6.4 mm)

TRANSVERSE BRACE b

(E)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (E) Alternate Bracing for Pipes

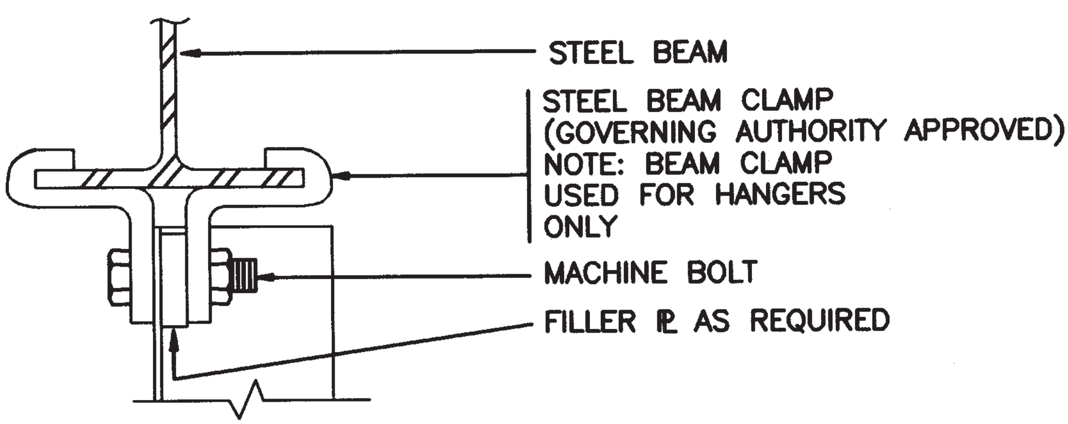
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(F)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (F) Strut Bracing for Pipe Trapeze

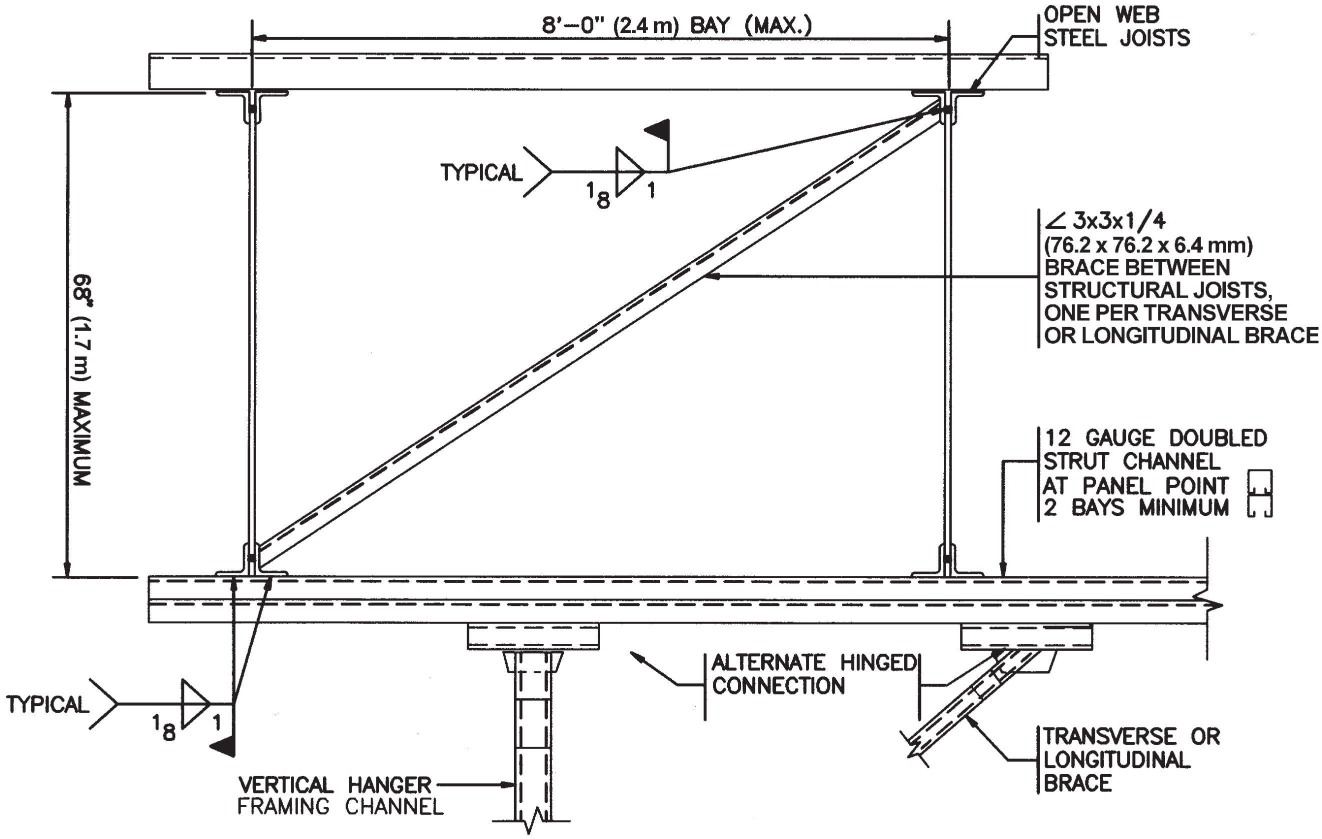
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(G)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (G) Connections to Steel Beams

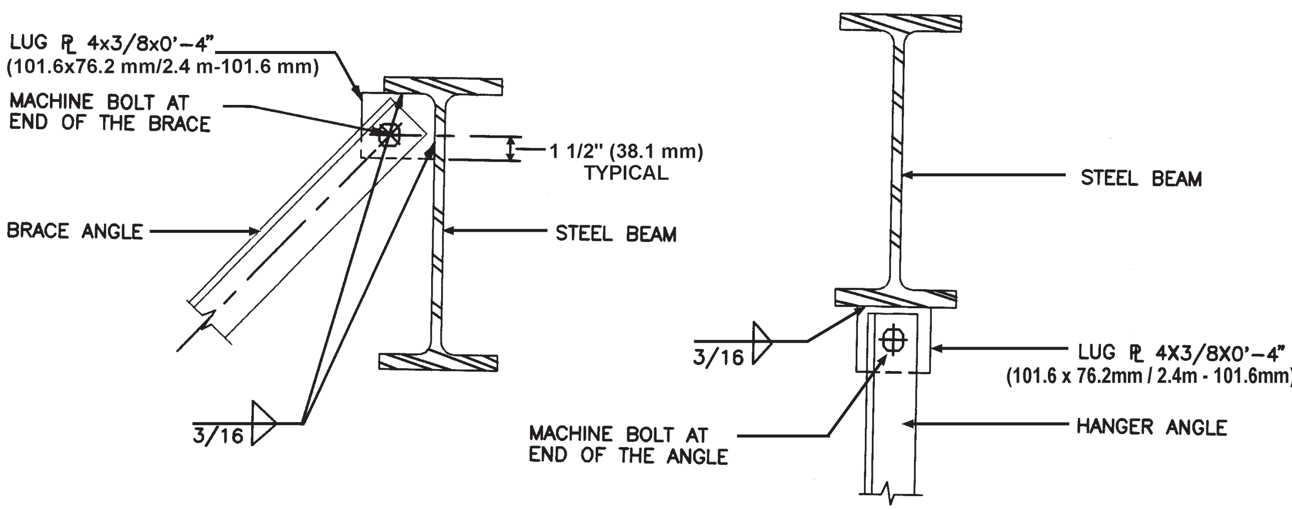
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(H)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (H) Connections to Open-Web Steel Joists

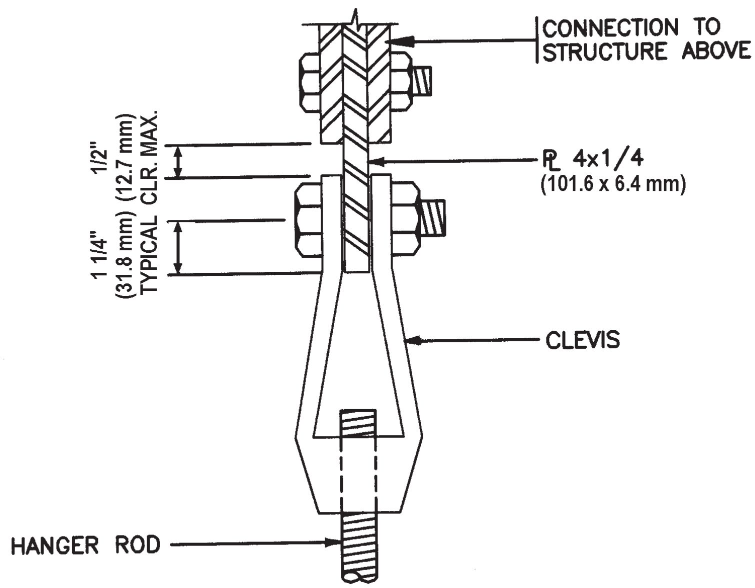
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(I)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (I) Connections to Steel

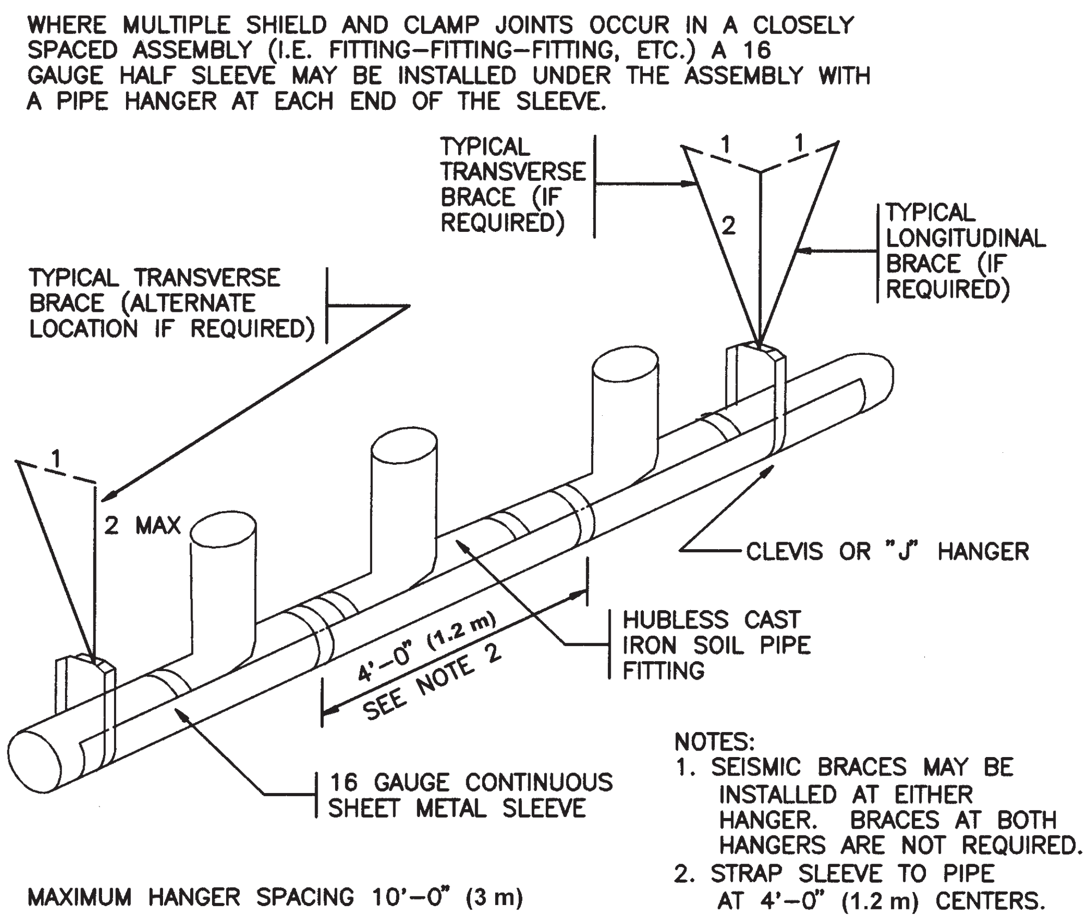
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(J)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (J) Hanger Rod Connections

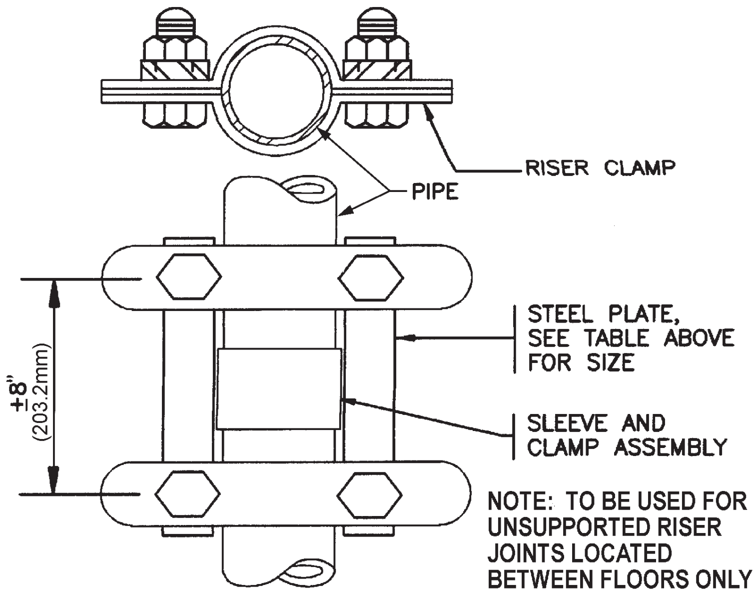
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(K)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (K) Hubless Cast-Iron Pipe

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.

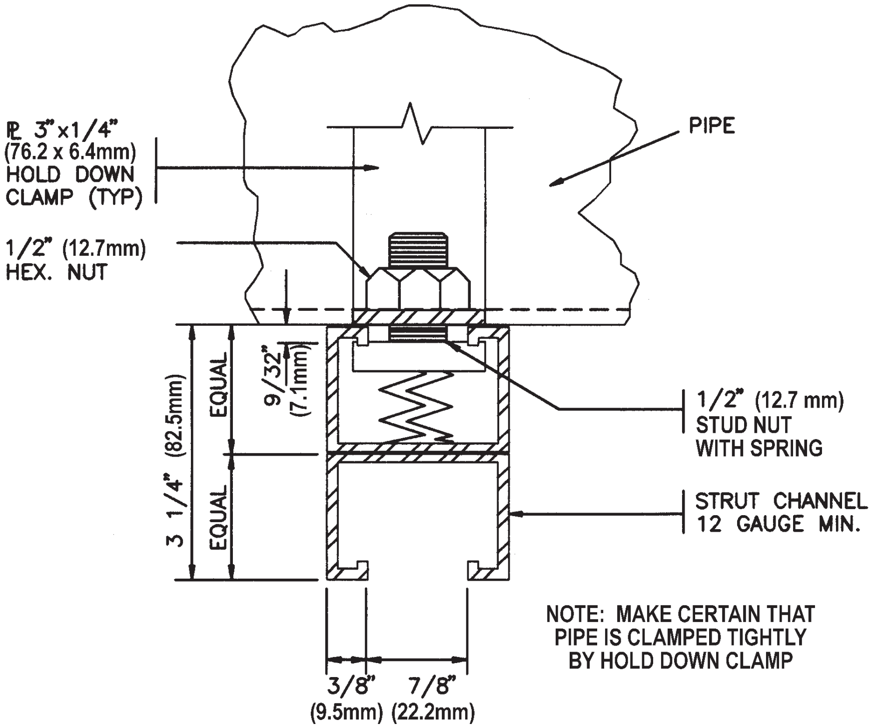


PIPE SIZE	PLATE SIZE	BOLT SIZE
Up To 2" (50.8mm)"	¼" x 1¼" (6.4 x 31.8mm)	¼" (6.4mm)
2½" to 3" (63.5 - 76.2mm)	¼" x 1¼" (6.4 x 31.8mm)	⅜" (9.5mm)
4" and 5" (101.6 & 127mm)	¼" x 1¼" (6.4 x 31.8mm)	½" (12.7mm)
6" (152.4mm)	⅜" x 1½" (9.5 x 38.1mm)	½" (12.7mm)
8" (203.2mm)	⅜" x 1½" (9.5 x 38.1mm)	⅝" (15.9mm)

(L)

Figure 9-12 Construction Details of Seismic Protection for Pipes: (L) Riser Bracing for Hubless Pipes

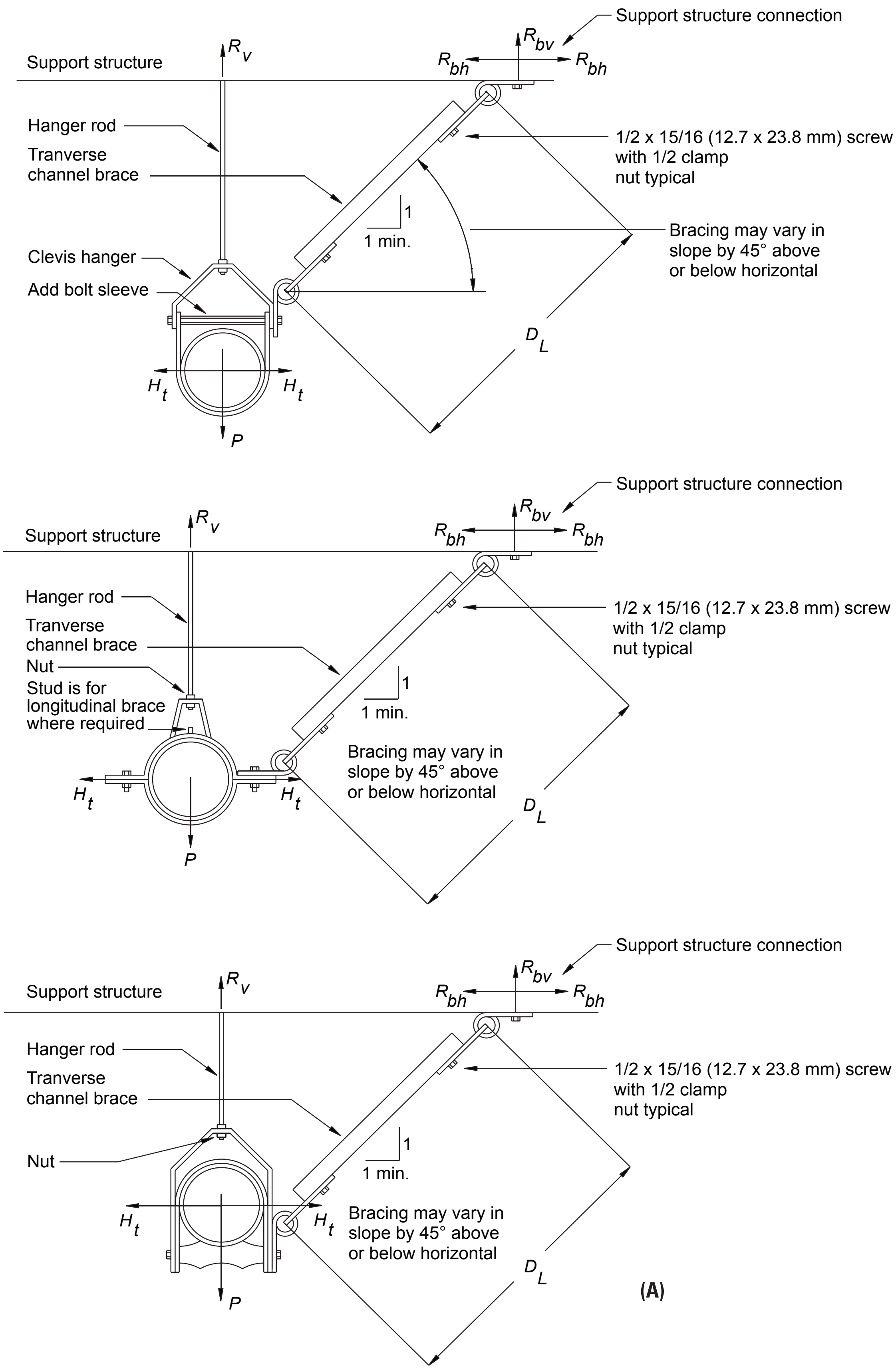
Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



(M)

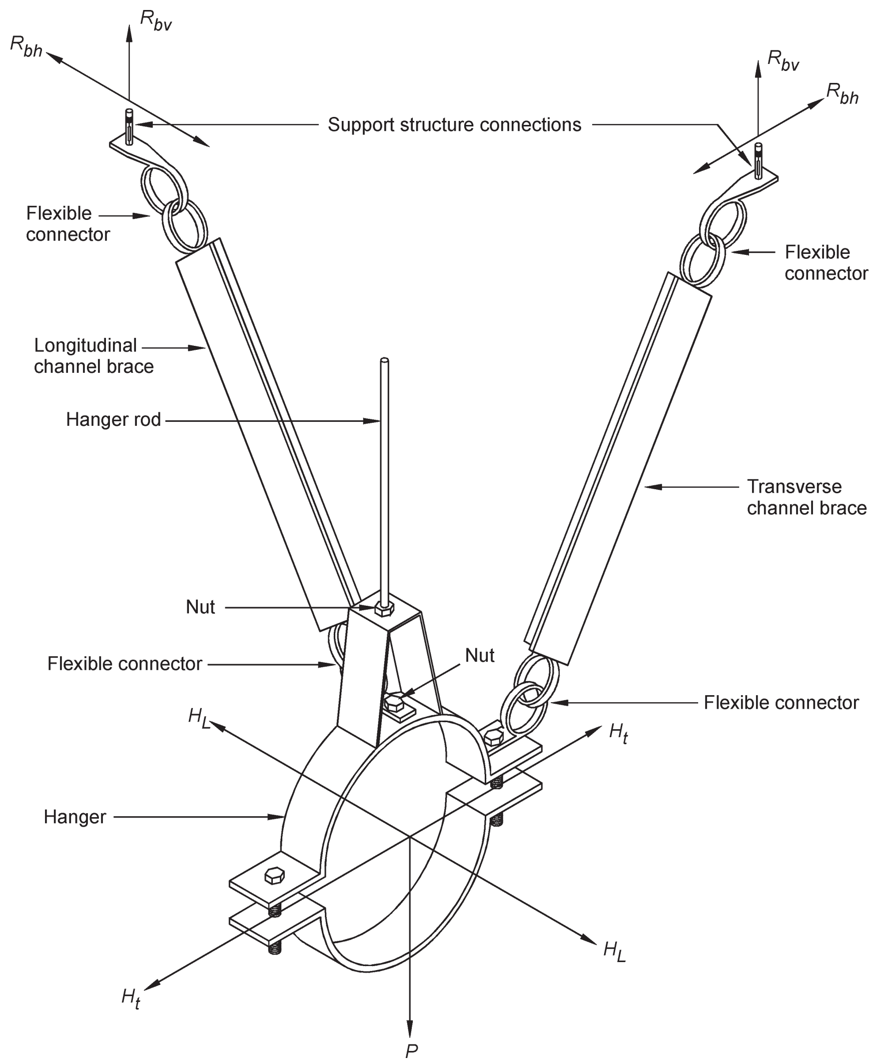
Figure 9-12 Construction Details of Seismic Protection for Pipes: (M) Connections for Pipes on Trapeze.

Source: SMACNA 1991. Note: For additional information, refer to SMACNA 1991.



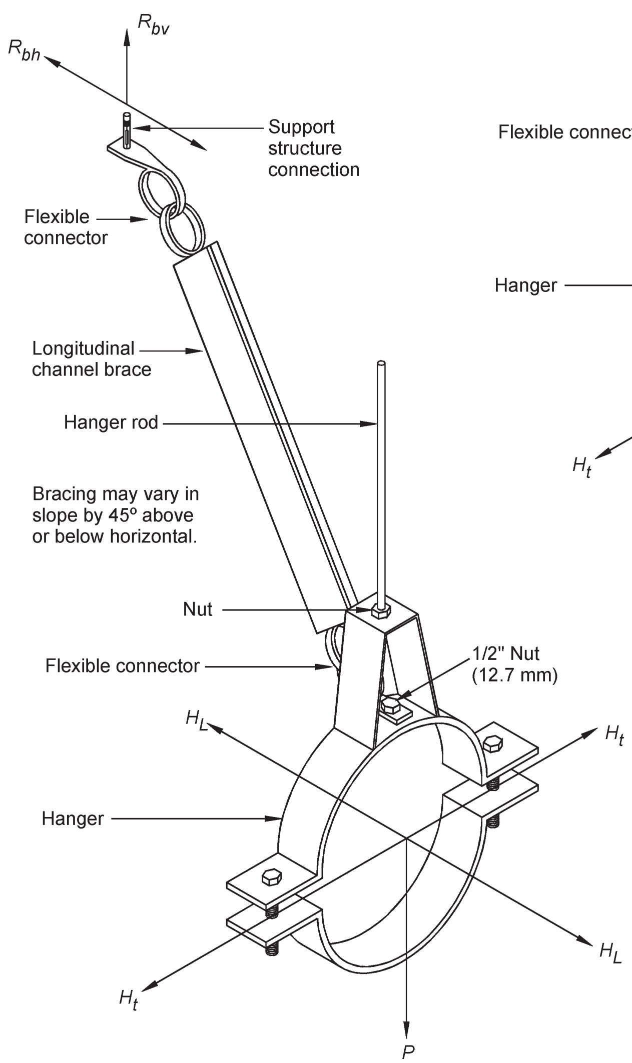
Transverse Only

Figure 9-13 Sway Bracing, 0.5 G Force



(B)

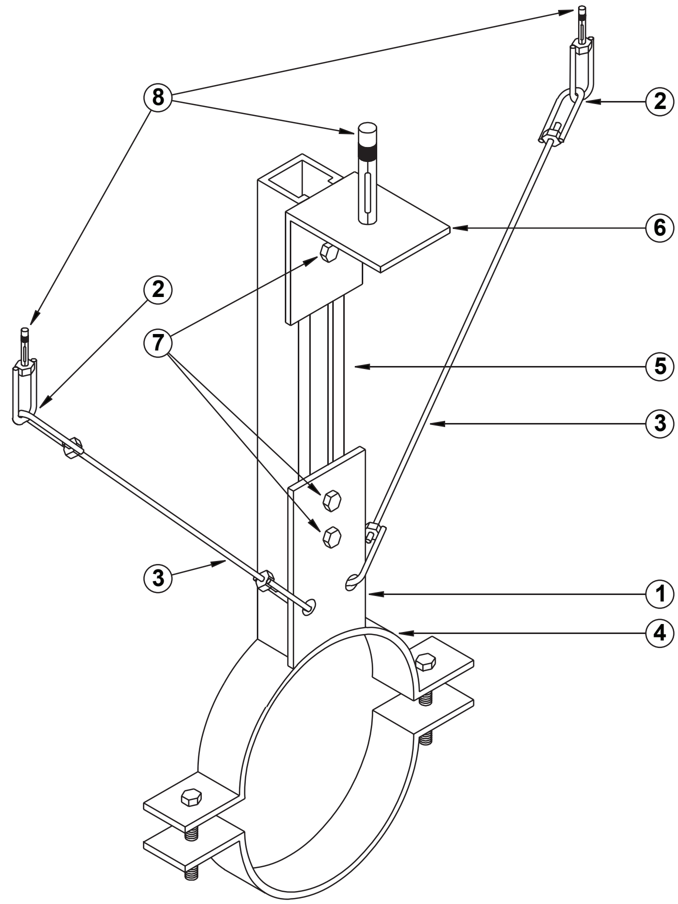
Longitudinal and Transverse

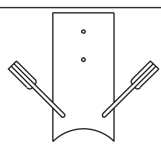
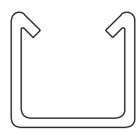
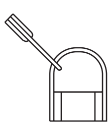
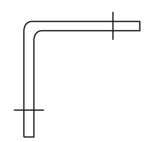
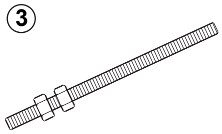
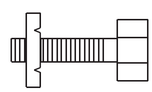
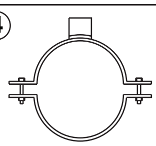
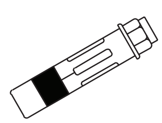


(C)

Longitudinal Only

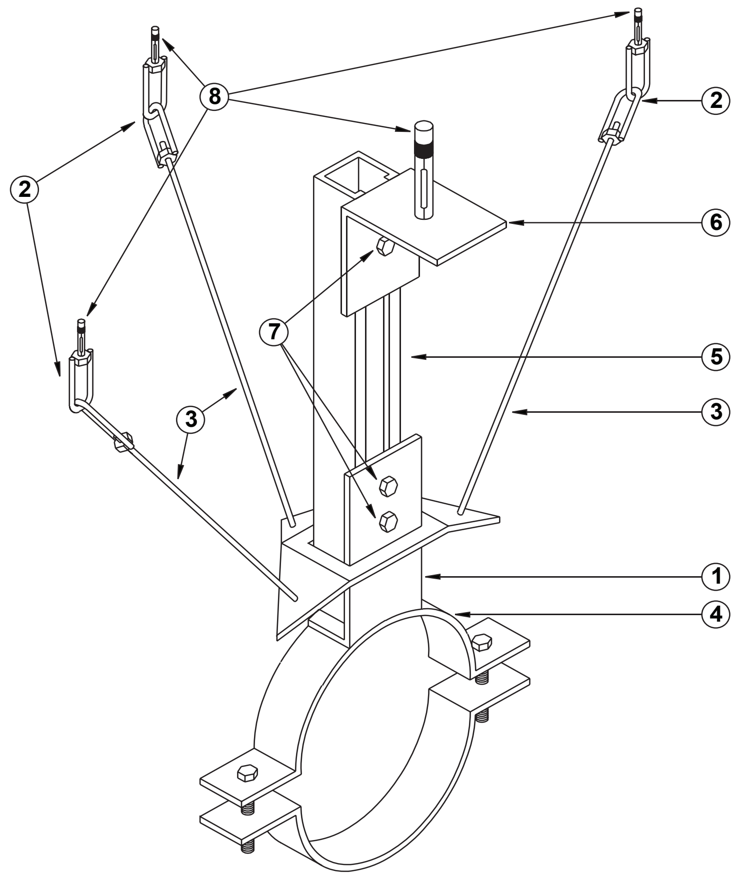
Figure 9-13 Sway Bracing, 0.5 G Force (continued)

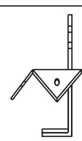
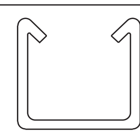
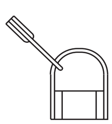
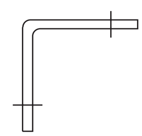
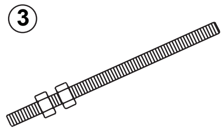
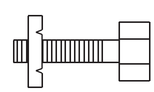
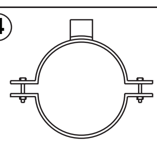
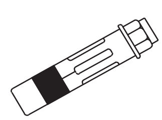


1 	Brace Plates Type Thickness Links 1 3/8" (9.5mm) 1/2" (12.7mm) 2 1/2" (12.7mm) 5/8" (15.8mm)	5 	Strut Type 1 1-5/8"(41.3mm)x1-5/8"(41.3mm)x12 Ga 2 1-5/8"(41.3mm)x1-5/8"(41.3mm)x12 Ga
2 	Connectors Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)	6 	Angle Clip Type Thickness Hole Dia. 1 3/8" (9.5mm) 9/16" (14.3mm) 2 1/2" (12.7mm) 11/16" (17.5mm)
3 	All-Thread Rod & Nylock Nuts Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm) (4 Tension Rods Required)	7 	Bolts & Clamping Nut Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)
4 	Pipe Clamp Model Selection per pipe Clamp & Accessory Detail	8 	Drilled Sleeve Anchor

(A)

Figure 9-14 A Seismic Bracing Method: (A) Lateral Sway Bracing



1 	Brace Plates Type Thickness 1 3/8" (9.5mm) 2 1/2" (12.7mm)	5 	Strut 1-5/8"(41.3mm) x 1-5/8"(41.3mm) x 12 Ga Length Varies		
2 	Connectors Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)	6 	Angle Clip Type Thickness Hole Dia. 1 3/8" (9.5mm) 9/16" (14.3mm) 2 1/2" (12.7mm) 11/16" (17.5mm)		
3 	All-Thread Rod & Nylock Nuts Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)	7 	Bolts & Clamping Nut Type Diameter 1 1/2" (12.7mm) 2 5/8" (15.8mm)		
4 	Pipe Clamp Model Selection per pipe Clamp & Accessory Detail	8 	Drilled Sleeve Anchor		

(B)

Figure 9-14 A Seismic Bracing Method: (B) Lateral and Longitudinal Sway Bracing.

4. Less-than-perfect compliance of the foundation to the ground motion.
5. Economic restraints on building codes.

The fact that the actual response of a building during an earthquake could be 3 or 4 times that represented by code forces must be understood and considered in good seismic design. Traditionally, this is done by rule of thumb and good judgment to ensure that structural yielding is not sudden or does not produce a collapsed mechanism. More recently, the response of many buildings to real earthquake input is being considered more specifically using computer analysis.

Design of seismic protection for nonstructural elements, including plumbing components and equipment, has neither the tradition nor a large number of in-place tests by actual earthquakes to enable much refinement of design force capability or design technique. Unfortunately, few of the effects listed above that mitigate the low force level for structures apply to plumbing or piping. Equipment and piping systems are generally simple and have low damping, and their lateral force resisting systems are usually nonredundant. It is imperative, therefore, when designing seismic protection for these elements, to recognize whether force levels being utilized are arbitrarily low for "design" or realistic predictions of actual response. Even when predictions of actual response are used, earthquake forces are considered sufficiently unpredictable when friction is not allowed as a means of "anchorage." Often, less-than-full dead load is used to both simulate vertical accelerations and to provide a further safety factor against overturning or swinging action.

Code Requirements

All current building codes require most structures and portions of structures to be designed for a horizontal force based on a certain percentage of its weight. Each code may vary in the method of determining this percentage, based on factors including the seismic zone, the importance of the structure, and the type of construction.

It is difficult to consider specific code requirements out of context. The code documents themselves should be consulted for specific usage. Most codes currently in use, or being developed, can generally be discussed by considering these four:

1. *Uniform Building Code 1997* (UBC).
2. *California administrative code of regulations*, parts 2 of 2001 Edition of Title 24 (Title 24, CAL).
3. International Building Code 2000 (IBC).
4. Seismic design for buildings. *Tri-Services Manual*. (See U.S. Department of Defense 1973.)
5. *Tentative provisions for the development of seismic regulations for buildings* (ATC-3). (See Applied Technology Council 1978.).

All of these codes require consideration of a lateral force that must be placed at the center of gravity of the element. The lateral force, or "equivalent static force," is calculated using some or all of the following parameters:

1. *Zone* Similar to Figure 9-2, the zone category affects the lateral force calculated by considering the size and frequency of potential earthquakes in the region.
2. *Soils* The effect of specific site soils on ground motion.
3. *Force factor* This considers the basic response of the element to ground motion and is affected by subparameters, which could include location within the building and possible resonance with the structure.
4. *Importance* A measure of the desirability of protection for a specific element.
5. *Element weight* All codes require calculation of a lateral force that is a percentage of the element weight.
6. *Amplification factor* This is defined by the natural period, damping ratio, and mass of the equipment and the structure.
7. *Response factor* Determined by driven frequency (equipment motors) and natural frequency.

It is of critical importance that the various building codes and their requirements be obtained and adhered to.

Sprinkler systems: NFPA 13 Because of the potential for fire immediately after earthquakes, sprinkler piping has long received special attention. The reference standard for installation of sprinkler piping, NFPA 13 (National Fire Protection Association 1996), is often cited as containing prototype seismic bracing for piping systems. In fact, in those cases observed, sprinkler piping has performed well. The bracing guidelines followed for some time in seismically active areas are actually contained in Appendix A of NFPA 13. However, good earthquake performance by sprinkler piping is also due to other factors, such as limited pipe size, use of steel pipe, coherent layouts, and conservative suspension (for vertical loads).

Use of NFPA 13 guidelines for pipe bracing is not discouraged, but it should not be considered a panacea for all piping systems. Other organizations, such as Factory Mutual (FM), have developed guidelines for properties insured by them and in many cases are more restrictive.

For reference, the following three tables provide good information for the engineer. Table 9-1 provides weights of steel pipes filled with water for determining horizontal loads. Table 9-2 provides load information for the spacing of sway bracing, and Table 9-3 provides maximum horizontal loads for sway bracing.

ANALYSIS TECHNIQUES

Determination of Seismic Forces

As discussed in the previous section, the most common method of defining seismic forces is by use of code static equivalents of dynamic earthquake forces. Regardless of the parameters used, this procedure reduces to the following formula:

Equation 9-1

$$F_p = K_g W_p$$

Table 9-1 Piping Weights for Determining Horizontal Load

Schedule 40 Pipe, in. (mm)	Weight of Water-Filled Pipe, lb/ft (kg/m)	½ Weight of Water-Filled Pipe, lb/ft (kg/m)
1 (25.4)	2.05 (0.28)	1.03 (0.14)
1¼ (31.8)	2.93 (0.40)	1.47 (0.20)
1½ (38.1)	3.61 (0.50)	1.81 (0.25)
2 (50.8)	5.13 (0.70)	2.57 (0.35)
2½ (63.5)	7.89 (1.08)	3.95 (0.54)
3 (76.2)	10.82 (1.48)	5.41 (0.74)
3½ (88.9)	13.48 (1.85)	6.74 (0.92)
4 (101.6)	16.40 (2.25)	8.20 (1.12)
5 (127)	23.47 (3.22)	11.74 (1.61)
6 (152.4)	31.69 (4.35)	15.85 (2.17)
8[a] (203.2)	47.70 (6.54)	23.85 (3.27)
Schedule 10 Pipe, in. (mm)	**Weight of Water-Filled Pipe, lb/ft (kg/m)**	**½ Weight of Water-Filled Pipe, lb/ft (kg/m)**
1 (25.4)	1.81 (0.25)	0.91 (0.12)
1¼ (31.8)	2.52 (0.35)	1.26 (0.17)
1½ (38.1)	3.04 (0.42)	1.52 (0.21)
2 (50.8)	4.22 (0.58)	2.11 (0.29)
2½ (63.5)	5.89 (0.81)	2.95 (0.40)
3 (76.2)	7.94 (1.09)	3.97 (0.54)
3½ (88.9)	9.78 (1.34)	4.89 (0.67)
4 (101.6)	11.78 (1.62)	5.89 (0.81)
5 (127)	17.30 (2.37)	8.65 (1.19)
6 (152.4)	23.03 (3.16)	11.52 (1.58)
8 (203.2)	40.08 (5.50)	20.04 (2.75)

a Schedule 30

where:

F_p = Lateral (seismic) force applied at element center of gravity

K_g = Coefficient considering the parameters discussed above, under "Codes." The final percentage of the element weight is often described in units of g, the acceleration of gravity, e. g., "0.5 g." This is equivalent to specifying a percentage of the weight; thus 0.5 = 50% of W.

W_p = Weight tributary to anchorage (pipe and contents weight)

Since F_p is a representation of vibratory response, it can be applied in a plus or minus sense.

In piping systems, since vertical supports will probably be placed more frequently than lateral braces, W_p will be greater than the dead load supported at that point. This mismatching of F_p and available dead load often causes uplift on the pipe, which should be taken into consideration.

The loading (F_p) can also be calculated using a response spectrum determined for the appropriate floor or by modeling the equipment or piping as part of the structure and, by computer, inputting an appropriate time history of motion at the base. In practice, these techniques are seldom used except in buildings of extreme importance, or when the mass of the equipment becomes a significant percentage of the total building mass (10% is sometimes used as the limit).

Vertical seismic load, F_{pv}, of equipment or piping is normally considered by specifying a percentage of the horizontal force factor to be applied to the weight concurrently. In several codes the factor is taken as 30% K_g; therefore, $F_{pg} = 0.3\ K_g W$, where W is the tributary vertical load.

The three generalized loadings that must be considered in the design of seismic restraints, F_p, F_{pv}, and W, are shown schematically in Figure 9-15.

Determination of Anchorage Forces

In most cases, anchorage or reaction forces, R_h and R_v [Figure 9-16(A)], created by the loading described above, are calculated by simple statistics. Although trivial for a professional familiar with statistics, calculations to find all maximums become numerous when the center of gravity is off one or both plan centerline axes, or if the base support is nonsymmetrical.

Table 9-2 Assigned Load Table for Lateral and Longitudinal Sway Bracing

Spacing of Lateral Braces, ft (m)	Spacing of Longitudinal Braces, ft (m)	Assigned Load for Pipe Size to Be Braced, lb (kg)						
		2	2½	3	4	5	6	9
10 (3.0)	20 (6.0)	380 (171)	395 (177.8)	410 (184.5)	435 (195.8)	470 (211.5)	655 (294.8)	915 (411.8)
20 (6.0)	40 (12.2)	760 (342)	785 (353.3)	815 (366.8)	870 (391.5)	940 (423)	1,305 (587.3)	1,830 (823.5)
25 (7.6)	50 (15.2)	950 (427.5)	980 (441)	1,020 (459)	1,090 (490.5)	1,175 (528.8)	1,630 (733.5)	2,290 (1030.5)
30 (9.1)	60 (18.3)	1,140 (513)	1,180 (531)	1,225 (551.3)	1,305 (587.3)	1,410 (634.5)	1,960 (882)	2,745 (1235.3)
40 (12.2)	80 (24.4)	1,515 (681.8)	1,570 (706.5)	1,630 (733.5)	1,740 (783)	1,880 (846)	2,610 (1174.5)	3,660 (1647)
50 (15.2)		1,895 (852.8)	1,965 (884.3)	2,035 (915.8)	2,175 (978.8)	2,350 (1057.5)	3,260 (1467)	4,575 (2058.8)

Note: Table based on half the weight of a water-filled pipe.

Table 9-3 Maximum Horizontal Loads for Sway Bracing

Shape and Size, in.	(mm)	Least Radius of Gyration	Maximum Length for 1/r = 200		Maximum Horizontal Load, lb (kg): 30-44° Angle from Vertical		Maximum Horizontal Load, lb (kg): 45-59° Angle from Vertical		Maximum Horizontal Load, lb (kg): 60-90° Angle from Vertical	
Pipe (Schedule 40)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$								
1	(25.4)	0.42	7 ft 0 in	(2.1 m)	1,767	(801.5)	2,500	(1134.0)	3,061	(1388.4)
1¼	(31.8)	0.54	9 ft 0 in	(2.7 m)	2,393	(1085.4)	3,385	(1535.4)	4,145	(1880.1)
1½	(38.1)	0.623	10 ft 4 in	(3.1 m)	2,858	(1296.4)	4,043	(1833.9)	4,955	(2241.5)
2	(50.8)	0.787	13 ft 1 in	(4 m)	3,828	(1736.3)	5,414	(2455.7)	6,630	(3007.3)
Pipe (Schedule 10)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$								
1	(25.4)	0.43	7 ft 2 in	(2.2 m)	1,477	(670.0)	2,090	(948.0)	2,559	(1160.7)
1¼	(31.8)	0.55	9 ft 2 in	(2.8 m)	1,900	(861.8)	2,687	(1218.8)	3,291	(1492.8)
1½	(38.1)	0.634	10 ft 7 in	(3.2 m)	2,194	(995.2)	3,103	(1407.5)	3,800	(1723.6)
2	(50.8)	0.802	13 ft 4 in	(4.1 m)	2,771	(1256.9)	3,926	(1780.8)	4,803	(2178.6)
Angles										
1½ x 1½ x ¼	(38.1 x 38.1 x 6.4)	0.292	4 ft 10 in	(1.5 m)	2,461	(1116.3)	3,481	(1578.9)	4,263	(1933.7)
2 x 2 x ¼	(50.8 x 50.8 x 6.4)	0.391	6 ft 6 in	(2 m)	3,356	(1522.2)	4,746	(2152.7)	5,813	(2636.7)
2½ x 2 x ¼	(63.5 x 50.8 x 6.4)	0.424	7 ft 0 in	(2.1 m)	3,792	(1720.0)	5,363	(2432.6)	6,569	(2979.6)
2½ x 2½ x ¼	(63.5 x 63.5 x 6.4)	0.491	8 ft 2 in	(2.5 m)	4,257	(1930.9)	6,021	(2731.1)	7,374	(3344.8)
3 x 2½ x ¼	(76.2 x 63.5 x 6.4)	0.528	8 ft 10 in	(2.7 m)	4,687	(2126.0)	6,628	(3006.4)	8,118	(3682.2)
3 x 3 x ¼	(76.2 x 76.2 x 6.4)	0.592	9 ft 10 in	(3 m)	5,152	(2336.9)	7,286	(3304.9)	8,923	(4047.4)
Rods		$= \frac{r}{2}$								
⅜	(9.5)	0.094	1 ft 6 in	(0.5 m)	395	(179.2)	559	(253.6)	685	(310.7)
½	(12.7)	0.125	2 ft 6 in	(0.8 m)	702	(318.4)	993	(450.4)	1,217	(552.0)
⅝	(15.9)	0.156	2 ft 7 in	(0.8 m)	1,087	(493.1)	1,537	(697.2)	1,883	(854.1)
¾	(19.1)	0.188	3 ft 1 in	(0.9 m)	1,580	(716.7)	2,235	(1013.8)	2,737	(1241.5)
⅞	(22.2)	0.219	3 ft 7 in	(1.1 m)	2,151	(975.7)	3,043	(1380.3)	3,726	(1690.1)
Flats		= 0.29 h (where h is smaller of two side dimensions)								
1½ x ¼	(38.1 x 6.4)	0.0725	1 ft 2 in	(0.4 m)	1,118	(507.1)	1,581	(717.1)	1,936	(878.2)
2 x ¼	(50.8 x 6.4)	0.0725	1 ft 2 in	(0.4 m)	1,789	(811.5)	2,530	(1147.6)	3,098	(1405.2)
2 x ⅜	(50.8 x 9.5)	0.109	1 ft 9 in	(0.5 m)	2,683	(1217.0)	3,795	(1721.4)	4,648	(2108.3)
Pipe (Schedule 40)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$								
1	(25.4)	0.42	3 ft 6 in	(1.1 m)	7,068	(3206.0)	9,996	(4534.1)	12,242	(5552.8)
1¼	(31.8)	0.54	4 ft 6 in	(1.4 m)	9,567	(4339.5)	13,530	(6137.1)	16,570	(7516.0)
1½	(38.1)	0.623	5 ft 2 in	(1.6 m)	11,441	(5189.5)	16,181	(7339.5)	19,817	(8988.8)
2	(50.8)	0.787	6 ft 6 in	(2 m)	15,377	(6974.9)	21,746	(9863.8)	26,634	(12080.9)
Pipe (Schedule 10)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$								
1	(25.4)	0.43	3 ft 7 in	(1.1 m)	5,910	(2680.7)	8,359	(3791.6)	10,237	(4643.4)
1¼	(31.8)	0.55	4 ft 7 in	(1.4 m)	7,600	(3447.3)	10,749	(4875.6)	13,164	(5971.1)
1½	(38.1)	0.634	5 ft 3 in	(1.6 m)	8,777	(3981.2)	12,412	(5630.0)	15,202	(6895.5)
2	(50.8)	0.802	6 ft 8 in	(2 m)	11,105	(5037.1)	15,705	(7123.6)	19,235	(8724.8)
Rods		$= \frac{r}{2}$								
⅜	(9.5)	0.094	0 ft 9 in	(0.2 m)	1,580	(716.7)	2,234	(1013.3)	2,737	(1241.5)
½	(12.7)	0.125	1 ft 0 in	(0.3 m)	2,809	(1274.1)	3,972	(1801.7)	4,865	(2206.7)
⅝	(15.9)	0.156	1 ft 3 in	(0.4 m)	4,390	(1991.3)	6,209	(2816.3)	7,605	(3449.6)
¾	(19.1)	0.188	1 ft 6 in	(0.5 m)	6,322	(2867.6)	8,941	(4055.5)	10,951	(4967.3)
⅞	(22.2)	0.219	1 ft 9 in	(0.5 m)	8,675	(3934.9)	12,169	(5519.7)	14,904	(6760.3)
Pipe (Schedule 40)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$	1/r = 300							
1	(25.4)	0.42	10 ft 6 in	(3.2 m)	786	(356.5)	1111	(503.9)	1,360	(616.9)
1¼	(31.8)	0.54	13 ft 6 in	(4.1 m)	1,063	(482.2)	1,503	(681.7)	1,841	(835.1)
1½	(38.1)	0.623	15 ft 7 in	(4.7 m)	1,272	(577.0)	1,798	(815.5)	2,202	(998.8)
2	(50.8)	0.787	19 ft 8 in	(6 m)	1,666	(755.7)	2,355	(1068.2)	2,885	(1308.6)
Pipe (Schedule 10)		$= \frac{\sqrt{r_0^2 + r_1^2}}{2}$								
1	(25.4)	0.43	10 ft 9 in	(3.3 m)	656	(297.8)	928	(420.9)	1,137	(515.7)
1¼	(31.8)	0.55	13 ft 9 in	(4.2 m)	844	(383.2)	1,194	(541.6)	1,463	(663.6)
1½	(38.1)	0.634	15 ft 10 in	(4.8 m)	975	(442.3)	1,379	(625.5)	1,194	(541.6)
2	(50.8)	0.802	20 ft 0 in	(6.1 m)	1,234	(559.7)	1,745	(791.5)	2,137	(969.3)

(CONTINUED)

Table 9-3 Maximum Horizontal Loads for Sway Bracing (continued)

Shape and Size, in. (mm)		Least Radius of Gyration	Maximum Length for 1/r = 200		Maximum Horizontal Load, lb (kg) 30-44° Angle from Vertical		45-59° Angle from Vertical		60-90° Angle from Vertical	
Rods		$= \frac{r}{2}$								
⅜	(9.5)	0.094	2 ft 4 in	(0.7 m)	176	(79.8)	248	(112.5)	304	(137.9)
½	(12.7)	0.125	3 ft 1 in	(0.9 m)	312	(141.5)	441	(200.0)	540	(244.9)
⅝	(15.9)	0.156	3 ft 11 in	(1.2 m)	488	(221.4)	690	(313.0)	845	(383.3)
¾	(19.1)	0.188	4 ft 8 in	(1.4 m)	702	(318.4)	993	(450.4)	1,217	(552.0)
⅞	(22.2)	0.219	5 ft 6 in	(1.7 m)	956	(433.6)	1,352	(613.3)	1,656	(751.1)

In typical pipe braces [Figure 9-16(B)], it is important to note that R, the gravity force in the hanger rod, is significantly affected by the addition of the brace and is not equal to W, as indicated previously. Dealing with these loads is a huge problem. A tension rod hanger commonly goes into compression in such a situation. Cable restraints do not have this problem.

COMPUTER ANALYSIS OF PIPING SYSTEMS

Computers programs have been used to analyze piping systems for stress for some time. These programs were initially developed to consider thermal stresses and anchor point load, but software is now commonly available that can consider seismic and settlement loading, spring or damping supports, snubbers (similar to equipment snubbers), differing materials, and nonrigid couplings. The seismic loading normally can be figured by using a full-time history, as a response spectrum, or equivalent static forces. The time history has the inherent problem of requiring a search of each time increment for worst-case stresses and brace loadings. The computer time and man-hours required are seldom justified. In fact, for seismic loading alone, computer analysis is almost never performed because brace loadings can easily be determined by tributary length methods, and rule-of-thumb pipe spans (brace spacing) are contained in several publications (see National Fire Protection Association 1996; Hillman, Biddison, and Loevenguth; and U.S. Dept. of Defense 1973). Computer analysis may be appropriate, however, when it is necessary to combine seismic loading with several of the following considerations:

1. Temperature changes and anchorage.
2. Nonlinear support conditions (springs, snubbers, etc.).
3. Complex geometry.
4. Several loading conditions.
5. Piping materials other than steel or copper.
6. Joints or couplings that are significantly more flexible or weaker than the pipe itself.

Because of the variety of computer programs available and because many have proprietary restrictions, specific programs are not listed here. Piping analysis programs are available at most computer service bureaus, many universities, and national computer program clearinghouses.

DESIGN CONSIDERATIONS

Loads in Structures

It is always important to identify unusual equipment and piping loads during the first stages of project design to assure that the structural system being developed is adequate. Consideration of seismic effects makes this coordination even more important because seismic forces produce unusual reactions. During an earthquake, not only must horizontal forces be taken into the structure, but vertical load effects are intensified due to vertical accelerations and overturning movements. These reactions must be acceptable to the structure locally (at the point of connection) and globally (by the system as a whole).

If the structural system is properly designed for the appropriate weights of equipment and piping, seismic reactions will seldom cause problems to the overall system. However, local problems are not uncommon. Most floors are required by code to withstand a 2000-pound (908 kg) concentrated load, so this is a reasonable load to consider acceptable without special provisions. However, seismic reactions to structures can easily exceed this figure; for example:

1. A longitudinal brace carrying a tributary load of 80 feet (24.8-m) of 8-inch (203-mm) steel pipe filled with water will generate reactions of this magnitude.
2. Transverse or longitudinal braces on trapezes often have larger reactions.
3. A 4000-pound (1816-kg) tank on legs could also yield such a concentrated load. In addition, possible limitations on attachment methods due to structure type could reduce the effective maximum allowable concentration.

Roof structures have no code-specified concentrated load requirement and often are the source of

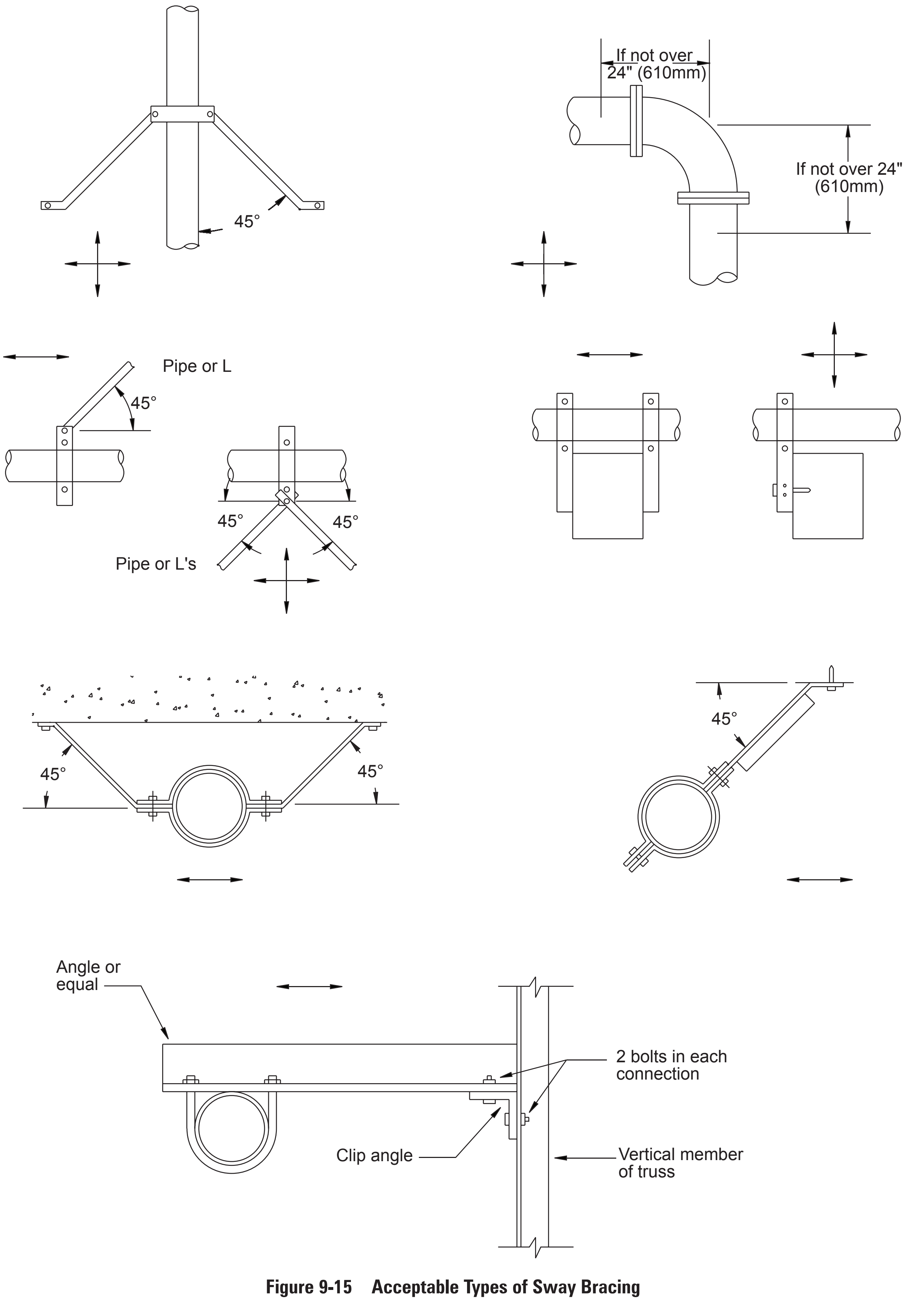
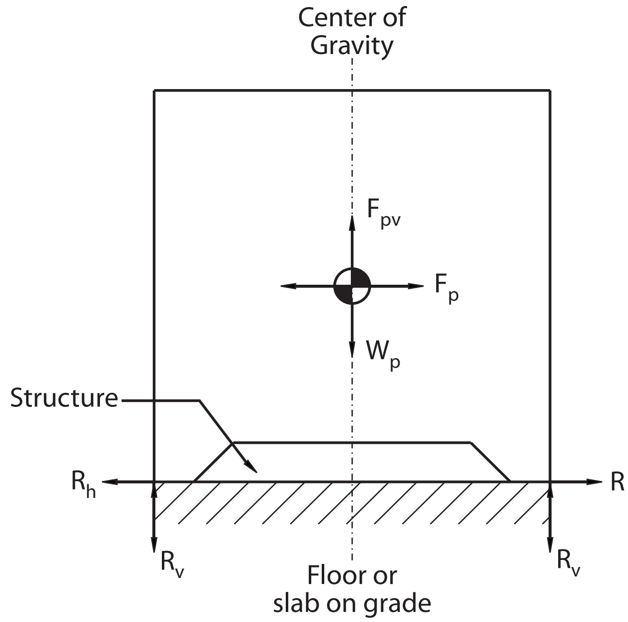


Figure 9-15 Acceptable Types of Sway Bracing



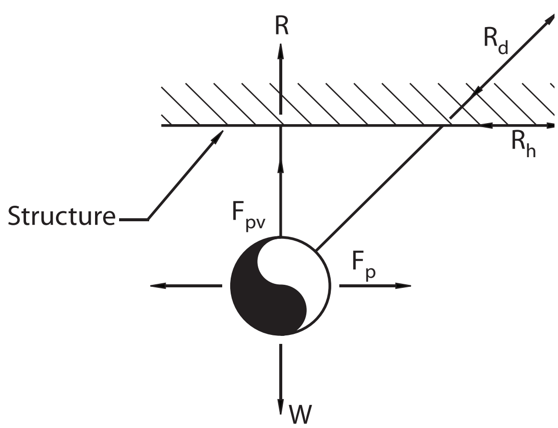


Figure 9-16 Forces for Seismic Design: (A) Equipment; (B) Piping.

problems, particularly concerning piping systems, because of the random nature of hanger-and-brace locations. Many roof-decking systems cannot accept concentrations greater than 50 pounds (22.7 kg) without spreaders or strengthening beams. Such limitations should be considered both in the selection of a structural system and in the equipment and piping layout.

If equipment anchorage or pipe bracing is specified to be contractor supplied, attachment load limitations or other structural criteria should be given. Compliance with such criteria should be checked to assure that the structure is not being damaged or overloaded.

POTENTIAL PROBLEMS

It would be impractical to cover the details of structural design for seismic anchorage and bracing in this chapter. The engineer can get design information and techniques from standard textbooks and design manuals or, preferably, obtain help from a professional experienced in seismic and/or structural design. Simple, typical details are seldom appropriate, and all-encompassing, seismic-protection “systems” quickly become complex. Certain common situations that have the potential to create problems can be identified, however; these are shown schematically in Figure 9-17 (see page 194) and discussed below.

Condition 1 in Figure 9-17 occurs frequently in making attachments to concrete. Often an angle is used, as indicated. The seismic force, P, enters the connector eccentric to the reaction, R, by the distance e; this is equivalent to a concentric force plus the moment P_e. In order for the connector to perform as designed, this moment must be resisted by the connection of the angle either to the machine or to the concrete. To use the machine to provide this moment, the machine base must be adequate, and the connection from angle to base must be greatly increased over that required merely for P. Taking this moment into the concrete significantly increases the tension in the anchorage, R, which is known as “prying action.” The appropriate solution must be decided on a case-by-case basis, but eccentricities in connection should not be ignored.

Legs 18 inches (457 mm) or longer supporting tanks or machines clearly create a sideways problem and are commonly cross-braced. However, shorter legs or even rails often have no strength or stiffness in their weak direction, as shown in Condition 2, and should also be restrained against base failure.

Conditions 3 and 4 point out that spring isolators typically create a significant height, h, through which lateral forces must be transmitted. This height, in turn, creates conditions similar to the problems shown in 1 or 2 and must be treated in the same manner.

Condition 5 is meant to indicate that seldom can the bottom flange of a steel beam resist a horizontal force; diagonal braces, which are often connected to bottom flanges, create such a horizontal force. This condition can be rectified by attaching the diagonal brace near the top flange or adding a stabilizing element to the bottom flange.

Condition 6 depicts a typical beam connection device (beam clamp), which slips over one flange. Although this is often acceptable, significant stresses can be introduced into the beam if the load is large or the beam small. Considering the variability and potential overload characteristics of seismic forces, this condition should probably be avoided. Condi-

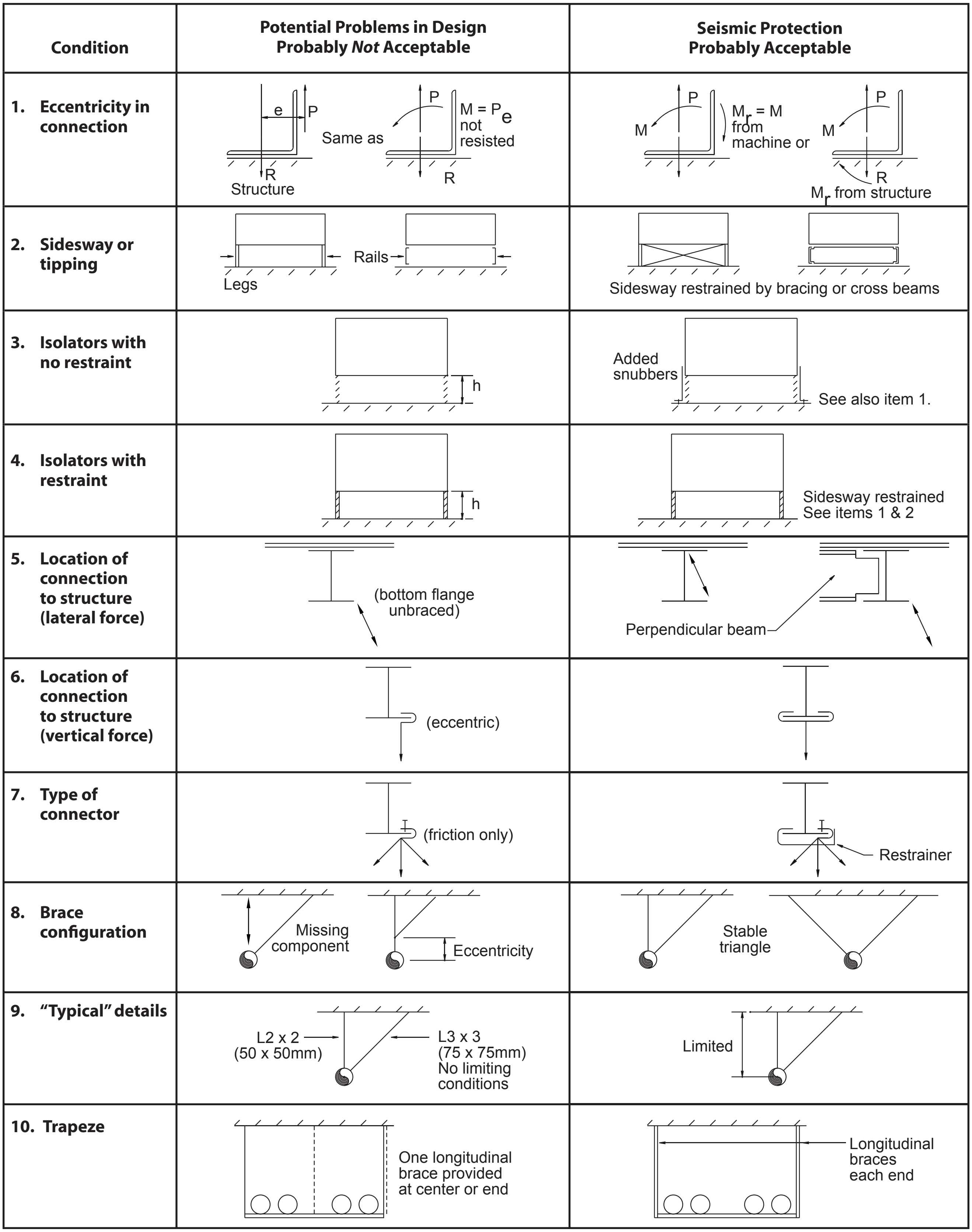


Figure 9-17 Potential Problems in Equipment Anchorage or Pipe Bracing

tion 7 also shows a connector in common use, which is probably acceptable in a nonseismic environment but which should be secured in place as shown under dynamic conditions.

Most pipe bracing systems utilize bracing members in pure tension or compression for stiffness and efficiency. This truss-type action is only possible when bracing configurations make up completed triangles, as shown on the right under condition 8. The brace configuration on the far left is technically unstable and the eccentric condition shown produces moment in the vertical support.

As previously indicated, "typical" details must be carefully designed and presented to prevent their misuse. Condition 9 shows the most common deficiency: A lack of limiting conditions.

Condition 10 shows a situation often seen in the field where interferences may prevent placement of longitudinal braces at the ends of a trapeze and either one is simply left out or two are replaced by one in the middle. Both of these "substitutions" can cause an undesirable twist of the trapeze and subsequent pipe damage. All field revisions to bracing schemes should be checked for adequacy.

Other potential problems that occur less frequently include incompatibility of piping systems with differential movement of the structure (drift) and inadvertent "self bracing" of piping through short, stiff service connections or branches that penetrate the structure. If the possibility of either is apparent, pipe stresses should be checked or the self-bracing restraint eliminated.

A few problems associated with making connection to a structure were discussed above, in relation to 9-17. When connecting to structural steel, in addition to manufactured clip devices, bolting and welding are also used. Holes for bolting should never be placed in structural steel without the approval of the structural engineer responsible for the design. Field welding should consider the effects of elevated temperatures on loaded structural members.

The preferred method of connecting to concrete is through embedments, but this is seldom practical. Since the location of required anchorages or braces is often not known when concrete is poured, the use of drilled-in or shot-in anchors is prevalent for this purpose. Although these anchors are extremely useful and practically necessary connecting devices, their adequacy has many sensitivities and they should be applied with thorough understanding and caution. The following items should be considered in the design or installation of drilled or shot-in anchors:

1. Manufacturers often list ultimate (failure) values in their literature. Normally, factors of safety of 4 or 5 are applied to these values for design.
2. Combined shear and tension should be considered in the design. A conservative approach commonly used is the following equation:

Equation 9-2

$$(T/T_a) + (V/V_a) < 1$$

where:

T = Tension, lbf/in^2
T_a = Allowable tension, lbf/in^2
V = Shear, lbf/in^2
V_a = Allowable shear, lbf/in^2

3. Edge distances are important because of the expansive nature of these anchors. Six (6) diameters are normally required.
4. Review the embedments required for design values. It is difficult to install an expansion bolt over ½-inch (12.7-mm) diameter in a typical floor system of 2½-inch (63.5-mm) concrete over steel decking.
5. Bolt sizes over ¼-inch (6.4-mm) diameter have embedments sufficient to penetrate the reinforcing envelope. Bolts should therefore not be placed in columns, the bottom flange of beams, or the bottom chord of joists. Bolts in slabs or walls are less critical, but the possibility of special and critical reinforcing bars being cut should always be considered. The critical nature of each strand of tendon in prestressed concrete, as well as the stored energy, generally dictates a complete prohibition of these anchors.
6. Installation technique has been shown to be extremely important in developing design strength. Field testing of a certain percentage of anchors should be considered.

Additional Considerations

Seismic anchorage and bracing, like all construction, should be thoroughly reviewed in the field. Considering the lack of construction tradition, the likelihood of field changes or interferences, and other potential problems (discussed above), seismic work probably should be more clearly controlled, inspected, and/or tested than normal construction.

Another result of the relative newness of seismic protection of equipment and piping is the lack of performance data for the design and detailing techniques now being used. Considerable failure data were collected in Anchorage and San Fernando, but essentially no field data are available to assure that our present assumptions, although scientifically logical and accurate, will actually provide the desired protection. Will firm anchorage of equipment cause damage to the internal workings? Will the base cabinet, or framework (which is now seldom checked), of equipment be severely damaged by the anchorage? In contrast, the present requirements for structures are largely the result of observations of damage to structures in actual earthquakes over 75 years.

The net result of current standards in seismic protection can only be positive. The fine-tuning of scope, force levels, and detailing techniques must wait for additional, full-scale testing in real earthquakes.

GLOSSARY

Anchor A device, such as an expansion bolt, for connecting pipe-bracing members into the structure of a building.

Attachment See "positive attachment."

Bracing Metal channels, cables, or hanger angles that prevent pipes from breaking away from the structure during an earthquake. See also "longitudinal bracing" and "transverse bracing." Together, these resist lateral loads from any direction.

Dynamic properties of piping The tendency of pipes to change in weight and size because of the movement and temperature of fluids in them. This does not refer to movement due to seismic forces.

Essential facilities Buildings that must remain safe and usable for emergency purposes after an earthquake in order to preserve the health and safety of the general public. Examples include hospitals, emergency shelters, and fire stations.

Equipment For the purposes of this chapter, "equipment" refers to the mechanical devices associated with pipes that have significant weight. Examples include pumps, tanks, and electric motors.

Gas pipe For the purposes of this chapter, "gas pipe" is any pipe that carries fuel gas, fuel oil, medical gas, vacuum, or compressed air.

Lateral force A force acting on a pipe in the horizontal plane. This force can be in any direction.

Longitudinal bracing Bracing that prevents a pipe from moving in the direction of its run.

Longitudinal force A lateral force that happens to be in the same direction as the pipe.

OSHPD Office of Statewide Health Planning and Development (California).

Positive attachment A mechanical device designed to resist seismic forces that connects a nonstructural element, such as a pipe, to a structural element, such as a beam. Bolts and screws are examples of positive attachments. Glue and friction due to gravity do not create positive attachments.

Seismic Related to an earthquake. Seismic loads on a structure are caused by wave movements in the earth during an earthquake.

Transverse bracing Bracing that prevents a pipe from moving from side to side.

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10 Acoustics in Plumbing Systems

INTRODUCTION

The plumbing system can be the source of one of the most intrusive, unwanted noises in high-rise apartment buildings, hospitals, hotels, and dormitories. It is essential, therefore, that plumbing engineers understand the terminology and theory of the field of acoustics in order to reduce the acoustical impact of plumbing.

ACCEPTABLE ACOUSTICAL LEVELS IN BUILDINGS

Acceptable acoustical levels in buildings are usually assessed in a number of ways, depending upon the classification of a building occupancy (or normal usage), the time of the day (or night), the extent of the intrusion of external noises from other sources (including traffic), and the socioeconomic nature of a building (or of the areas in which it is located).

Typical sound levels are normally established in terms of their relationship with a preexisting background sound level, which is often specified in standards. Thus, for example, the background sound levels for broadcast studios would be specified in the range of 10 to 25 decibels, A-weighted [dB(A)]; those for sleeping quarters would be specified in the range of 20 to 35 dB(A); and those for offices would be specified in the range of 30 to 50 dB(A).

ACOUSTICAL PERFORMANCE OF BUILDING MATERIALS

Insulation Against Airborne Sound

The noise reduction provided by a barrier, partition, or wall is dependent on the transmission loss of that particular barrier, partition, or wall, together with the acoustical characteristics (and, specifically, the amount of sound absorption) existing on each side of the element.

For damped, single-leaf barriers, this transmission loss will depend primarily on the product of the surface weight of the barrier and the frequency of the signal being attenuated. This phenomena is described as the "mass law." Doubling the surface weight of the barrier only results in a 3-dB improvement in transmission loss.

For double-leaf barriers, the transmission loss is determined by the spacing between the leaves at the edges of the barrier system and the respective surface weights of the two leaves. Maximizing the spacing between the leaves has the result that the performance of the barrier tends to be the highest possible value at all frequencies. At minimum spacing between the leaves, the maximum improvement is at the highest frequencies, while the typical improvement may be as little as 3 dB at the low frequencies.

In any barrier system, maximum performance requires the closing off and effective sealing of all holes and gaps, particularly around penetrations of the type required for pipe and pipe fittings. Such penetrations usually require an effective flexible sealing in order to accommodate the thermal movement while simultaneously minimizing the extent of vibration transmission from the pipe into the surrounding barrier system. The preferred type of sealing system should incorporate fire-rated flexible fiberglass, mineral wool, or ceramic wool wrapping retained by sealant and, where required, metal sleeving for protection or to span between the cavity access on the opposite sides of thick walls or large cavities.

Barrier systems used to surround or enclose piping should incorporate acoustic-absorbing linings or retained fiberglass or mineral wool together with effectively sealed external barriers of high-mass drywall construction fixed to steel stud framework, or masonry, as required. Barriers in close contact with pipe or fittings should provide noise reduction or have a sound-absorption capability not less than that indicated by laboratory tests carried out on large-scale samples evaluated under normal conditions.

ACOUSTICAL RATINGS OF PLUMBING FIXTURES AND APPLIANCES

The acoustical rating tests for fixtures are still in their infancy and have not yet been internationally standardized. While some countries, most notably Germany, do have useful standards, the United States has yet to formalize any plumbing acoustic tests. The problem of adequately defining the direct airborne and structure-borne components of vibration still constitutes a major problem in performing acoustic rating tests. Only the German standard DIN 52218, *Laboratory Testing on the Noise Emitted by Valves, Fittings and Appliances Used in Water Supply Installations (Part 1)*, has so far addressed this problem. Also, the International Organization for Standardization (ISO) has published standard 3822/1, *Laboratory Tests on Noise Emission by Appliances and Equipment Used in Water Supply Installations*, and the American Society for Testing and Materials (ASTM) has established a project E-33.08B, Plumbing Noise, to investigate this problem.[1]

The airborne sound radiated by showers, dishwashers, waste-disposal units, washing machines, water closets and bathtubs is specified by the fixture/appliance manufacturer. The sound ratings for fittings are normally expressed in terms of sound power or A-weighted and octave-band levels measured in a reverberant toilet room or kitchen-type environment at a distance of 3 feet (0.9 m). Because of the differences in the reverberations between one environment and another, the characteristics of the test environment should ideally have a reverberation time lying in the range of 1 to 2 seconds and be independent of the frequency.

Valves The sound levels from valves are dependent upon the size of the fitting, the mass flow rate, and the pressure differential across the fitting. Sound levels from taps and valves at a distance of 3 feet (0.9 m) may range between 30 and 50 dB(A) for well-designed and properly installed fittings, 50 and 70 dB(A) for adequately designed and adequately installed fittings, and 70 and 90 dB(A) for poorly designed and poorly installed fittings. Improvements in the performance of faucets are most notably achieved through the incorporation of aerators, which may result in reductions in noise levels of as much as 15 or more dB.

Water closets The noise from water closets can be subdivided into:

- The noise of the water flushing the closet bowl.
- The noise of the water refilling the tank.
- The noise of a flush-valve operation, including water discharge into the fixture and the ejection of materials from the closet bowl.

The noise of the water flushing the closet bowl is a function of the specific flow rate from the tank, the proximity of the tank to the closet bowl, and the method of mounting the tank itself. While sound levels as high as 90 dB(A) at 3 feet (0.9 m) are possible in older style fittings with the tank located as much as 6 feet (1.8 m) above the bowl, modern, close-coupled tanks, when properly installed (with bowl cover down), may be as low as 55 dB(A).

The noise of the tank refilling is a function of its design, which includes the type of construction of its envelope, the method of mounting to the wall (or closet bowl), the type of tank valve used, the water, and the time required for the refill cycle. There are many cases where the noise of the tank refilling is far more annoying than the noise produced by the toilet flushing. The noise of toilet tanks refilling may be as low as 40 dB(A) at 3 feet (0.9 m) in well-designed units incorporating quiet valves and silenced, tail-pipe assemblies. In poorly designed installations operating at the maximum flow rate, this noise may be as high as 95 dB. Flush-valve operation can be as high as 95 dB, while blowout-type fixtures have been recorded at as high as 120 dB.

Urinals The noise associated with urinals is a function of the wall-mounting method used to install the fixture and the flushing action of the urinal—water discharge into the fixture and the ejection of the materials. The flush-valve operation may be as high as 95 dB, with blowout units as high as 110 dB.

Bathtubs The noise from bathtubs is usually caused by the impact of a high-velocity water stream into a glazed metallic, fiberglass, or acrylic bathtub. While this noise varies during the filling cycle, it may also be significant during the drainage cycle.

In both cases, this noise is a function of the bathtub material and its structural design as well as its method of installation, particularly the extent of its structural decoupling from the walls and floor (in order to reduce the acoustical impact on adjacent rooms or other apartments). In many European countries, the building regulations specify stringent decoupling procedures to minimize the structure-borne noise propagation. Outside these countries, such procedures are relatively unknown and are not generally utilized. The noise of a bathtub filling typically lies in the range of 60 to 100 dB(A) at 3 feet (0.9 m), depending on the flow rate. The point of impact of the water stream with the side of the bathtub is generally reduced by using an aerator on the spout. Good design practice calls for the water spout to be installed so that the water stream is not directed to strike the bottom of the bathtub.

Showers Shower noise is mostly a function of the floor surface in the shower enclosure and the type of

[1]Copies of the DIN and ISO standards are available from the American National Standards Institute (ANSI), 1430 Broadway, New York, NY 10018.

shower head. The constant-temperature controller is only significant when the water-pressure drop across it is unusually high or the method of supporting the pipe from the walls results in the generation of resonant noise. Shower noise typically lies in the range of 60 to 90 dB(A) at 3 feet (0.9 m).

Dishwashers Dishwasher noise is a function of the basic design of the unit, the choice of the mounting procedures employed, and the extent to which the installer provides additional thermal and acoustical insulation. The noise from dishwashers can be minimized by mounting the units on rubber isolation devices or by providing layers of fiberglass or mineral wool insulation on their tops, rear and sides. Significant noise is created by the activation of solenoids and solenoid-activated valves that create water hammer and sound propagation through the piping.

The use of flexible connections and the incorporation of surge eliminators to minimize the water hammer are highly recommended. Typical noise levels from dishwashers are in the range of 65 to 85 dB(A) at 3 feet (0.9 m) with peaks as high as 105 dB(A) created by solenoid operation.

Waste-disposal units Sink or waste-disposal-unit noise is a function of the design of the unit as well as the design of the sink or basin to which it is attached. Lightly constructed, stainless-steel sinks or basins will tend to amplify the sound energy. The supporting cupboards or fixtures may also have a similar effect. The sinks and basins used to support such fittings should be designed to incorporate an effective dampening of the bowl through the application of damping materials or framework.

The plumbing connection to the waste-disposal units should be flexible at the inlet and the discharge. The noise levels produced by these units can vary widely and most manufacturers do not publish the noise-rating data. Noise levels can vary between 75 and 105 dB(A) at 3 feet (0.9 m), depending on the method of mounting and the extent to which the protective covers are used.

Washing machines Washing-machine noise is a function of the design of the unit and, to a lesser extent, the method of mounting or type of plumbing connections used. The airborne noise levels can be somewhat reduced through the application of dampening material on the inside surfaces of the enclosing panels.

The incorporation of isolation mounts does not normally reduce the direct airborne sound but may drastically reduce the structure-borne component audible in adjacent apartments or rooms and perceptible vibration in the floor during spin cycle. The noise levels produced by washing machines range between 65 and 90 dB(A) at 3 feet (0.9 m), and few manufacturers publish the sound-rating data.

An indirect discharge of the wastewater into a trough or hub drain may be very loud in the room but may have a reduced noise transmission through the piping system.

GENERAL ACOUSTICAL DESIGN

Water Pipes

Origin and spread of noise The causes of noise are the surge due to the sudden opening or closing of valves and flow where the cross sections of such valves are greatly restricted. In addition, because of the high velocity, cavitation and turbulence are also created by the sudden changes in direction. The higher the pressure head of the fittings, the louder the noise. Water hammer arrestors (shock absorbers) may be beneficial in eliminating sound noise generated by these problems.

Noises originate when a stream of water strikes the base of the bathtub, sink, or lavatory. In the emptying operation, gurgling noises often occur because of the whirlpool action. These noises are conducted partly along the pipe and partly by the column of water. The pipes induce the walls and ceilings to vibrate and radiate sound.

Reducing the noise at its origin Fittings of satisfactory design with a low noise level should be employed whenever possible.

Flush tanks, in particular, can be substantially quieter than pressure flush valves, especially when insulated. Low-flush, gravity-flush valve fixtures will operate more quietly than high-velocity (blowout) type fixtures.

The largest possible cross sections for the pipes should be used and the water supply pipes in all critical areas should be designed for a maximum velocity of 4 ft/s (1.2 m/s).

The emptying noise can be reduced by using waste fittings to ensure that the air is simultaneously and uninterruptedly sucked out of the stream of water and carried away with it.

The pressure in the pipes inside of the building can be reduced to the extent that the operating conditions allow closed-circuit pressure.

Reducing the spread of noise The designer must make a distinction among the pipes laid on a wall, those in a wall, and those in shafts.

In the case of pipes installed on a wall or in pipe shafts, structure-borne, sound-damping packing (e.g., cork, felt, profiled strips of rubber, or other elastic materials) should be inserted between the fastenings and the pipe. The packing should not be compressed by excessive tightening of the pipe clips. Instead of packing for structure-borne sound control, vibration isolation mounts should be used.

Pipes in the wall should be wrapped with sound-damping materials (e.g., felt, bituminized felt, or viscoelastic damping materials) without leaving any gaps. The same effect may be achieved by having pipes elasticity mounted in a firm outer casing.

Several pipes running in the same direction in shafts can be fastened to a single common rack. This rack should not have any structural, noise-conducting connections with the walls. Common racks should be fastened to the wall with rubber/metal connections interposed.

When pipes pass through ceilings or walls, they should be taken through sound-control sleeves of fibrous damping materials and resilient sealant. This approach must not adversely affect the airborne sound control (for instance, through joints), in particular in the case of party ceilings and walls of separate tenants. In the case of ceilings and walls that have to be fire resistant, this approach must be complied with when deciding on the fire-rated sleeves that will generally be sealed with a fire-rated silicone foam.

In the case of apparatus and equipment, such as washing machines, spin dryers, bathtubs, and wash sinks that generate noise or in which noise occurs during filling and emptying, resilient sound-damping materials should be used at the places where they touch or are attached to the structure. In the case of bathtubs, a solid joint between the bathtub outlet and the waste pipe should be avoided. Rubber pads under the bathtub supports are recommended.

Bear in mind, in the case of water pipes and apparatus in or on walls that border occupied spaces, that the permissible loudness levels are not exceeded. In such cases, conventional water-closet flush valves should be avoided and quiet-acting siphon jet actions should be used.

Occupied Domestic Spaces

Keeping within the maximum allowable loudness levels in occupied rooms requires that steps be taken during the planning and construction stages of the building. The term "occupied domestic spaces" generally covers hotels, motels, dormitories, and other locations where, in addition to domestic appliances, the elevators, incinerators, ventilation equipment, switch gear, boilers, and refuse-disposal installations can cause unacceptable noise levels in habitable areas, particularly sleeping quarters. As early as the planning stage, the various points requiring consideration must be taken into account by the plumbing designer.

Because of the multiplicity of influences involved, no simple or standard rules can be given for keeping within the permissible loudness levels. For some groups of installations, the following criteria apply:

1. Apparatus and machines in which the noise is predominantly transmitted as structure-borne sound (e.g., motors, pumps, pressure-increasing installations, ventilation machinery, drives for elevators, gearing, and heavy switch gear) must be sound insulated/vibration isolated from the building.
2. In order to reduce the structure-borne sound transmission from the heating installations into occupied rooms,a concrete floating floor should be added in the rooms where the solid fuel is stored and where there is heating equipment. The boilers must be supported on vibration isolators and be separated from other components and from the floating floor. The pipes can be supported by collector blocks on the floating floor. Rigid fastening to ceilings, floors, or walls should be avoided.
3. Ceilings over rooms where there is heating equipment should be provided with a floating barrier consisting of plaster or gypsum board in order to increase the airborne soundproofing.
4. In the case of refuse-disposal installations, the inside shaft should be constructed in such a way that the building is insulated against structure-borne sounds. Whenever possible, low-noise materials should be used. Metal sheeting should be provided with a resilient impact-absorbing coating on the inside and/or covering. The roof of the shaft should be made of sound-absorbent material.
5. Refuse bins should stand on a floating concrete slab and be enclosed by walls and ceilings complying with the requirements for party walls and ceilings of apartments. If deflector plates are provided, these devices must be fixed in a flexible manner and with structure-borne sound insulation.

Pumps

Sources of noise The following items are some of the major sources of noise from pumps in plumbing systems:

1. Unbalanced motors.
2. Pulsation of the air mass flow from electric fans. (This is a major source of noise in 2-pole, fan-cooled, electric motors. The noise from the fan is usually so dominant that all other sources of noise in the electric motor can be neglected.)
3. Pulsation of the magnetic field in the electric motor.
4. Motor/gear/pump journal and thrust bearings.
5. Contacting of the components in parallel-shaft and epicyclic gears.
6. Imbalance of the pump impellers.

7. Pulsation in the pumps. (Hydrodynamic noise generation is inherent in all types of pumps; the fundamental frequency of noise, when the pump runs at the design point, is governed by the number of blades and their interaction with the volute cut-water or diffuser guide vane ring. The intensity of the noise generated and the relative strength of the various harmonics produced are determined by the velocity profile shape leaving the impeller passages, vortex wakes shed by vanes, and the impulsive effect as they pass under the volute cut-water. The impulse wave form, although very complex, can be resolved into a fundamental equal to the speed times the number of blades and a series of harmonics. Manufacturing errors, which produce angle or pitch variations between the blades, are instrumental in generating a less-prominent series of harmonics with fundamental frequency equal to the speed with the amplitude and/or the frequency modulation of the blade-passing frequency. At off-design operation, unsteady flow conditions can arise due to flow separation and rotating stall effects.)
8. Cavitation. (Air is entrained in the solution, which can damage the pump; impellers constructed with open-grain material, such as cast iron, may disintegrate because of the implosive effect of cavitation.)

Possible modifications Obviously, if the overall noise level of the pumping plant is considered to be too high to comply with the accepted specifications, identifying and reducing the noise output from the components and equipment in the plumbing system contributing the most noise will yield the most dramatic results.

Some possible modifications the plumbing engineer should consider in order to reduce the noise output from the system are as follows:

1. *Gearbox.* A silencing enclosure or cladding should be provided.
2. *Motor fan.* A silencer should be provided at the air inlet and outlet or, if possible, the design should be modified.
3. *Motor rotor.* The number of slots should be changed or, if possible, its design should be modified.
4. *Pump and pump bearings.* Sleeve types should be employed.
5. *Pump operation.* The pump should be operated near design flow conditions in order to achieve the correct system matching. (Modifying the characteristics of the system or altering the diameter of the impeller, resulting in operation at lower speeds, will make the pump operate more quietly.)
6. *Pump impeller blades.* The clearance between the tip of the impeller and cut-water should be increased (a maximum of 85% impeller diameter to volute diameter is recommended).
7. *Impeller and guide-vane tips.* Should be dressed in order to reduce the thickness and intensity of the trailing wakes.
8. *Out of balance.* Should be balanced to fine limits. Impeller, motor, blades, and rotor should be balanced at all rpms to eliminate—or minimize—vibrations.
9. *Cavitation.* The suction characteristics of the installation/system should be improved. (Ideally, the pump should always be under positive head at the pump suction.)

Plant noise The resulting noise output of the plant, as installed on the site, is dependent upon all of the above factors coupled with the induced resonance of the adjacent parts (such as pipes, bedplates, fabricated stools, tanks, and panels). These factors form part of the final environment of the pump and are discussed under the section "Noise and Vibration Control," which follows. The effects are best investigated by determining the natural frequency of these parts, by separate excitation, or by operating the pump through its service-speed range. The natural frequency of the part can be modified by a simple trial-and-error stiffening or damping.

Other effects are also likely to appear for the first time on the site. One of them is the interaction of the pump with the intake sump. Testing a model of the sump intake before installation can prevent air-entraining vortices, eddies, and distorted flow distributions, which cause a mismatch at the impeller leading edges. Vortex formations generated entirely below the water level can be particularly troublesome in actual practice, since these formations are caused by water spinning at high velocities, which causes submerged cavitating vapor cores to be generated and drawn into the sump intake. These vortices cannot be observed on the site; however, they can be prevented at the outset by testing the sump model with observation windows fitted below the surface level.

Associated venturi-meters, valves, and pipes, in the final installation, contribute to raising the general noise level of the station. Water at high velocities passing through partially closed valves, particularly in high-pressure systems, can produce severe cavitation noise, which is generated by the rapid collapse of the vapor bubbles against the walls of the valve and downstream pipe. Sound-pressure levels of 110 dB have been recorded.

These high sound-pressure levels can be greatly reduced by using multistage pressure breakdown systems and by paying special attention to the valve's port design. Thick-walled pipe and external acoustic installation are only effective for localized noise reduction; they do not reduce the noise in the fluid stream but shroud it where treatment is used. Much of the noise is still carried downstream and, at times, upstream as well, depending on the system. Poor pipe design, involving many sharp bends and sudden expansions and contractions, can induce considerable turbulence and noise.

Estimating the noise level of a pump Small, motor-driven pump sets, which are commonly employed in plumbing systems, can be conveniently tested in an anechoic chamber with accurate results. However, the most important sources of sounds in large pumping stations are usually associated with custom-built units.

Pump noise levels are measured by the near-field technique 3 feet (0.9 m) from the unit in order to minimize the sound transmissions from pipe coupled to the pump. The sound-pressure level, at 3 feet (0.9 m) from the pump, can be estimated by using the following equation (presented in the International System of Units, or SI units, which is the best means for available test data):

Equation 10-1

$$\text{Pump sound-pressure level} = 163.9 + 8.5 \log \frac{(\text{volume flow rate} \cdot \text{head})}{(\text{rpm} \cdot \text{specific speed} \cdot \text{impeller diam.} \cdot \text{impeller width})}$$

where

Pump sound-pressure level = dB(A)
Volume flow rate = L/s
Head = stages/m
Specific speed = m/s
Width and diameter of impeller = mm

Where the noise characteristics of a particular pump are already known, the change of the noise level with the pump speed can readily be determined by using the following equation:

Equation 10-2

$$\text{dB} = 50 \log \left(\frac{N1}{N2} \right)$$

where

N_1 and N_2 = Pump speeds

Flow Velocity and Water Hammer

In simple terms, the magnitude of the pressure increase due to water hammer is a function of the velocity of the pressure wave and the rate of exchange of the flow velocity. The velocity of the pressure wave (which is the same as the velocity of sound in the water contained in the pipe) depends on the physical properties of the water and of the pipe material. For all commercially available copper pipes, the velocity of the wave propagation has a value in the range of 3000 to 4000 ft/s (915 to 1220 m/s).

If the flow velocity changes abruptly (e.g., by the sudden closing of a tap or valve), the pressure increase can be determined by using the following equation:

Equation 10-3

$$\text{Pr} = \frac{\text{WaV}}{144\text{g}}$$

where

Pr = Pressure rise, $\text{lb/ft}^2 \cdot \text{s}$
W = Specific weight of liquid, lb/ft^3
a = Velocity of pressure wave, ft/s^2
V = Change in flow velocity, ft/s
g = Acceleration due to gravity, ft/s^2

The pressure generated by water hammer may cause straight pipe lengths to vibrate. If the pipes are in close contact with the walls and not fixed at sufficiently rigid short intervals, they may strike against the walls with a succession of blows.

If such fittings (solenoid valves, foot-action valves, spring-loaded taps, and check valves) could be eliminated, then the incidence of water hammer could be greatly reduced. However, as these fittings are integral parts of a plumbing installation, the designer must allow for this condition. The following guidelines are recommended to the plumbing engineer:

- Maintain a water velocity in the range of 4 ft/s (1.2 m/s) at the appliance.
- Secure the piping so that it does not come into contact with the building structure.
- Use rubber isolators.

The use of air vessels (chambers) will reduce the effects of water hammer. A vessel with a flexible membrane to separate the air chamber from the water (water hammer arrestor or shock absorber) is recommended to prevent loss of air.

Design Procedures

To provide a plumbing system that conforms to specific acoustic standards, the designer requires the following information:

1. The maximum noise levels allowable in each habitable room.
2. Location of equipment with respect to adjacent spaces.
3. The data on the acoustic performance of the building materials and the method of construction.
4. The acoustic ratings of the plumbing appliances and fixtures, piping, and valves.
5. The acoustic performance of the noise-isolation devices that can be incorporated in the plumbing installation (i.e., vibration mountings and rubber spacers).
6. The data on the effects of the background noises to screen out the effects of the plumbing noises.

7. Supervision of the plumbing installation in order to ensure adherence to the acoustic details.

Specific acoustic performance guarantees for plumbing installations should be avoided where sufficient research has not been carried out. On any critical projects, the retention of an acoustical consultant may be essential. In the end, the final results are as much dependent on the quality of the workmanship and supervision as they are on the design details. Many well-designed projects fail to achieve the required performance because of inadequate supervision, which is necessary in order to pinpoint and correct substandard details.

Noise and Vibration Control

All noise-control problems can be reduced to three basic elements: source, path, and receiver.

Noise-control problems frequently involve consideration of several sources of noise, several paths for the transmission of noise, and several different receivers. The relationship among these elements defines the seriousness of the problem. In order to solve a noise problem, the source strength can be reduced, the path can be made less effective in transmitting sound, or the receiver can be made more tolerant of disturbance. However, most practical solutions involve a trade-off, so concentration on only a single aspect of the problem may result in over-design or an unsatisfactory solution.

For sources that not only produce noise and vibration problems but also have the potential to lead to damage or decrease the useful channel space for liquids, it is desirable to reduce the source strength. Cavitation is a typical example of this kind of problem. The solution to this problem hinges on the pump suction (i.e., net positive suction head, NPSH). One may consider placing the pump at a lower elevation, if practical, or one may improve the suction piping and raise or pressurize the supply tank. In recent years, efficient suction-assisting devices (such as booster pumps) have become commonly used where low NPSH must be handled at low cost. Several manufacturers supply add-on or built-in inducers for end-suction pumps.

For noise and vibration sources that do not influence systems operating conditions or reliability, control of noise transmission (i.e., the path) from the source to the noise-sensitive area may be the most economical solution. Noise may be transmitted through structure-borne, airborne, and fluid-borne paths. Structure-borne noise travels in the form of high-frequency structural vibrations; airborne noise travels in the form of sound waves; and fluid-borne noise travels in the form of pressure fluctuations. The structure-borne path usually plays an important role because the noise source within the pump, or piping , often can communicate with the surroundings only by setting the enclosure into vibration. These vibrations may radiate sound directly or may be transmitted through the supporting structure, to be converted to airborne sound elsewhere.

Vibration isolators, such as resilient mounts and resilient pipe hangers, are commonly used to reduce structure-borne vibrations. Theoretically, in order to design an adequate isolation system, the engineer must realize how much vibratory force is generated by the equipment and the maximum permissible force transmission to the building. Since these design parameters cannot readily be obtained, some practical guidelines have been formulated to provide effective isolation at a reasonable cost. These are generally adequate for all but the most critical or special applications (such as very light or flexible structures or equipment installed above adjoining very quiet spaces).

To ensure that the desired noise isolation is achieved, a detailed vibration-control specification and its stringent enforcement are required. With increased public awareness of noise, government agencies such as the General Services Administration (GSA Guide Specification Number 4-1515-71, *Public Building Service*) and Federal Housing Administration (FHA *A Guide to Airborne, Impact and Structure-Borne Noise Control in Multifamily Dwellings*) have established recommended guidelines on noise and vibration control.

However, it is not enough merely to have noise-control specifications. Adequate detailing techniques are most essential for communications between the design engineers and the contractors. For most situations, acoustical details are well developed and are available for most applications. From a practical point of view, most plumbing fixtures cannot be effectively isolated, although they can be installed to minimize vibration.

When pipes are connected to vibrating equipment installed on vibration isolators, sufficient flexibility must be built into the piping systems to match the equipment vibration isolators. In addition, adequate flexibility is required in order to protect the equipment from any strains imposed by misalignment and by thermal movement of the piping. Piping flexibility can be achieved by the inherent resilience of the pipe in simple bend-and-loop configurations (if there is sufficient length) or by the use of flexible pipe connectors, which also attenuate the transmission of noise and vibration along the piping system. However, their use as vibration-isolation devices should be considered very carefully for the following reasons:

- They are the weakest component in the piping system. (Without proper specification of the material, installation, and maintenance, they may fail and cause severe water damage.)

- In many instances, sound energy may flank the flexible pipe connectors so that pipe-wall noise is exited downstream of the resilient break. Indeed, the various restraints added by the manufacturers to reduce the possibility of failure make the flexible pipe connectors almost as rigid as the pipe itself.

Studies have found that flexible pipe connectors are most effective in the case of cavitation. Flexible pipe connectors have also been found to be effective in the attenuation of the tonal components at the impeller passage frequency of a pump.

Equipment design Quiet operation of pumps begins with proper design. Although today's state-of-the-art design and development of pumps and plumbing fixtures has a long heritage, noise is still seldom considered by the manufacturer. This is perhaps because of the designer's lack of awareness and experience, but even knowledgeable designers yield to economic pressures for cost reduction.

It is obvious that the primary purpose of a pump or plumbing fixture is to move liquids and to perform the necessary plumbing functions. These considerations must come first. However, noise and vibration controls should be integrated in the design and may then be expected to lead to improved performance with little or no cost penalty. Quite often, the cost of modification is negligible. The key to effective noise control is a complete understanding of the noise-generating mechanisms.

By simply changing the cut-water clearance of a pump, a major reduction in the blade-passage-frequency noise is achieved. Similarly, water faucets can easily be designed for quiet operation. For a particular value of pressure drop, a valve can be designed to minimize cavitation and its resulting noise within the water-pressure design range.

Some water-closet manufacturers indicate that, like dishwashers and food-waste disposers, economy models are noisier than more expensive ones. Nevertheless, quietness in water closets is a marketable attribute. One of the problems with flush-valve-operated water closets is the high initial noise impulse that is associated with the opening of the flush valve. However, if the valve discharges against a properly selected resistance, the noise impulse can be substantially reduced. There is no doubt that a cost-saving, quiet fixture could be achieved with more research.

SYSTEM DESIGN

Equipment selection To select a quiet unit, the engineer must have an understanding of the noise characteristics of plumbing fixtures and appliances. Good matching between machine characteristics and system requirements is essential for performance, as well as for noise control. For example, in a system operating over a narrow load range, a pump of single-volume design (selected for near-peak efficiency operation) is acceptable because the unbalanced radial load on the impeller is the least at optimum delivery.

Adequate criteria should be established for equipment vibration to ensure that there are no excessive forces that must be isolated or will adversely affect the performance or the life of the equipment. There are many ways to develop equipment-vibration criteria. A simple but satisfactory approach would be to use the criteria that have been developed on the basis of the experience of persons and firms involved with vibration testing of mechanical equipment in the building construction industry.

Pressure Most model plumbing codes have established the rate of flow desirable for many common types of fixtures as well as the average pressure necessary to provide this rate of flow. Although the pressure varies with the design of the fixture, a pressure of 5 to 8 psi (34.5 to 55.2 kPa) at the entrance to the fixture is generally the minimum required for good service at lavatory faucets and tank-type water closets. A pressure of 15 psi (103.4 kPa) may be ample for most of the manufacturer's requirements. Some fixtures, especially wall-hung water closets, require a pressure up to 25 psi (172.4 kPa).

Water pressure in many mains is typically 50 to 80 psi (334.7 to 551.6 k Pa). As the water flows through a pipe, the pressure continually decreases along the pipe, due to the loss of energy from friction and the difference in elevation between the water main and the fixture.

From a noise-control point of view, it is desirable to keep the fixture inlet water pressure as low as possible. This condition usually can be achieved by installing pressure-regulating devices in order to balance the pressure gradient in the water system. Many cities experience large pressure fluctuations in the hydraulic gradient of their water systems due to demand changes (such as after working hours). The inlet water pressure must be kept higher than the required minimum pressure to ensure good service. The alternative, if it were practical, would be to have continuous adjustments of the system's inlet pressure as the demand changes. The system pressure also has a great effect on the occurrence of cavitation. The plumbing system must be operated at a pressure level high enough to prevent cavitation.

Speed Changes in the operating conditions of the pump have a significant effect upon the level of pressure fluctuations, particularly for plumbing systems in which resonance exists. It is possible that a 5% change in the pump speed may result in a 70% change in the pressure fluctuations. Also, a valve's pressure-flow characteristics and structural elasticity may be such that, at some operation point, it will oscillate (perhaps in resonance with parts of the piping system) so as to produce excessive noise or even physical damage. A change in the operating conditions or details of the valve geometry may then result in significant noise reduction.

Pipe sleeves One very important consideration for piping-system noise control that seldom receives any attention is the detailing of the piping sleeves at the wall and floor penetrations. Each type of piping sleeve has a specific application, and its acoustical treatment cannot easily be generalized. For example, the acoustical requirements for a piping sleeve used on water piping that passes through a foundation wall will be different than those for a piping sleeve used for sprinkler pipes that pass through a double-wall construction enclosing a concert hall. However, each case should be treated so that the pipe penetration will match the acoustical value of the wall and provide the proper separation between the piping and the building construction. This requirement must be made clear to the contractor, and entails showing the construction details on the contract drawings.

Most plumbing systems contain many points at which the piping must penetrate floors, walls, and ceilings. If such penetrations are not properly treated, they provide a path for noise transmission that can destroy the acoustical integrity of the occupied space. Accepted practice is to seal the openings with fibrous material and caulking in a manner similar to that illustrated in Figures 10-1 and 10-2. Some penetration seals, as shown in Figure 10-3, are also available commercially.

Water hammer A common method of controlling water hammer noise is to install a shock absorber or air chamber where the water hammer is most likely to originate, such as at a faucet or a control valve. In many residential systems, it is common to install one similar to that shown in Figure 10-4.

Pipe wrapping The noise from a pipe may be reduced by applying a wrapping (lagging) to the pipe. Such a wrapping normally consists of a layer of porous insulation material placed between the pipe surface and an external, impervious cover. The insulation should be glass or mineral fiber; do not use closed-cell sponge rubber or rigid blown cellular glass or calcium cilicate. The cover must be supported by the blanket with no structural ties between the outer cover and the pipe. Structural connections reduce the effectiveness of the pipe wrapping. The porous insulating material serves three purposes:

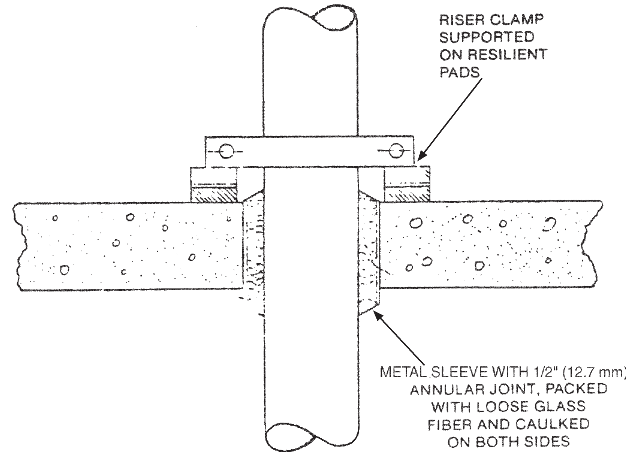


Figure 10-1 Pipe-Sleeve Floor Penetration

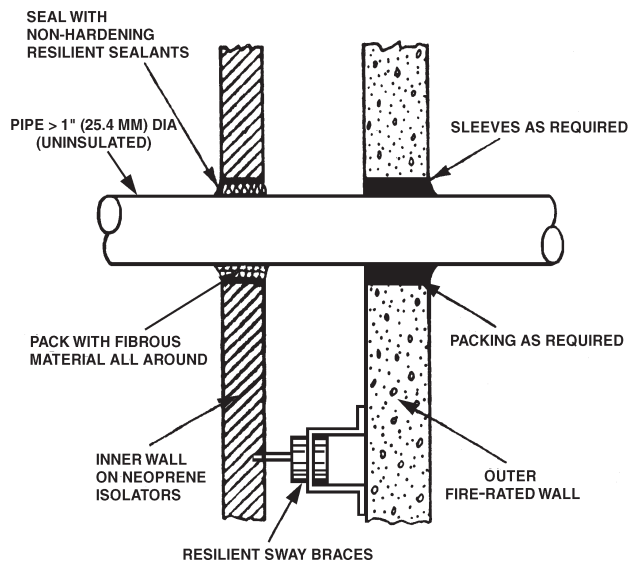


Figure 10-2 Acoustical Treatment for Pipe-Sleeve Penetration at Spaces with Inner Wall on Neoprene Isolators

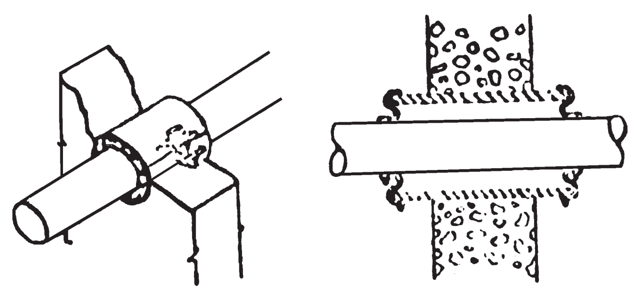


Figure 10-3 Acoustical Pipe-Penetration Seals

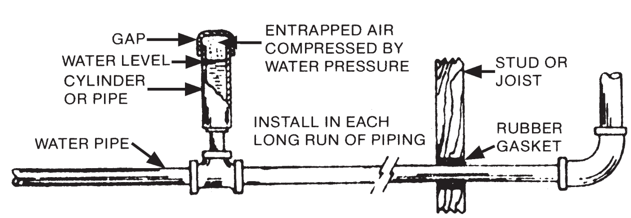


Figure 10-4 Installation of an Air Lock in a Residential Plumbing System

- It keeps the external, impervious cover separated from the surface.
- It attenuates sound (particularly, at high frequencies).
- It reduces the amplitude at the resonant frequency defined by the mass of the cover and the stiffness of the layer of porous material.

The typical noise reduction from a pipe wrapping is in the range of 0 to 5 dB at low frequency and 15 to 25 dB at high frequency.

System layout A system that is undersized (or that contains a section of undersized piping) will usually generate excessive noise. It is good engineering practice to use simple-design pipe layout (i.e., long straight runs with a minimum of elbows and tees) and long radius elbows and connectors. The straight run can be estimated as being 12 times the diameter of the pipe. Piping layout near pumps and valves is also of great importance. Figure 10-5 illustrates some examples of suction-piping installations.

Vibration isolation The sources most commonly responsible for the generation of noise in plumbing systems are discussed in this section. However, most plumbing noise problems are not caused directly by the noise radiated to the air from these sources. Usually, the plumbing system transmits the sounds so that the mechanical vibration follows its support system to the surface and is eventually radiated as noise.

A complete discussion of vibration-isolation theory is beyond the scope of this chapter. Only the methods of vibration control that are readily applied and broadly useful in practical problems are considered here. This chapter does not address the various, specific, vibration-control techniques that are useful only in the hands of a specialist or that require detailed measurements and analyses.

Selection criteria A vibration-isolating device should be selected using the following criteria:

1. It must be soft enough to provide the desired isolation effect and have a stiffness that is less than the local stiffness of each of the items it connects.
2. It must provide a natural frequency that is considerably lower than the lowest excitation frequency of concern.

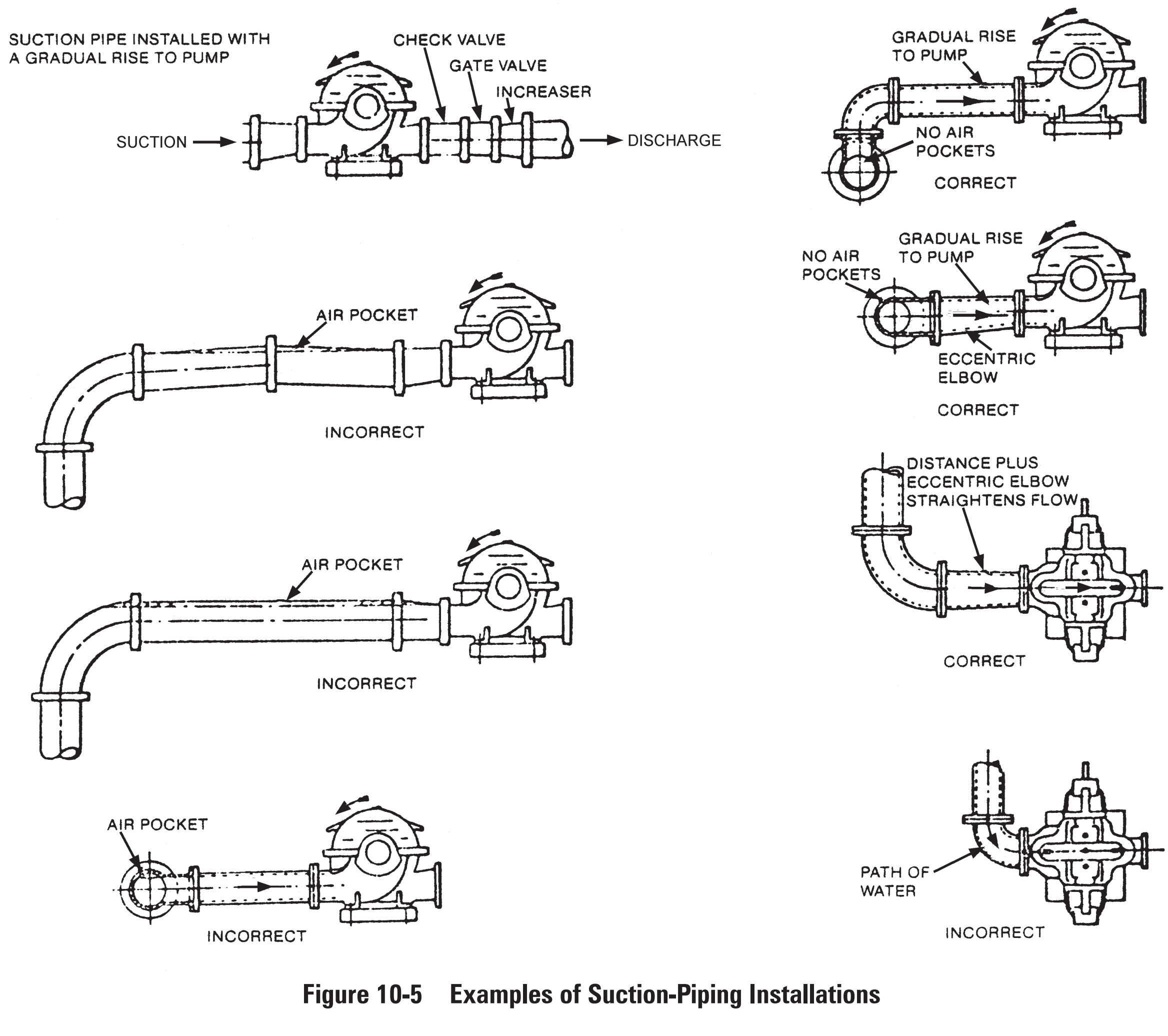


Figure 10-5 Examples of Suction-Piping Installations

3. It must be capable of carrying the loads imposed on it.
4. It must be able to withstand the environment to which it will be exposed.

Vibration-control devices In plumbing systems, vibration-control devices generally consist of steel springs, air springs, rubber isolators, pads or slabs of fibrous (or other resilient) materials, isolation hangers, flexible pipe connectors, concrete bases, or any combination of these items. Some of the most common vibration-isolation devices are illustrated in Figures 10-6 and 10-7. Additionally, refer to Table 10-1 for the recommended static deflection for pump vibration-isolation devices.

Steel springs Steel springs are available for almost any desired deflection. These devices are generally used as vibration isolators that must carry heavy loads where more isolation performance is desired than rubber or glass fiber provides or where the environmental conditions make other materials unsuitable. They are generally available for deflection only up through 4

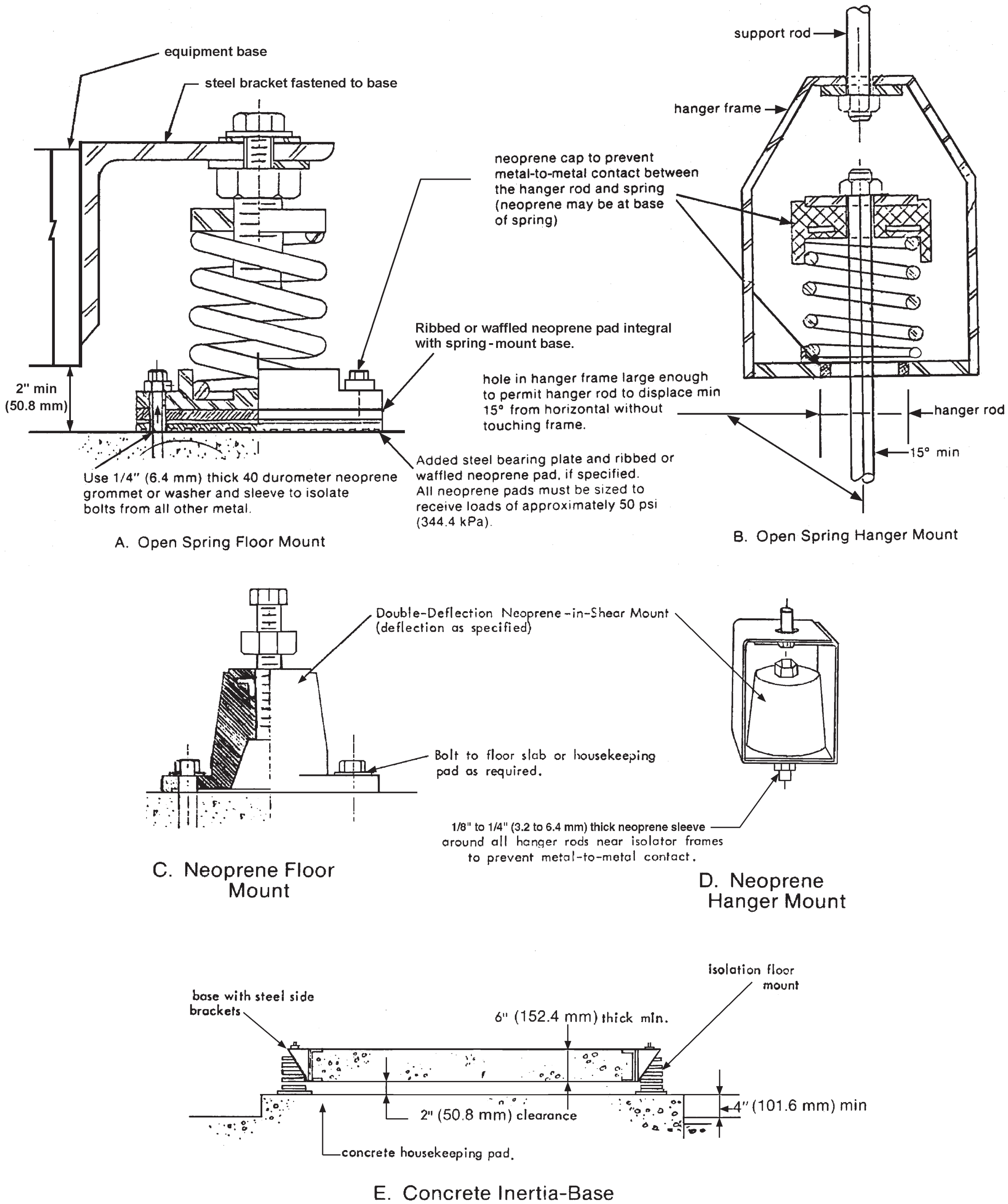


Figure 10-6 Typical Vibration-Isolation Devices

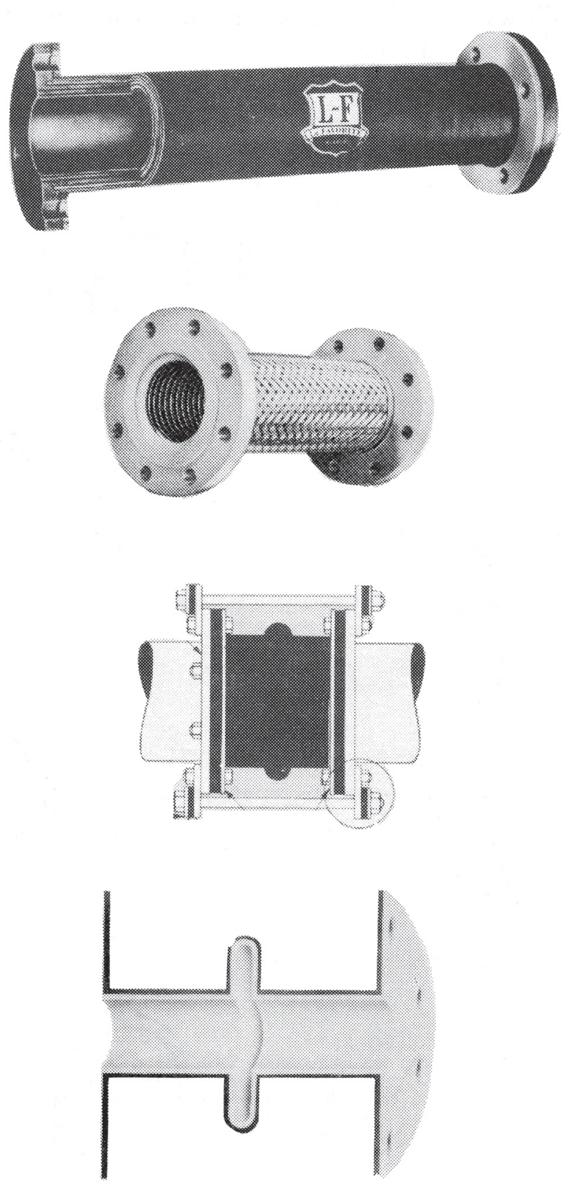


Figure 10-7 Typical Flexible Connectors

inches. The basic types of steel spring mountings are as follows:

1. Housed-spring mountings.
2. Open-spring mountings.
3. Restrained-spring mountings.

Because steel springs have little inherent damping and can increase their resonance in the audio-frequency range, all steel-spring mountings should be used in series with pads of rubber, fibrous or other resilient materials to interrupt any possible vibration-transmission paths.

Air springs Air springs, as steel springs, are available for almost any desired deflection where 6 inches. (152.4 mm) or more is required. By varying the air pressure in the bladder, air springs are capable of carrying a wide range of loads. The shape, rather than the pressure, determine the spring frequency. Air springs have the advantage of virtually no transmission of high-frequency noise. They have the disadvantage of higher cost, higher maintenance, failure rates and low damping.

Rubber isolators (neoprene mounts and hangers) Rubber isolators are generally used where deflections of 0.3 inches (7.6 mm) or less are required. These devices can be molded in a wide variety of forms designed for several combinations of stiffness in the various directions. The stiffness of a rubber isolator depends on many factors, including the elastic modules of the material used. The elastic modules of the material vary with the temperature and frequency and are usually a characteristic of a durometer number, measured at room temperature. Materials in excess of 70 durometers are usually ineffective as vibration isolators. Rubber isolating devices can be relatively light, strong, and inexpensive; however, their stiffness can vary considerably with the temperature. They are effective primarily against high-frequency disturbances with very limited performance at low frequencies.

Precompressed, glass-fiber pads These devices are generally used where deflections of 0.25 inch (6.4 mm) or less are required. Precompressed, glass-fiber pads are available in a variety of densities and fiber diameters. Although glass-fiber pads are usually specified in terms of their densities, the stiffness of the pads supplied by different manufacturers may differ greatly, even for pads of the same density.

Sponge rubber Sponge-rubber vibration-isolation materials are commercially available in many variations and degrees of stiffness. The stiffness of such a material usually increases rapidly with increasing load and increasing frequency. This material is rarely used in manufactured isolators but is often used in job-site fabricated installations.

Concrete base Concrete-base devices are usually masses of concrete, poured with steel channel, weld-in reinforcing bars and other inserts for equipment hold-down and vibration-isolator brackets. These devices perform the following functions:

1. Maintain the alignment of the component parts.
2. Minimize the effects of unequal weight distribution.
3. Reduce the effects of the reaction forces, such as when a vibration-isolating device is applied to a pump.
4. Lower the center of gravity of the isolated system, thereby increasing its stability.

Table 10-1 Recommended Static Deflection for Pump Vibration-Isolation Devices

Equipment Location	Power Range, HP (kW)	Speed, RPM	Indicated Floor Span, in. (mm) 30 ft (9.1 m)	40 ft (12.2 m)	50 ft (15.2 m)
Slab on grade	Up to 7.5 (5.6)	1800	¾ (19.1)	¾ (19.1)	¾ (19.1)
		3600	¼ (6.4)	¼ (6.4)	¼ (6.4)
	Over 7.5 (5.6)	1800	1 (25.4)	1 (25.4)	1 (25.4)
		3600	¾ (19.1)	¾ (19.1)	¾ (19.1)
	50-125 (37.3-93.2)	1800	1½ (38.1)	1½ (38.1)	1½ (38.1)
		3600	1 (25.4)	1 (25.4)	1 (25.4)
Upper floor above noncritical areas	Up to 7.5 (5.6)	1800	¾ (19.1)	¾ (19.1)	1½ (38.1)
		3600	¾ (19.1)	¾ (19.1)	1 (25.4)
	Over 7.5 (5.6)	1800	1 (25.4)	1½ (38.1)	2 (50.8)
		3600	¾ (19.1)	1 (25.4)	1½ (38.1)
	50-125 (37.3-93.2)	1800	1½ (38.1)	2 (50.8)	2½ (63.5)
		3600	1 (25.4)	1½ (38.1)	2 (50.8)
Upper floor above critical areas	Up to 7.5 (5.6)	1800	1 (25.4)	1½ (38.1)	2 (50.8)
		3600	¾ (19.1)	1 (25.4)	1½ (38.1)
	Over 7.5 (5.6)	1800	1½ (38.1)	2 (50.8)	3 (76.2)
		3600	1 (25.4)	1½ (38.1)	2 (50.8)
	50-125 (37.3-93.2)	1800	2 (50.8)	3 (76.2)	4 (101.6)
		3600	1½ (38.1)	2 (50.8)	3 (76.2)

5. Reduce motion.

Concrete bases can be employed with spring isolators, rubber vibration isolators, and neoprene pads. Usually, industrial practice is to make the base in a rectangular configuration approximately 6 inches (152.4 mm) larger in each dimension than the equipment being supported. The base depth needs not to exceed 12 inches (0.3 m) unless specifically required for mass, rigidity, or component alignment. A concrete base should weigh at least as much as the items being isolated (preferably, the base should weigh twice as much as the items). The plumbing designer should utilize the services of a structural engineer when designing the concrete base.

Flexible connectors When providing vibration isolation for any plumbing system or component, the engineer must consider and treat all possible vibration-transmission paths that may bypass (short-circuit or bridge) the primary vibration isolator. Flexible connectors are commonly used in pipe connecting between isolated and unisolated plumbing components. Flexible pipe connectors are usually used for the following reasons:

1. To provide flexibility of the pipe and permit the vibration isolators to function properly.
2. To protect the plumbing equipment from strains due to the misalignment and expansion or contraction of the piping.
3. To attenuate the transmission of the noise and vibration along the piping system.

For plumbing systems, the flexible pipe connectors usually consist of hose connectors and expansion joints.

Most commercially available flexible pipe connectors are designed for objectives (1) and (2) denoted above and not primarily for noise reduction. For noise control, resilient pipe isolators should be utilized.

Vibration isolation of plumbing fixtures From a practical point of view, most plumbing fixtures cannot be effectively isolated, although these components can be installed in a manner to minimize vibration transmission. Figures 10-8, 10-9, 10-10 and 10-15 illustrate some examples of resiliently mounted plumbing fixtures.

Vibration isolation of pumps Concrete bases with spring isolators or neoprene pads are preferred for all floor-mounted pumps. It is common practice to isolate a pump in a manner similar to that illustrated in Figure 10-11. Figure 10-12 shows some of the most common errors found in pump-isolation systems. Table 10-1 contains the recommended static deflection for the selection of pump vibration-isolation devices.

For critical system applications, sump pumps and roof drains should also be isolated. See Figure 10-13 for a typical installation.

Vibration isolation of piping All chilled, condenser, domestic, and hot-water piping, including the heat exchanger and the hot-water storage tank, should be isolated in addition to the following:

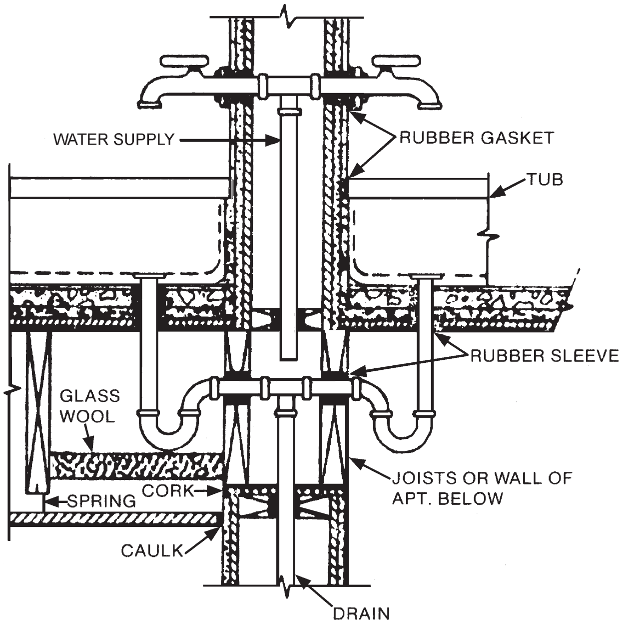


Figure 10-8 Bathtub and/or Shower Installation

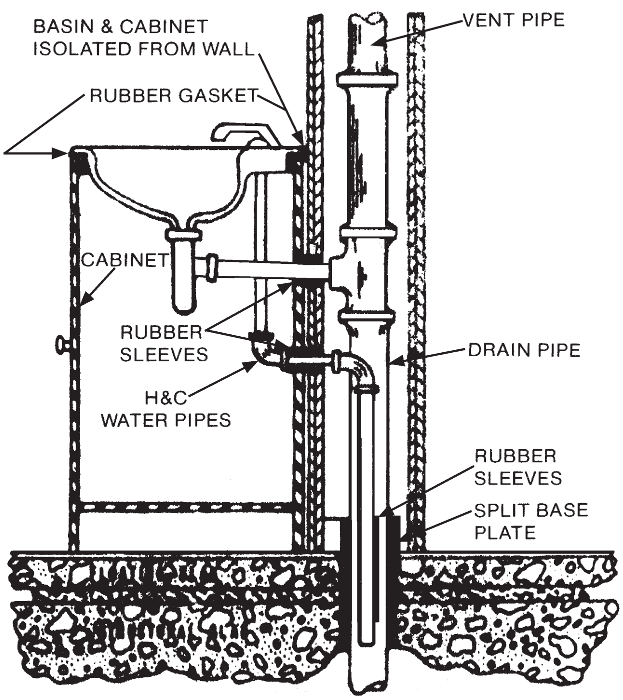


Figure 10-9 Suggested Mounting of Piping and Plumbing Fixture

1. All piping in the equipment room.
2. All piping outside of the equipment room, within 50 feet (15.2 m) of the connected pump.
3. All piping over 2 inches in diameter (nominal size) and any piping suspended below or near a noise-sensitive area.
4. The first three (3) supports provide the same deflection as the pump vibration isolators. They should be a precompressed type in order to prevent a load transfer to the equipment when the piping systems are filled.
5. The remaining vibration isolators should provide one-half (½) the deflection of the pump isolators or 0.75 inch (19.1 mm) deflection, whichever is larger.

All piping connected to plumbing equipment should be resiliently supported or connected. See Figures 10-14 and 10-15 for typical installations.

Seismic protection The seismic protection of resiliently mounted systems presents a unique problem for vibration-isolation selection and application. Since resiliently mounted systems are much more susceptible to earthquake damage (due to resonances inherent in the vibration isolators), a seismic specialist should be consulted if seismic protection of such a system is desired. (Refer to the *Plumbing Engineering Design Handbook* chapter "Seismic Protection of Plumbing Equipment" for more information on this topic.)

GLOSSARY

Acoustics The study of airborne sound and structural vibration propagation over the frequency range 2 to 20 kHz.

Decibel The unit used to qualify the level of sound (or loudness) relative to an arbitrary reference point [zero is equal to 20 Pa (20 x 10^{-6} pascals)]. These units are also employed to quantify sound power. This unit is the smallest increment of change in sound intensity that a normal human being can detect, while a 10-decibel change of increasing or decreasing sound is commonly regarded as a subjective doubling or halving of loudness, respectively. Abbreviated "dB."

Decibel (A) scale A frequency-modified sound level in which low-frequency and high-frequency sounds are attenuated in a similar manner to that in which the human ear responds to wide-range sounds. It is the most common unit used for sound measurement to relate sound intensity to normalized subjective loudness. Abbreviated "dB(A)."

Hertz The unit of frequency internationally accepted to be equivalent to cycles per second of sound. 1 Hertz is equal to 1 cycle/second. Abbreviated "Hz."

Net positive suction head (NPSH) Actual fluid energy available or required at the inlet of a pump.

Noise criteria (NC) curves Employed to assess loudness or annoyance on an octave band basis. These noise criteria (NC) curves have been partially superseded by the "preferred noise criteria (PNC) curves."

Octave A doubling of the frequency. Also used as the most common frequency division for the specification

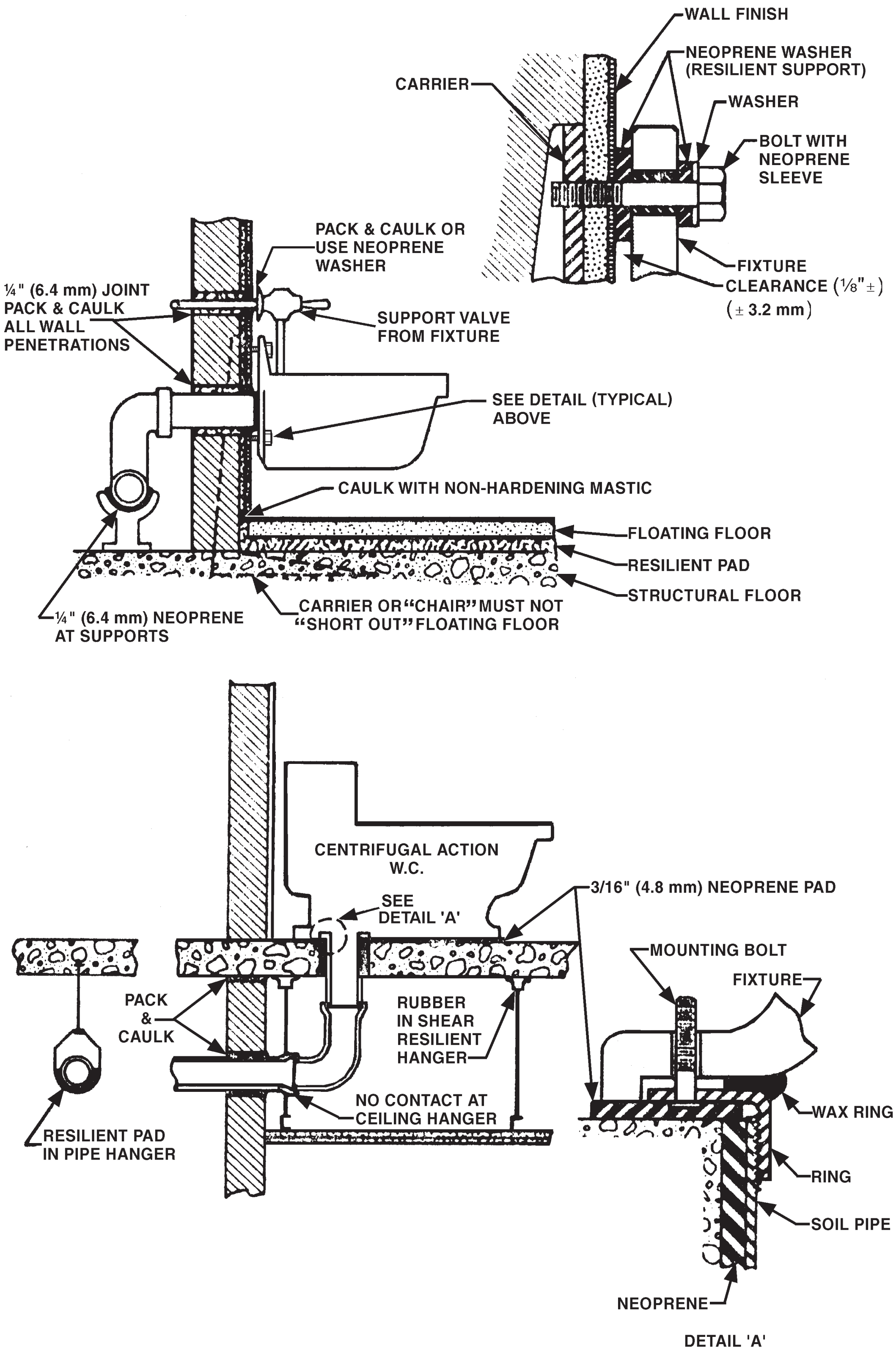


Figure 10-10 Suggested Installation of Plumbing Fixtures

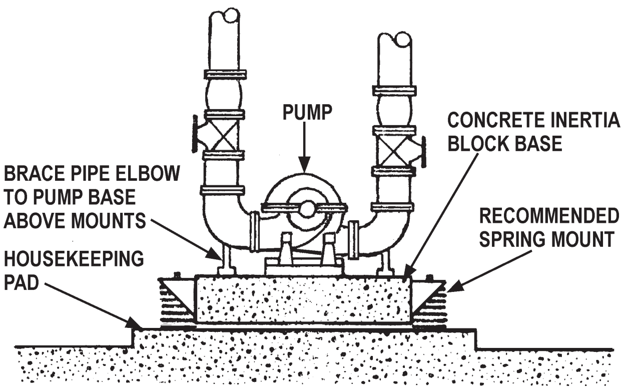


Figure 10-11 Vibration Isolation of Flexible-Coupled, Horizontally Split, Centrifugal Pumps

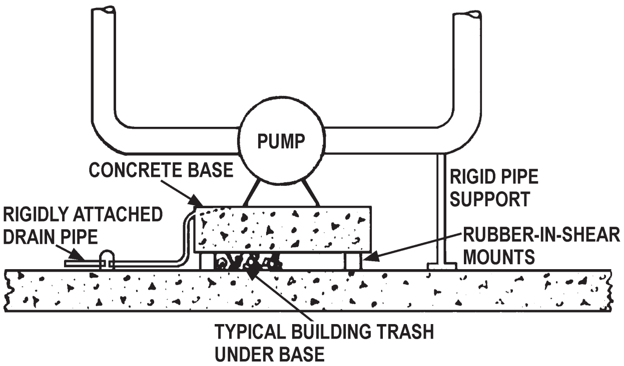


Figure 10-12 Common Errors Found in Installation of Vibration-Isolated Pumps

of filters employed for acoustical analyses.

Pure tones Detectable and generally audible frequency components with characteristics similar to whistles or shrieks generally regarded as being more obtrusive and more likely to give rise to annoyance than other broadband sounds devoid of such components.

Sound power The total acoustical energy radiated by a device or fitting operating under normal working conditions.

Sound-power level The acoustical output, in decibels, radiated by a device or fitting with reference to a sound power of watts and normally determined in octave bands and, typically, at octave bands center frequencies in the range between 63 Hz and 8 kHz.

Sound pressure The oscillation in pressure that gives rise to a sound field in a gas or a liquid.

Sound-pressure level The logarithmic value of sound pressure referenced to a point of absolute zero (usually 20 μPa) in order to provide a convenient numerical value, in decibels, typically occurring within the range 0 to 120 dB. Typical sound levels are denoted in Table 10-2.

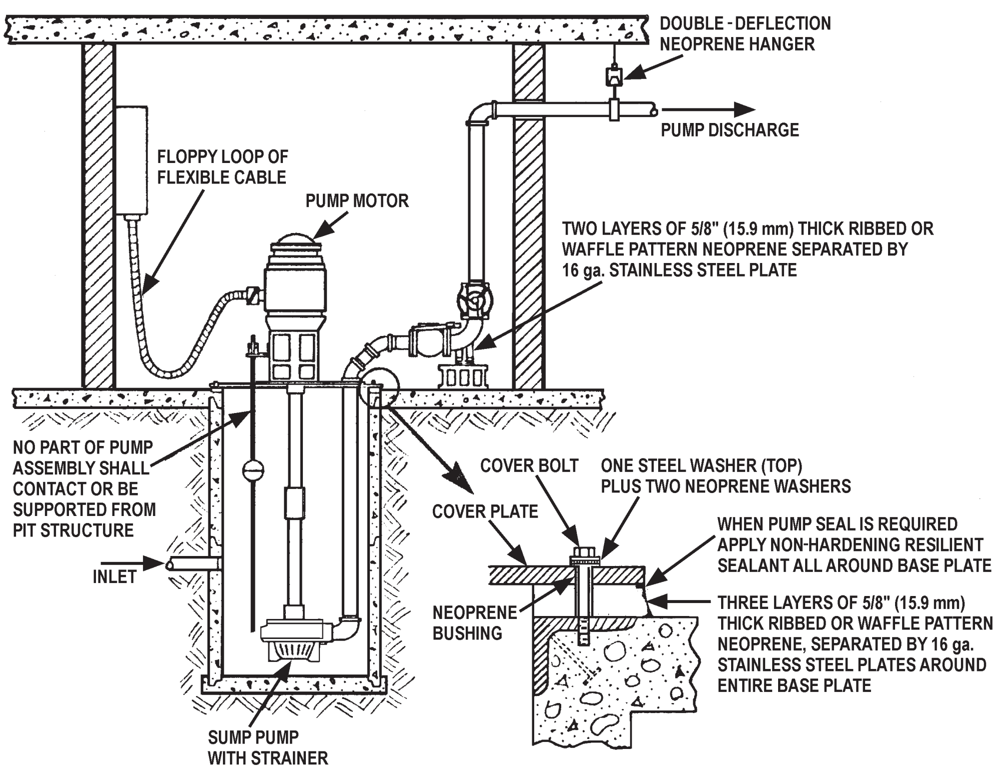


Figure 10-13 Vibration Isolation of a Sump Pump

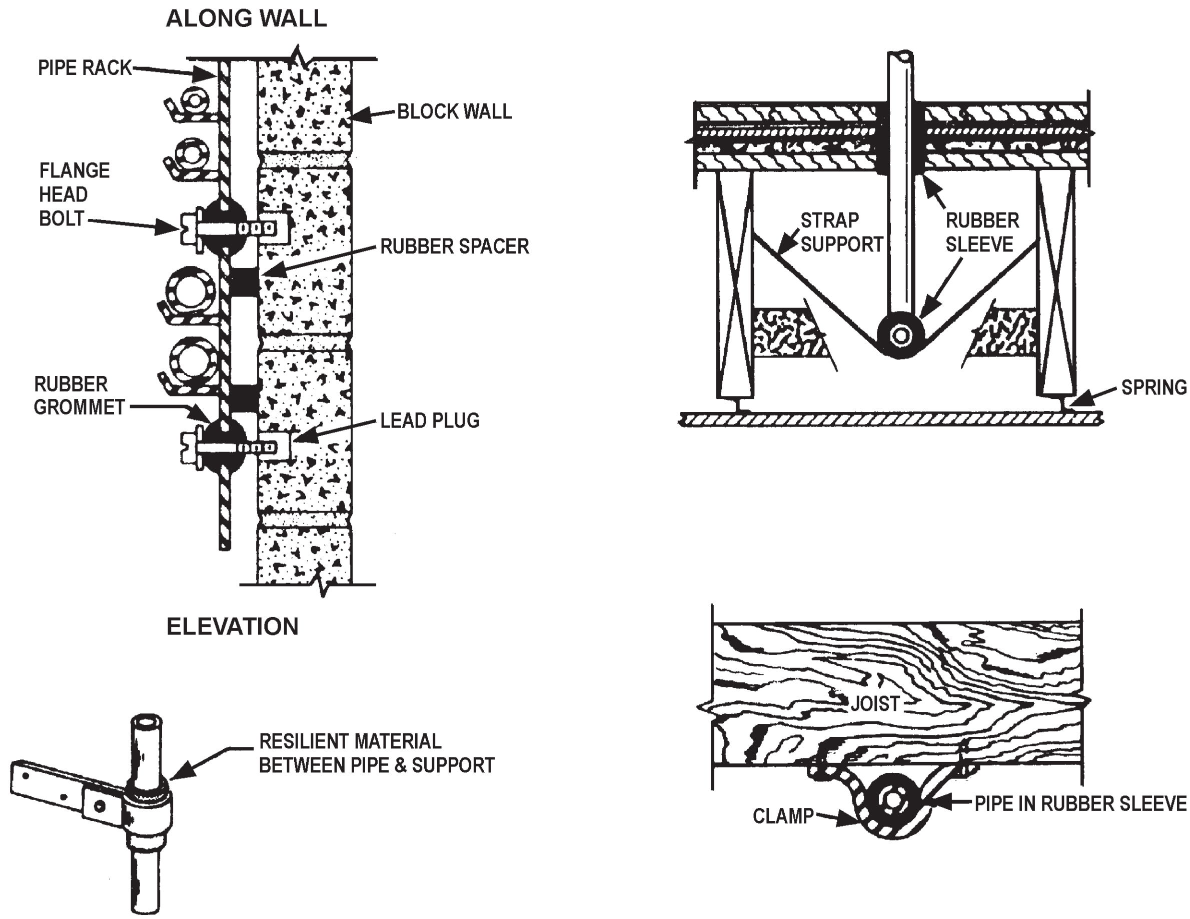


Figure 10-14 Typical Pipe Run Installations

Table 10-2 Typical Sound Levels

Sound Level (dB)	Type of Operation
100	Hammering on pipes
70	Normal speech levels
50	Background sound in office
30	Background sound in urban bedroom
10	Threshold of hearing for normal adult

Transmission loss A measure of the sound insulation of a partition or wall, in decibels. It is equal to the number of decibels by which the sound energy passing through it is reduced. The value of the transmission loss is independent of the acoustical properties of the two spaces separated by the partition.

Vibration The generation of cylic or pulsating forces through a physical medium other than air that converts to sound energy at the boundary between a solid and a gaseous medium. Sound energy may be converted to vibration at the interface between a gaseous medium and a solid medium.

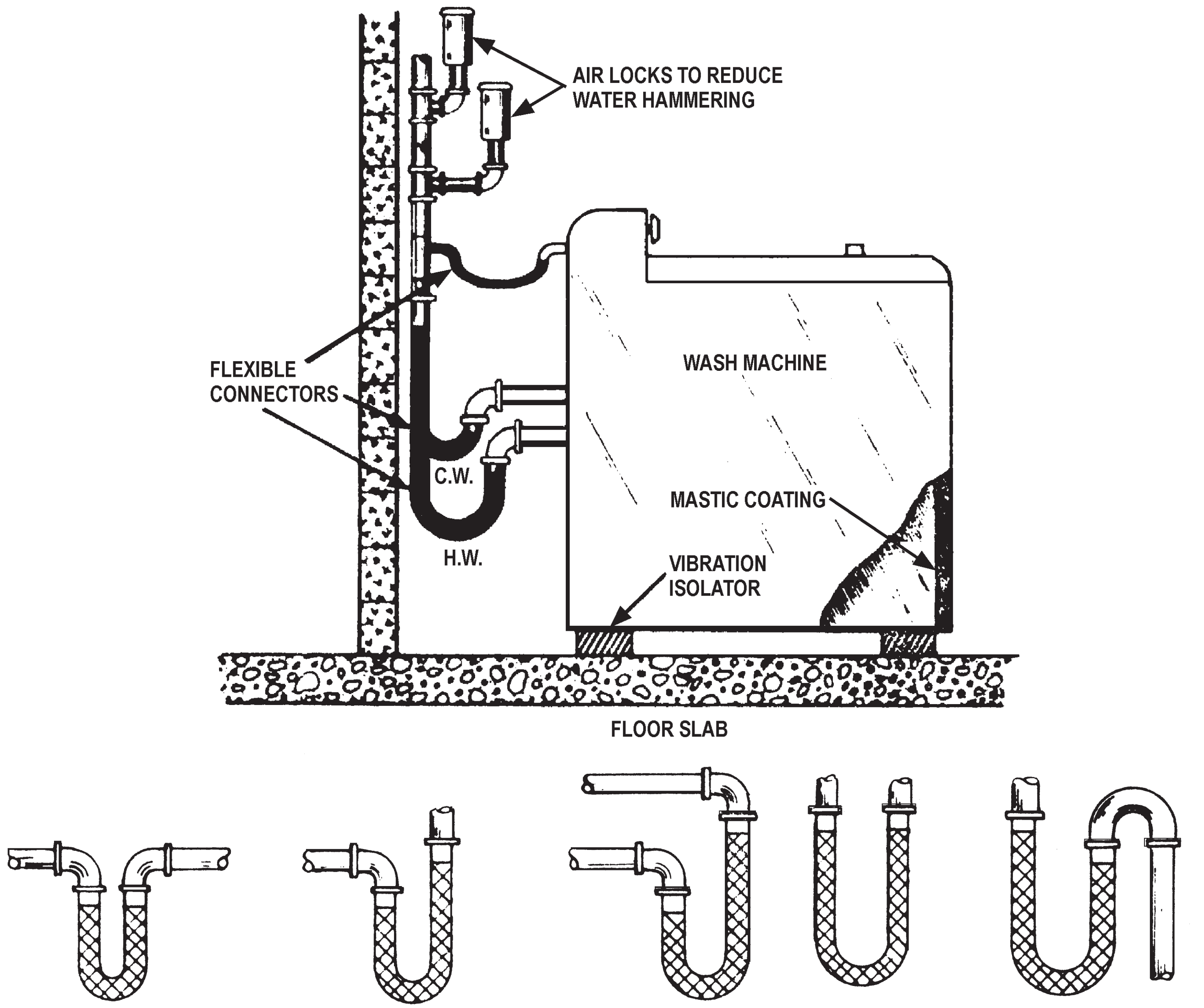


Figure 10-15 Typical Flexible Pipe-Connector Installations

11 Basics of Value Engineering

"Value Engineering" (VE)—the term alone, is often enough to bring chills and a sweat to a design engineer's brow, be it in plumbing or any construction phase. Value Engineering's intended definition is simply to apply a systematic and planned analysis to engineering and design applications in order to obtain some desired effect; in a perfect-world situation, this result would equate to equal or improved performance at a reduced, or minimal total cost. All too often, unfortunately, the definition that has become synonymous with the term "Value Engineering" is: Cutting application engineering and design, including the substitution of products and services, with the intended end result to be reduced costs, by any and all means. However, this is not the intended result of value engineering.

From a historical perspective, the concept of value engineering began in 1947 when the General Electric Company instituted a value-analysis approach to purchasing. The concept was actually nothing more than applying a "systematic" analysis to what was being purchased and how to get the best for the least cost. This systematic analysis approach evolved and began to be employed in all aspects of business—from products and services, to manufacturing, software engineering, and general business management.

In its original incarnation, value engineering was envisioned to be an analysis approach that provided for cost controls to be instituted at any point in a project or product's life cycle. The only standard or constant was emphasizing the reduction or elimination of costs. However, the "first law" of such analysis was the requirement that any and all cost reductions maintain the engineered or design standards, quality, and reliability of the project or product to which it was being applied. In fact, the definition from the Society of American Value Engineers is:

> *"Value Engineering is the systematic application of recognized techniques which identify the function of a product or service, establish a monetary value for that function, and provide the necessary function reliably at the lowest overall cost. "*

The key to the definition is that the objective of value engineering is to not diminish, devalue, or degrade the quality or effectiveness of the engineering or design of the project or product. Therefore, reductions in cost are not to be made to degrade or cheapen a project's quality, effectiveness, or reliability.

A similar definition used by the U.S. federal government as part of its procurement process is:

> *"Value Engineering is an organized study of functions to satisfy the user's needs, with a quality product at the lowest life cycle cost through applied creativity. The study is conducted by a multi-disciplinary team that provides an independent look at the project. Value Engineering is directed at reducing cost, while maintaining or improving quality, maintainability, performance, and reliability."*

Unique to the government definition is the addition of:

> *"In addition, emphasis is placed on preserving unique and important ecological, aesthetic, and cultural values of our national heritage in accord with the general environmental objectives of the Corps of Engineers."*

There are a lot of terms that have been used over the years to describe this concept, including value analysis, value control, value assurance, and value management — all tend to be synonymous terms for value engineering. All have the same basic objectives: Reduce costs, increase productivity, and improve quality. Value engineering is also unique in that it may be introduced at any point of the construction or life-cycle of a project.

What then is the purpose of value engineering? It is to provide a means to systematically analyze a project and control its total costs. It is designed to analyze the functions of a project and determine the "best value," or the best relationship between its worth and its cost. For a facilities construction project, "best value" is a finished project that will consistently perform its required basic function and has the lowest total cost. Therefore, construction of a facility can yield maximum value when value engineering is incorporated into the project. This is accomplished by providing and developing alternatives that produce the desired results and maintain the quality and reliability of the project utilizing the most efficient and effective mix of resources at the least cost.

It would seem that implementing value engineering would be fairly simple; all you need to do is control and/or reduce costs. First, however, we need to have some perspective about where, how and why value engineering will be applied. For the plumbing engineer and designer, the most typical application is the creation of a building. In this regard, there are at least three major aspects of costs that will be of concern to the overall development/engineering/construction "team": The development costs, the engineering and design costs, and the construction costs. Within these three areas all related costs associated with the creation of a building will be lumped, such as property acquisition, inspections, licenses and permits, build-out, finishing, etc.

In the end, there is one "person" or organization concerned with the total picture in the creation of a building—the owner or developer. And, as noted earlier, value engineering can be introduced at any point in the construction or life-cycle of the project. Therefore, for maximum efficiency and to assure maximum value, value engineering needs to be integrated from the beginning and continue throughout a project's life-cycle. In this regard, it is important that the concept of a "team" be immediately integrated into all aspects and phases of the project. For it is this "team" that needs to ultimately be responsible for the finished project and its final total cost.

As with any project, there are three major components that comprise the cost cycle: Material costs, labor costs, and administrative and operation cost (which is typically described as overhead). It is up to the "team" to constantly monitor and evaluate all aspects of the project, including any changes and modifications that may affect the quality, life-expectancy or life-cycle, maintenance cycles, and reliability of each aspect of the project; from development through engineering, design, and construction. Interestingly, although labor is a major component for each area of a building's creation, it is not often subject to any in-depth analysis in value engineering. Instead, the main effort of value engineering is directed at the cost and value of "things" — the cost of the elements of construction, the functionality of each element, and the materials and products being utilized.

The Intent of Value Engineering

In 1965, the U.S. Department of Defense conducted a study to evaluate cost-saving opportunities that could accrue from the use of value engineering. The study examined a number of projects and analyzed 415 project changes that were considered successful "value changes." The result of the study was that only a limited number of factors could achieve over 95 percent of cost savings. These factors were: Excessive cost, additional design effort, advances in technology, and the questioning of specifications.

Reason for Change	Percent Total Savings Achieved	Change Definitions
Advances in technology	23	Incorporation of new materials, components, techniques or processes not available a the time of the previous design effort.
Additional design effort	15	Application of additional skills, ideas and information available but not utilized during previous design effort.
Change in user's needs	12	User's modification or redefinition of mission, function or application of item.
Feedback from test/use	4	Design modifications based on user tests or field experience suggesting that specified parameters governing previous design were unrealistic or exaggerated.
Questioning specifications	18	User's specifications were examined, questioned, determined to be inappropriate, out-of-date or over specified.
Design deficiencies	4	Prior design proved inadequate in use (e.g., was characterized by inadequate performance, excessive failure rates or technical deficiency.
Excessive cost	22	Prior design proved technically adequate, but subsequent cost analysis revealed excessive cost.
Other	2	

Source: Directorate of Value Engineering, Office of the Assistant Director of Defense as taken from "Value Engineering Theory & Practice in Industry," Thomas R. King, 2000, Lawrence D. Miles Foundation, Washington, DC.

Figure 11-1 Qualitative Results From the Implementation of Value Engineering

The study (see Figure 11-1) revealed: no single factor was ever dominant in the implementation of value engineering. It was rare for the implementation of the change the result of a "bad" design; trying to "second-guess" a design looking for deficiencies provided little value, because the majority of designs perform as expected. What was discovered is that many designs did not always provide maximum value due to excessive costs, over specifying and the lack of value for the project.

What is Value?

"Value" means different things to different people. Thus, there is no one perfect definition of value. For purposes of value engineering, value does not simply equate to "cost reduction." There are all kinds of "values" — economic, moral, social, political, etc. In terms of value engineering, it is the economic value that most conforms to what is being measured or evaluated. Value, then, is:

> *The lowest cost to provide the necessary and required products, functions, or services at the chosen time to its needed place with the requisite quality.*

For engineering purposes, value can be best defined by the following formula:

$$\text{Value} = \frac{\text{Worth}}{\text{Cost}}$$

In this formula, when value is equal to or greater than 1 (V=1), it is understood that there is equality of value. As an example, consider the specification of a vacuum pump. The pump is vital to the function of the design. If the pump costs $1,000 and it is indeed worth $1,000, then there is equality of value ("good value"). If the pump is only worth $800 and cost $1,000, then there is imperfect value ("poor value"). If the pump is worth $1,200 and cost $1,000, then there is increased value ("outstanding value").

Which then brings up the whole concept of cost and worth. Cost seems pretty straight forward. It's what you pay for the product or service. But, what is worth? For value engineering purposes, worth is the concept of the value of a function, product, system, etc. Or, alternately stated, worth is the least cost to provide the function, product, or service. Still confused? It's no wonder. The concept of value and worth are amorphous; they are not easily measured or defined. A number of basic questions were developed as part of the concept of value engineering. To help determine "value" and "worth," it is important to note that these questions relate to the general nature of value engineering, and are relevant for all types of engineering, from construction to manufacturing. They have been modified below to be more construction specific.)

1. Are the products, systems, and materials necessary for the functionality of the project, and do they contribute value to the project?
2. Are the costs of the products, systems, or materials in proportion to their usefulness within the project?
3. Do the designed or specified products, systems, or materials need all the designated features?
4. Are there other products, systems, or materials available that will accomplish the intended use or purpose and provide better performance?
5. Are the exact products, systems, or materials available for less?
6. Are there other products, systems, or materials available that will accomplish the intended use or purpose at a lower cost?
7. Are there other products, systems or materials available that will accomplish the intended use and purpose with an equal performance?
8. Is there another dependable supplier that can provide the products, systems, or materials for less?
9. Does the total cost of the products, systems, or materials include all materials, reasonable labor, and overhead?
10. Are the products, systems, or materials the proper ones considering the quantity available or manu-

Job Plan Phases Noted Practitioners Name SAVE*					
Miles	**Fowler**	**King**	**Parker**	**Mudge**	**International**
Information Analysis Creativity Judgement Development Development Presentation Follow-up	Preparation Information Analysis Creativity Synthesis	Information Function Analysis Creative Evaluation Implementation Presentation Implementation Follow-up	Information Function Creative Judicial Development Investigation Recommendation	General Information Function Creation Evaluation Presentation	Information Function Analysis Creative Evaluation Development

Figure 11-2 Value Engineering Job Plan Examples

* SAVE International, Society of American Value Engineers, International.

factured, or the quantity that is needed and will be used?

ELEMENTS OF VALUE ENGINEERING

In the world and vernacular of value engineering, a value engineering analysis incorporates a VEJP (Value Engineering Job Plan). Because this analysis is in itself an engineering project, the job plan is divided into "phases." The number of phases can vary (see Figure 11-2). It all depends on what "expert" you have learned from, what books you've read and what direct experience you have had in conducting value engineering projects.

It doesn't really matter how many phases there are in a VEJP. What is vital is that the engineer be comfortable with all the phases of his/her plan, understand the various techniques for each phase's evaluation and analysis, and that the plan provide a systematic and consistent approach for implementation of the project. This introduction to value engineering integrates the six general phases as listed by Society of American Value Engineers (SAVE) with the five phases from Lawrence E. Mills (considered the "father" of value engineering) and incorporates the various techniques of implementation within each.

Phase One: Information

This phase addresses three questions: "What is it?" "What does it do?" and "What does it cost." In practice this phase describes the project and collects the necessary information, both critical components for the remainder of the value engineering project. Actually, gathering information is pretty simple and straightforward. The really hard part is making sure the information gathered is factual, accurate, unbiased, untainted by opinion, and contains no assumptions.

As every plumbing engineer knows, the hardest part of the project is collecting accurate and factual information. A project can only be engineered and designed according to the quality of information used. Likewise, value engineering is only as good and accurate as the quality and accuracy of the data and information collected and used throughout the process.

The information phase of value engineering is the heart of the overall process. It is also undoubtedly the hardest to explain and understand as the collection of the data that will be vital to a successful value engineered result is often colored by layers of subjectiveness, biases and lack of objectivity.

The key to successful information gathering is being prepared. The value engineer, like the plumbing engineer, depends on organization and structure and design standards. The value engineer collects the key information in a standardized format. The use of forms or checklists is helpful in this endeavor. The value engineer's job is compounded by having to collect information from many individuals and disciplines. For this reason, it is best to integrate value engineering throughout each phase of the project: Conception, design, engineering, bidding, construction, commissioning, and occupancy.

For the plumbing design portion of a facility, the value engineer must follow the engineer's thinking and collect and assemble the same information used by the engineer (see figure 11-3). This means detailing every product and design element.

ABC Project — Plumbing Design

Project Description Documents
Original Client Directions/Specifications
Architectural Drawings
Engineering Drawings
Detail Drawings
Materials List
Details of Materials Examined/Considered
Material Line Information
Product List
Details of Products Examined/Considered
Product Line Information
Vendor Information

Figure 11-3 Information Gathering

There are many variations of VE worksheets, but typically they include the basic information form that describes the project and related data such as in Figure 11-4A. Additional information forms such as Figure 11-4B, allow each detail of the project or design.

The next phase of the information collection process is to understand the background and purpose of the complete project and each of its elements. This requires developing the right questions or checklist of items that need to be collected, understood, and used for the remainder of the engineering process. Figure 11-5 is a sample of such a checklist.

As the VE collects all this information, he/she needs to keep a detailed record of information sources and types of actions needed or taken. This record provides the forensic trail that will backup the final conclusions. It is a way to track each stage of the information collection process and provides a reference record and a source record for the analysis and recommendations. A sample of a source record form is shown in Figure 11-6.

With all the information and data that has been collected, the engineer must still make a qualitative determination of its value. The following can help make that determination of questions:

1. Does the information/data support the definition/specifications/requirements of the project?
2. Does the information/data seem to be factual and valid for the project/detail being analyzed?

Value Engineering Consultants
Project Information

Reference Number: ____________ **Date:** ____________

Name of Project: ____________

Project Element: ____________ Project Detail: ____________

Detail Name: ____________

Description: ____________

____

Detail Location: ____________

Description: ____________

____

Drawing Number: ____________

Materials List Number: ____________

Product List Number: ____________

Pertinent Information: ____________

____

____

____

Figure 11-4A General Project Information Collection

Value Engineering Consultants

Project Information

Reference Number: ____________ **Date:** ____________

Name of Project:
Project Location:
Address:____________
City: ____________ State: ____________ Zip: ____________
Lot Number:____________ Lot Description:____________

Owners:____________
Address:____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax:____________ E-mail: ____________

Developers:____________
Address:____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax:____________ E-mail: ____________

Architects:____________
Address:____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax:____________ E-mail: ____________

Engineers:
Structural:____________
Address:____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax:____________ E-mail: ____________

Electrical:____________
Address:____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax:____________ E-mail: ____________

Plumbing:____________
Address:____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax:____________ E-mail: ____________

HVAC:____________
Address:____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax:____________ E-mail: ____________

Communications:____________
Address:____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax:____________ E-mail: ____________

Other:____________
Address:____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax:____________ E-mail: ____________

Figure 11-4B Detailed Basic Project Information Collection (Continued)

Value Engineering Consultants
Project Information

Reference Number: ________ **Date:** ________

Name of Project:
Project Location:
Address: ________
City: ________ State: ________ Zip: ________
Lot Number: ________ Lot Description: ________

Owners: ________
Address: ________
City: ________ State: ________ Zip: ________
Telephone: ________ Fax: ________ E-mail: ________

Developers: ________
Address: ________
City: ________ State: ________ Zip: ________
Telephone: ________ Fax: ________ E-mail: ________

Architects: ________
Address: ________
City: ________ State: ________ Zip: ________
Telephone: ________ Fax: ________ E-mail: ________

Engineers:
Structural: ________
Address: ________
City: ________ State: ________ Zip: ________
Telephone: ________ Fax: ________ E-mail: ________

Electrical: ________
Address: ________
City: ________ State: ________ Zip: ________
Telephone: ________ Fax: ________ E-mail: ________

Plumbing: ________
Address: ________
City: ________ State: ________ Zip: ________
Telephone: ________ Fax: ________ E-mail: ________

HVAC: ________
Address: ________
City: ________ State: ________ Zip: ________
Telephone: ________ Fax: ________ E-mail: ________

Communications: ________
Address: ________
City: ________ State: ________ Zip: ________
Telephone: ________ Fax: ________ E-mail: ________

Other: ________
Address: ________
City: ________ State: ________ Zip: ________
Telephone: ________ Fax: ________ E-mail: ________

Figure 11-4B Detailed Basic Project Information Collection (Continued)

Value Engineering Consultants

Project Information — Continued

Reference Number: ____________ **Date:** ____________

Contractors:

Structural: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

Electrical: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

Plumbing: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

HVAC: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

Communications: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

Other: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

Suppliers:

Structural: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

Electrical: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

Plumbing: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

HVAC: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

Communications: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

Other: ____________
Address: ____________
City: ____________ State: ____________ Zip: ____________
Telephone: ____________ Fax: ____________ E-mail: ____________

Figure 11-4B Detailed Basic Project Information Collection (Continued)

Value Engineering Consultants
Project Information Checklist

Reference Number: ________________ **Date:** ________________

Project Details

1. Detailed Specificatons established by user/owner: ____________________
2. Detailed Requirements established by user/owner: ____________________
3. Project Considerations:
   A. Environmental Conditions (before, during, after): ____________________
   B. Physical Space Limitations: ____________________
   C. Desired/Required
      a. Reliability: ____________________
      b. Serviceability: ____________________
      c. Maintainability: ____________________
      c. Operability: ____________________
4. Prior Experiences/Concerns
   A. History of projects: ____________________
   B. Operation of projects: ____________________
   C. Maintenance of projects: ____________________
5. Anticipated Market
   A. Requirements: ____________________
   B. Expected Percentage of Total Market: ____________________
   C. Market Expected to Serve: ____________________
6. Anticipated Life
   A. Of Original Built Project: ____________________
   B. Total Life With Rehab: ____________________
7. Project Competitors: ____________________
8. What Liscensing or Permits Need to be Considered: ____________________
9. What Are Desired:
   A. Physical Requirements: ____________________
   B. Performance Requirements: ____________________
   C. Workmanship Requirements: ____________________
10. Is This Project to be Part of a Larger Project: ____________________
11. What New Developments, Technology, State-of-the-Art Engineering/Design/Materials are Contemplated: ____________________
12. Are There Any Special Processes or Uses for the Project: ____________________
13. Who Is Responsible for Overseeing Purchasing for Overall Project: ____________________
14. Who Is Responsible for Overseeing Contractors for Overall Project: ____________________
15. Anticipated Project Milestones for:
   A. Changes/Modifications: ____________________
   B. Improvements ____________________

Figure 11-5 Project Description (Continued)

Value Engineering Consultants
Project Information Checklist

Reference Number: ____________ **Date:** ____________

Detail/Product/Material Specification

Detail/Product/Material Description: ____________

1. Detailed Specificatons established by user/owner: ____________
2. Detailed Requirements established by user/owner: ____________
3. Detail/Product/Material Considerations:
   A. Environmental Conditions (before, during, after): ____________
   B. Physical Space Limitations: ____________
   C. Desired/Required
      a. Reliability: ____________
      b. Serviceability: ____________
      c. Maintainability: ____________
      d. Operability: ____________
      e. Special Features: ____________
4. Prior Experiences/Concerns With This Detail/Product/Material
   A. History of Detail/Product/Material: ____________
   B. Operation of Detail/Product/Material: ____________
   C. Maintenance ofDetail/Product/Material: ____________
   D. Reasons for Replacement Needs of Detail/Product/Material: ____________
   E. Operating Life of Detail/Product/Material: ____________
5. Anticipated General Market for This Detail/Product/Material
   A. Requirements: ____________
   B. Expected Percentage of Total Market: ____________
   C. Market Expected to Serve: ____________
6. Anticipated Life of Detail/Product/Material: ____________
7. Detail/Product/Material Competitors: ____________
8. Are There Any Liscensing or Use Limitations That Need to be Considered: ____________
9. For the Detail/Product/Material What Are Desired (consider weight, dimentsions, tolerances, shock and vibration, facility environment, operating environment, life, performance, appearance):
   A. Physical Requirements: ____________
   B. Performance Requirements: ____________
   C. Workmanship Requirements: ____________
10. Is This Detail/Product/Material to be Part of a Larger Detail/Product/Material ____________
11. Is This Detail/Product/Material to be Used In Quantity? If So, Explain: ____________
12. What New Developments, Technology, State-of-the-Art Engineering/Design/Materials are Contemplated for the Detail/Product/Material: ____________
13. Are There Any Special Processes or Uses for the Detail/Product/Material: ____________
14. How Many Suppliers/Manufactures/Sources Are There for the Detail/Product/Material: ____________
15. Who Are the Suppliers/Manufactures/Sources for the Detail/Product/Material: ____________

Figure 11-5 Project Description

Value Engineering Consultants
Project Information & Data Sources

Reference Number: ____________________ **Date:** ____________________
Information/Data Collector: ____

Source of Information/Data	Information/Data Received	Action Taken

Figure 11-6 Information and Data Sources

3. Is all the information/data current and up-to-date?
4. Does the information/data form an integrated whole? Does each item support the other items?
5. Are there any conflicts within the information/data collected?
6. Does the information/data conform to the expectations of the investigator?
7. Is there information/data that is suspect? Does some of the information/data seem to be inaccurate or nonrepresentative of the project/detail?
8. Is there additional information/data that needs to be collected?
9. Do the relationships/associations between the information/data sets require further exploration?
10. Is there any reason to suspect that any of the information/data is biased, not objective?
11. If the information/data causes any concern or creates a restrain to the analysis can, it be verified by more than one source?

Determine/Collect Costs: Collection of the costs related to the project/detail/material being analyzed is the next step in the information/data collection phase. Cost determination can quickly become complex and overwhelming. Suffice to say, the smaller the design element of a project— such as a stand-alone product, like a pump or water heater that is being analyzed—the easier it will be to come to grips with a cost determination. The total value engineering of a facility will involve determining costs for *all* aspects of the development, engineering, design, construction, and commissiong of the project.

For the value engineer, these costs are a measurement tool for the other information/data that has been collected and a determinant of the economic impact of the item under consideration (and thus a measure for the level of effort that should be applied.)

The are two primary elements of establishing the cost of a design/product/material: the material cost and the labor cost. It is important to note at this juncture that a cost is not the same as the acquisition price. Cost determination becomes complicated by economic forces applied throughout the project life-cycle. There are project costs, development costs, product/assembly/material costs, labor costs, overhead costs and, of course, a markup for "profit."

All the costs associated with a project need to be determined. Furthermore, they need to be segregated into actual and estimated, and a record must be kept of the original source for the information/data.

What is Cost? Value engineering is big on the term "cost." However, as noted earlier, cost can mean different things to different people and for different reasons. The first important "law" is that, in most instances, cost and price are not synonymous. Consider cost to be the valuation of labor, time, and other resources used to achieve the end result. A "price" is a fixed sum for a given item or service that results in the transfer of ownership of the product or service. The difference between cost and price is often nothing more than perception (i.e., whether you are the buyer or the seller). So, for example, the cost of the product for the seller is included in the price to the buyer. On the other hand, the price to the buyer may be the "cost" and additional value will be added to determine a new and different price.

In value engineering, the primary element is cost! Of course, to complicate matters there are product and producer costs and total cost to a user. For most facility projects, both of these cost structures are going to be part of the analysis.

There are three costs involved with any project/design/material: The major or prime costs, the overhead costs, and the cost of goods. The best way to describe all this is with a simple diagram (see Figure 11-7).

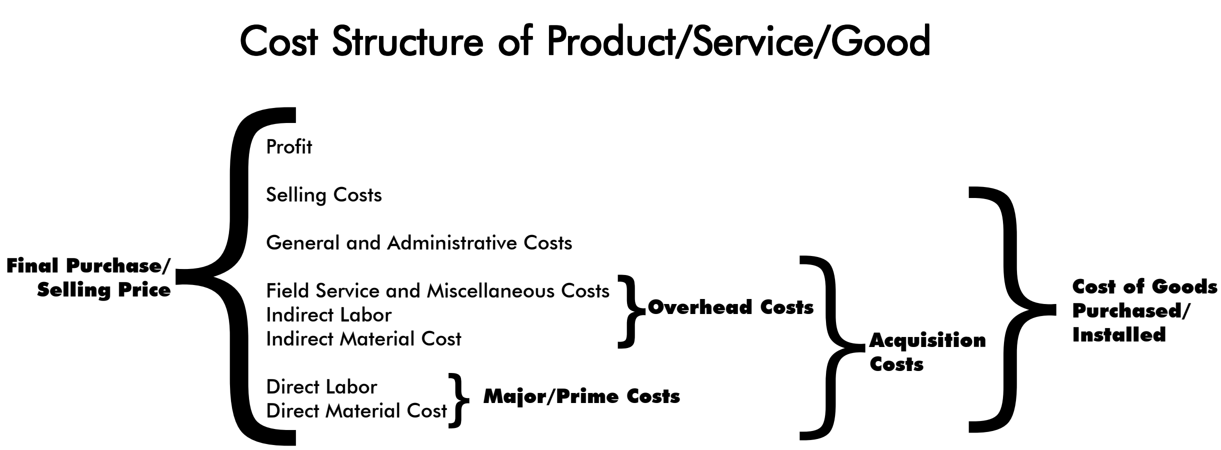


Figure 11-7 Cost Structure of Product/Service/Material

In the facility "business" there may be myriad levels of purchasers—from the owner to the developer to the architect to the engineer/designer to the contractor. Therefore, the cost structure actually becomes a pyramid of costs and prices with different "users" along each link in the project chain. Figure 11-8 gives a generalization of the cost makeup for each "user" at the different stages of the facility project process.

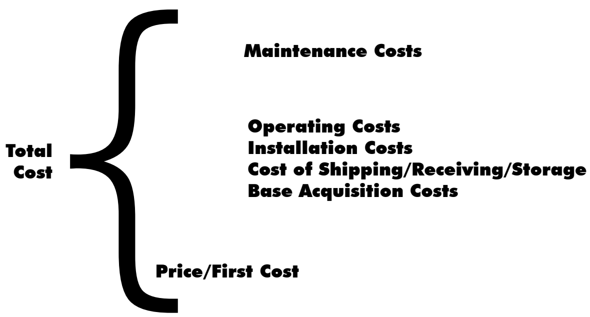


Figure 11-8 Generalized Total Cost to Each User

A wide variety of costs go into each element and aspect of a facility. These costs are divided into ongoing costs and one-time costs. Ongoing costs are those that will occur throughout the life of the project. The owner has one set of ongoing costs, while each product/service/material provider has its own ongoing cost structure. Likewise, there are one-time costs for all of these providers. Figure 11-9 offers an example of the differing cost elements that will not only comprise the cost of a total project but also be considered at each stage of the project process.

With all the costs collected and detailed, the analysis can proceed. The next step is to relate all of the costs to each other, define relationships, and establish which of the costs are related to specifications for the project/design and which are imposed requirements. Costs associated with specifications are those imposed by the owner/developer/user of the facility. These costs can be connected to the land, construction limitations, or user-defined needs.

Required costs are those that different vendors, project managers, and contractors impose on the project due to his/her experience and knowledge. They are the "expert" costs that form the basis for the creation of the facility.

It is the value engineer's job to discover and understand all these different potential costs. Then, as part of his/her analysis, the engineer must differentiate between costs that are "real"— based on specifications, available information, and conditions—and those that are "imaginary" (skewed by bias, attitudes, habits, lack of information, old technology, lack of ideas and creativity, and temporary conditions).

Ongoing Costs

Labor
- Administration, Management, Operations
- Ongoing Staffing
- Technical Support
- Field Services
- Quality Control
- Administrative Support
- Documentation (In-house)
- Inspections
- Purchase orders/paperwork
- Reports: producing, receiving, sending
- Documentation
- Handbooks, User Manuals
- Certifications
- Training

Product/Services/Materials
- Basic Materials
- Subcontracts
- Intercompany Effort
- Administration & Operations (e.g., reproduction)
- Indirect supplies, services materials

Other & General
- Travel
- Equipment rental/leasing
- Contracted Services
- Shipping & Freight
- Inventory

One-time Costs

Labor
- Engineering
- Design
- Drafting and Review
- Production planning and engineering
- Procurement
- Development
- Testing & Review
- Field Engineering
- Training
- Administrative Support Services
- Documentation
- Licensing, Permits, Inspections
- Purchase orders/paperwork
- Reports: producing, receiving, sending
- Documentation
  - Handbooks, User Manuals
- Certifications & Inspections

Products/Supplies/Materials
- Special Tools
- Special Equipment (e.g., test equipment)
- Administration & Operations (e.g., reproduction
- Change orders, modification, corrections

Other & General
- Travel
- Equipment rental/leasing
- Contracted Services
- Shipping & Freight
- Disposition of Equipment/Materials

Figure 11-9 Cost Breakdown Checklist

Value engineering has come about because users will inevitably overestimate their needs and have unrealistic expectations. This will be compounded by those involved in a facility project who often over-engineer and over-design at the beginning of a project due to the unrealistic expectations and over-estimates of the owner/user. It is the value engineer who must bring expectations, estimates, and reality into focus.

The Pareto Principle: Vilfredo Pareto developed an economic theory regarding the distribution of wealth. This principle has found its way into many disciplines of engineering, and especially value engineering, where the principle is better known as the 80/20 Rule. In its original form, Pareto stated that 80 percent of all wealth is held by just 20 percent of all people. This 80/20 principle has been applied to everything from manufacturing to construction to engineering principles. In this chapter's context, it states that 80 percent of a facility's costs will be associated with just 20 percent of its components.

Is it true? The principle is stated as the theory of the Law of Inverse Proportions and is actually a concept. It is very useful when examining the resources available for a project and focusing on those that will provide the largest economic benefit and result in the highest levels of return for the expended effort.

Phase Two: Analysis/Function Analysis

The questions "What does it do?" and "What is it supposed to do?" continue to be addressed in this phase and concisely sum up this concept. In this phase the engineer needs to identify the functions of the project. The Analysis/Function phase is often considered the "heart" of value engineering because it is in this phase that the engineer has a methodology to reestablish the original project/element needs into simply workable expressions.

For example, value engineering, the accepted definitions for "Function" are:

> *That which makes a product work or sell; that which satisfies the needs or requirements of the user.*

If it were only that simple. The difficulty in this phase is the translation and giving of substance to the words used for project/element specifications and requirements. An engineering discipline has taken these words, brought them to life, and provided a vi-

Active Verbs (Desirable)

Apply	Amplify
Attract	Change
Collect	Conduct
Control	Create
Emit	Enclose
Establish	Filter
Hold	Induce
Impede	Insulate
Interrupt	Modulate
Prevent	Protect
Rectify	Reduce
Repel	Shield
Support	Transmit

(Less Desirable)

Provide

Measurable Nouns (Desirable)

Contamination	Current
Density	Energy
Flow	Fluid
Force	Friction
Heat	Insulation
Light	Liquid
Load	Oxidation
Protection	Radiation
Torque	Voltage
Weight	

(Less Desirable)

Article	Component
Damage	Device
Circuit	Part
Repair	Table
Wire	

Passive Verbs (Desirable)

Create	Decrease
Establish	Improve
Increase	

Nonmeasurable Nouns (Desirable)

Appearance	Beauty
Convenience	Costs
Exchange	Features
Style	

(Less Desirable)

Effect	Form
Loops	Symmetry

Figure 11-10 Function Definition Verbs and Nouns

sual interpretation. The value engineer must now also examine those same words and provide a structured evaluation and analysis to them — which results in a functional analysis and/or definitions.

RULES OF FUNCTION ANALYSIS

There are three generally accepted rules for conducting functional analysis or creating functional definitions.

Rule 1: The expression of all functions must be accomplished using two words; one must be an active verb, the other a descriptive or measurable noun. Figure 11-10 offers a sample listing of verbs and nouns typically used in value engineering functional definitions.

Rule 1 is based on the adage that less is more. The concept is if you cannot provide a definition of a function in two words, either you do not have enough information about the project/element, or the item has not yet been defined in its simplest form. By being limited to two words, you will be able to describe the simplest element of the project in a manner that reduces the potential for mis-communication or misunderstanding.

Rule 2: All functional definitions can be divided into one of two levels of importance: Work or appearance (or selling). Work functions are expressed in action verbs and descriptive or measurable nouns that establish a quantitative statement for the item. Appearance or Sell functions are expressed in passive verbs and in general or nonmeasurable nouns that describe a qualitative statement for the item.

Rule 2 provides meaning to the descriptive terms or rule 1. The definitions here are designed to amplify the meanings of the function under consideration. If the function cannot be described with action or active verb, the functionality of the element is questionable. If there is no action, then nothing is being accomplished and, thus, there is no end result or usefulness to the function.

By using measurable nouns, the evaluating engineer will establish a cost-to-function relationship. These nouns provide a quantitative measure to the function, and, therefore, provide a measurable level of usefulness for the function.

Why, then, have appearance or sell factors, if they do not provide any quantifiable or measurable attribute? First, having appearance or sell factors involved in the function that can be separated out, will help in the assignment of some proportionate amount of the elements cost. Second, by identifying these function descriptors, the engineer will be providing a further description of the specifications and requirements of the function. This will help the owner in the final decision process regarding the function. While the value engineer may well find an equal element at lower cost, it may be that the nonquantifiable part of the requirements is an overriding consideration. (E.g, color; while a basic white porcelain bowl may be less expensive, the use of a special color porcelain bowl may be an important and overriding appearance/selling requirement.)

Rule 3: All functional definitions can also be divided, into one of two descriptive uses: Basic or secondary. A basic function is one that describes the primary purpose for a product, system, or material. Secondary functions are all other functions of the product, system, or material that do not directly accomplish the primary purpose but support the primary purpose or are the result of a specific engineering or design approach. In functional analysis, the secondary functions are the ones that can be combined, modified, or eliminated.

This rule further enhances the ability to assign a relative importance to the function. For a majority of projects/products/materials, there is only one basic function to be derived. In those rare cases when more than one basic function is stated, usually it is just a restatement of the original basic function. When there are secondary functions, they tend to fall into two categories: Specific and dependent.

Specific functionality requires a specific action to be accomplished. Dependent functionality are those functions that require some prior action before it can be performed. Secondary functions can exist because they are part of the specifications or requirements, or because they are inherent to the engineering or design approach used.

Function Definitions

With all the rules in place and understood, the value engineer begins the function analysis. Figure 11-11 shows a sample of the type of form that helps in this phase. The form is straightforward, and, given all the definitions and explanations supplied, should be self-evident. The most important part of this phase is to define the function or the element under analysis and create its functional definitions.

Example 3 in Figure 11-11 is considered one of the quintessential examples in value engineering analysis for explaining the use of two-word definitions. The pencil is an everyday object that requires a successive and seemingly unnecessary number of items to define it and all of its elements. However, this remains the crux of the value engineering definition phase. Example 4 in Figure 11 provides an example that could well be used to evaluate a product used in plumbing engineering. However, as should be obvious, in both these examples, the emphasis of the value engineering would be in the manufacture of the item and is not related to its role in a construction project.

Only a portion of the form in Figure 11-11 is filled out at this early stage of the analysis process. At a

Value Engineering Consultants
Functional Definiton and Analysis

Reference Number: ____________ **Date:** ____________

Detail/Product/Material Specification: ____________
Function: ____________
Description (e.g., part number): ____________
____
____

Qty	Item Descrp.	FUNCTIONS*						Cost per Function (Estimate)	Label Function V= vital E = Essential N = Nice to Have	Notes/ Comments
		VERB	NOUN	B	S	W	AP SL			

Note: **B — Basic**
S — Secondary
W — Work
AP/SL — Appearance/Sell

Figure 11-11 Function Analysis/Definition Form

Example 1: Expansion Chamber

Qty	Item Descrp.	FUNCTIONS* VERB	NOUN	B	S	W	AP SL	Cost per Function (Estimate)	Label Function V= vital E = Essential N = Nice to Have	Notes/ Comments
1	Expansion Tank	Contain	Liquid	X						
		Provide	Pressure	X						

Example 2: Wall Box

Qty	Item Descrp.	FUNCTIONS* VERB	NOUN	B	S	W	AP SL	Cost per Function (Estimate)	Label Function V= vital E = Essential N = Nice to Have	Notes/ Comments
1	Wall Box	Confine	Material	X						
		Store	Material		X					
		Protect	Inside		X					
		Protect	Material	X						
		Prevent	Loss		X					
		Enhance	Appearance		X					
		Establish	Privacy		X					

Figure 11-11 Function Analysis/Definition Form (Continued)

minimum, the function is defined, and, if necessary, its elements. At this stage, only basic and secondary indicators are marked. The remaining portion of the form will become part of the evaluation phase.

FAST

There is a second approach that is an adjunct to, and works in tandem with, function definitional analysis. This approach is known as FAST, which stands for Functional Analysis System Technique. The FAST process is essentially a diagraming process. With diagraming, a visual representation is created that highlights the functions of a product/system/material and the interrelations between them.

A basic FAST model diagram is shown in Figure 11-12. The FAST model is a building process that will:

- Help to avoid a random listing of functions. The requirement of functional analysis requires the use of verb–noun definitions. The FAST diagram will help sort out the functions and show interrelationships.
- Help to find any missing functions.
- Aid in the identification of the basic function and understanding the secondary functions.
- Provide a visualization and better understanding of the product/system/material under study.
- Result in a team consensus in defining the product/system/material under study.
- Provide a test of the functions utilizing system analysis and determinate logic.
- Demonstrate the team approach has fully analyzed the elements.

The parts of FAST shown in Figure 11-12 are:

1. Scope Lines: The two vertical dotted lines provide a boundary to the function under study. It is that part of the function which is of concern.
2. Highest Order Function: The object or output side of the basic function under study is referred to as the highest order function. Additional functions to the left of another on the critical path is a “higher” order function.

Example 3: Pencil

Value Engineering Consultants
Functional Definiton and Analysis

Reference Number: ____________ **Date:** ____________

Detail/Product/Material Specification: Pencil
Function: Make Marks
Description (e.g., part number): ____________

Qty	Item Descrp.	FUNCTIONS* VERB	NOUN	B	S	W	AP SL	Cost per Function (Estimate)	Label Function V= vital E = Essential N = Nice to Have	Notes/ Comments
1	Eraser	Remove	Marks		X	X				
1	Band	Secure	Eraser		X					
		Improve	Appearance		X					
1	Body	Support	Lead	X						
		Tansmit	Force	X						
		Accomodate	Grip							
		Display	Info							
1	Paint	Protect	Wood							
		Improve	Appearance		X					
1	Lead	Make	Marks	X						

Note: **B — Basic**
S — Secondary
W — Work
AP/SL — Appearance/Sell

Figure 11-11 Function Analysis/Definition Form (Continued)

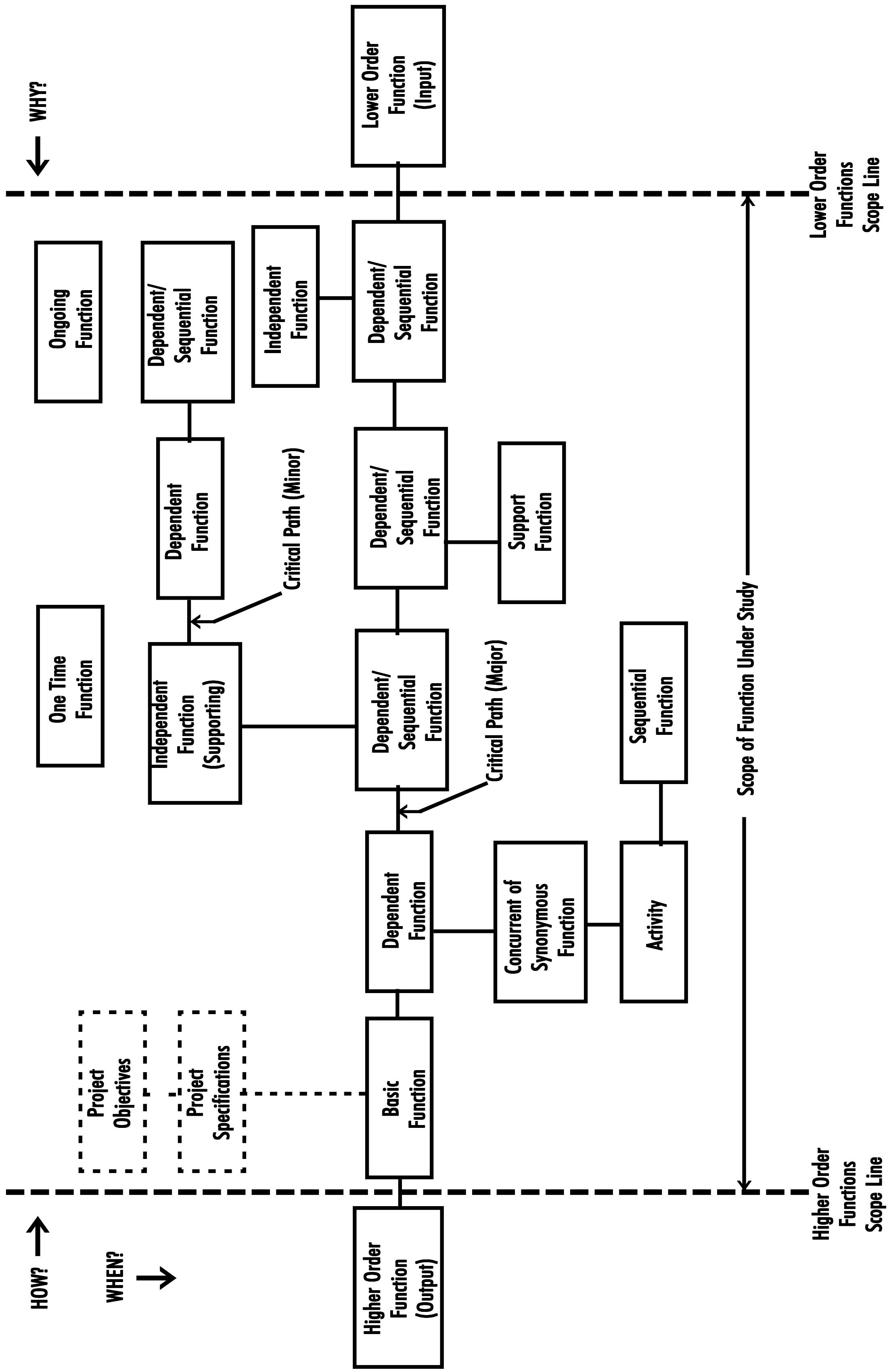


Figure 11-12 Function Analysis Systems Technique (FAST) Model

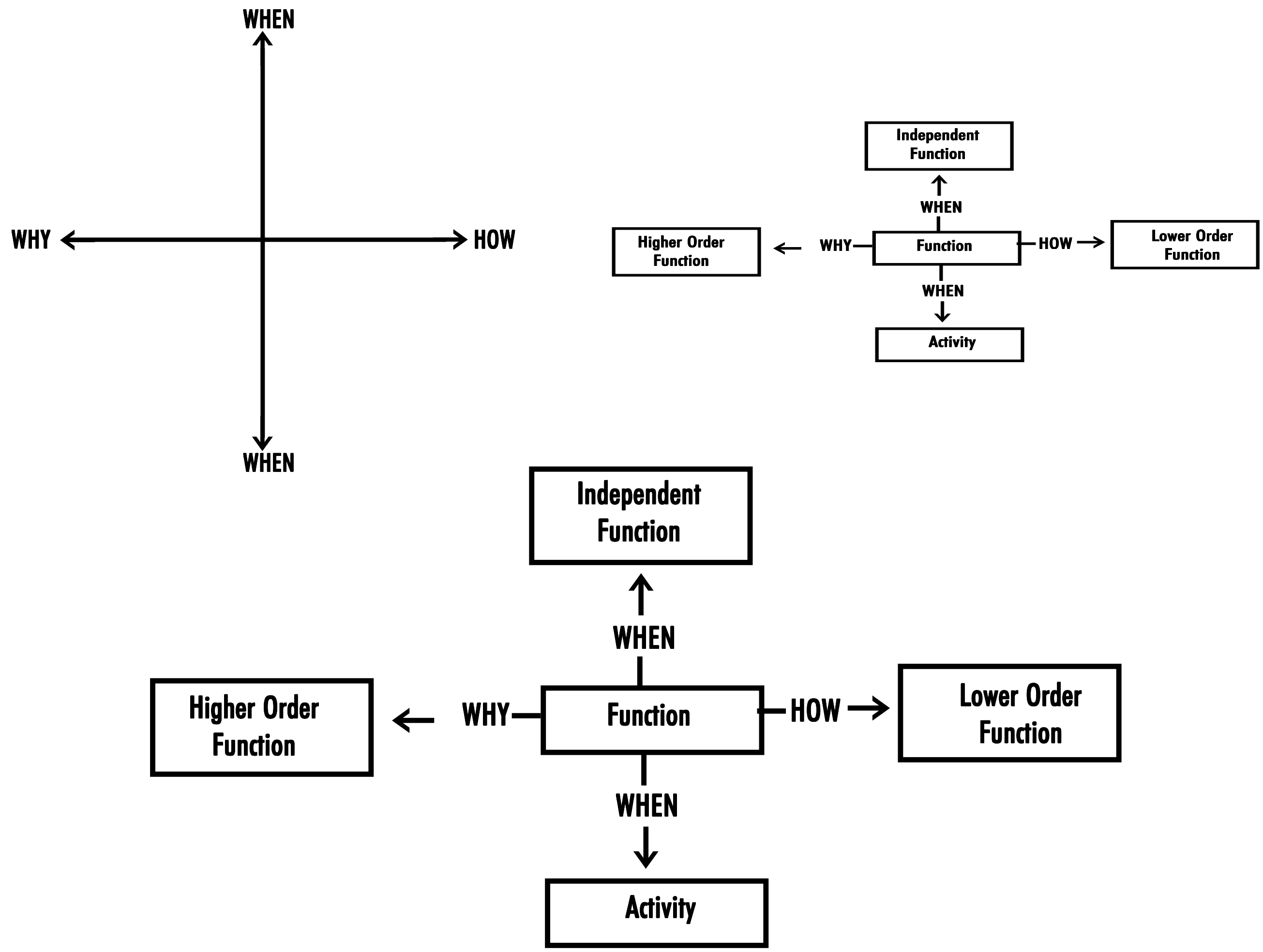


Figure 11-13 HOW and WHY Relationship with Example

3. Lower Order Function: Functions to the right of another function on the critical path are a "lower" order functions. This is not to imply a relative importance or ranking to these functions. Rather, the "lower" functions are those necessary to successfully perform the basic or higher order function.
4. Basic Function: The function under study. The basic function cannot change.
5. Objectives and Specifications: These are the parameters and requirements that must be achieved for the function to perform as needed in its operational place in the project. Objectives and specifications are not themselves functions; they influence the selection of lower order functions.
6. Critical Path Functions: Any function that is on the HOW or WHY logic path is a critical path function. If the function is on the WHY path it is considered a major critical path. Otherwise, like the independent supporting functions or the dependent functions, it becomes a minor critical path item. Supporting functions tend to be of secondary value and exist to meet the performance requirements specified in the objectives and specifications.
7. Dependent/Sequential Functions: To exist, functions to the right of the Basic Function are dependent on the functions to their left and require one to be completed before they enter as a performance requirement.
8. Independent Functions: These functions are above or below the critical path line and are necessary to satisfy the WHEN question in relationship to the main or basic function.
9. Independent (supporting) Functions: These functions do not depend on another function as does a dependent/sequential function. However, they are still considered secondary functions to the basic function and the major critical path.
10. Function: The end event or purpose of the product/system/material under analysis. It must first be expressed in a verb–noun form.

11. Activity: The method selected to perform a function.

For engineers familiar with systems-type diagraming, it would appear that the FAST diagram is backwards. As an example, consider the position of the WHY part of the function. For systems analysis, it is on the left. But for FAST the HOW function is in the left position and dominates the analysis. In this position, all the functions/activities to the right are dependent on the basic function or moving toward the WHY of the function.

Figure 11-13 diagrams the how, why, and when relationship, relates it to the FAST diagram, and shows a simple how functional relationship.

Purpose of the Model

As it turns out, in the team environment the FAST model, while a means to an end, is not the vital part of this process. The vital part is the dialogue and discussions between the team members as the model is formulated and built. It is the process of identification — functions, questions, justifications, relationships — that is the key to the structure of the function analysis and provides the team with a methodology to produce a desired result. In fact, once the model is created its only purpose remains as an explanatory, rationale, and communication to the decision makers and other engineering disciplines.

It would seem to be intuitive that the next step should be evaluation and cost determination. But in value engineering the next phase is creativy.

Creativity

The creative process evaluates the project with an emphasis on, "What else will do the job?" The creative part of the value engineering process is best summed by the trite expression, "start with a clean sheet of paper." Again, this phase requires a team approach to engineering disciplines. In the creativity phase the team needs to unstructure itself and separate itself from all of the previous phases. The team needs to leave the drawings, information, forms, and models behind and find a fresh environment in which to reassemble. In this creativity environment the only information permitted are the two-word, verb-noun functions that describe a single product/system/material being analyzed.

It is up to the team to now develop creative ideas. Creativity is not an exact science; but it is teachable and thus learnable. The creative phase is to be the act of putting together unconnected or seemingly unrelated factors or ideas to "create" a single new idea. Creativity is the art of bringing something new into existence. It is an original concept not an imitation of something else. The important element of creativity is perception: If the creative thought or idea is "new" to us, it is a creative act regardless of whether it may have existed somewhere else at some other time. Creativity is also the mother of innovation, and both are important elements of the value engineering process. If creativity is something "new", then innovation is a "creative" or imaginative use or application of the concept. Innovation is adaptive of creativity.

Creativity is conceptualizing a pipe structure; basically a hollowed or formed material that can be connected, bent, twisted, buried, hung or laid flat or vertical. The innovation is to use the creative idea to carry liquids or gases from point A to point B.

Creativity is divergent thinking. It is overcoming perceptions, preconceived notions, emotional blocks, cultural divides, and habits. To be successful it is imperative to avoid the path of least resistance: "Follow the past." After all if it worked before it must still be a workable solution today. No sense "reinventing the wheel."

Creative Thinking Personified

Positive creative thinking can be described by the invention of the cotton gin. Eli Whitney was trying to find a way to remove seed from raw cotton. One afternoon, on a walk, he noticed a cat trying to catch a chicken through a wire fence. The cat's claw would stick through the fence whenever a chicken came close, but all that came through the fence on the cat's claw was feathers. This was the observation that provided the creative incentive. Whitney conceived the concept of pulling the cotton (feathers) though a comb (fence). It was a subtle difference to all the thinking that went before. Instead of trying to remove seeds from the cotton by pulling on the seeds, Whitney's solution was to pull the cotton away from the seeds.

Inflexibility: An illustration of just the opposite inflexible thinking is of an innovation made to an invention that to this day remains a world-wide standard despite its outmoded purpose. It is the computer keyboard configured in the QWERTY style. This style was an innovation of Christopher Sholes who, invented the typewriter. Because of the mechanics of the typewriter, and that gravity was the engine to move the keys back into position, Sholes found that fast typists would quickly create key jambs as they stroked faster than the keys could clear each other and return to rest. Through persistence and experimentation, he developed a keyboard layout that separated the most often used letter keys and thereby SLOWED down the typing process. Today, that same "slow down" mentality continues with the modern computer keyboard. This despite the Dvorak and American Standard system of keyboard layout that produces a faster result. Ingrained habit is hard to overcome.

Roadblocks to Creativity: Creativity takes work. Hard work. Of course, as an alternative to providing the creativity phase in value engineering, the engineer can fall back on, and use one of the top ten reasons for why value engineering should not be used at this time:

1. It isn't in the budget.
2 We don't have the time.
3. Let's form a committee.
4. Has anyone else tried it on this type of project?
5. Why change it? It's always worked perfectly before?
6. We tried that before.
7. The developers will never buy into it.
8. You're years ahead of your time.
9. Let's shelve it for the time being.
10. It's against company policy.

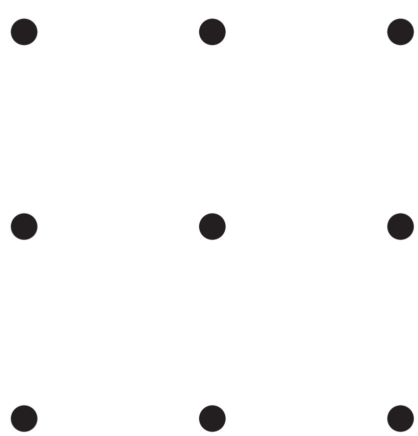
(Adapted form *Value Management*, General Services Administration, Washington, DC.)

Divergent Thinking

Creativity in value engineering is best described as speculation and brainstorming. An all too often overused and "trite" phrase, "Thinking Outside the Box" is an attempt to describe divergent thinking.

Outside the Box: What is outside the box thinking? One much used example is the Nine Dots:

Nine Dots



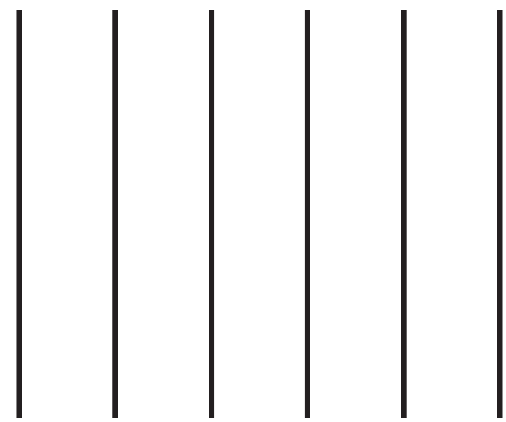
First draw nine dots in the form of a square on a piece of paper as shown.

Next, without lifting you pencil from the paper, draw four straight connected lines that will go through all nine dots. You may not backtrack on a line and each line must go through each dot only once.

See the end of this chapter for the solution.

Another often used example is the six sticks. You are given six "sticks" (use toothpicks, straightened paperclips or matchsticks) of equal length as shown below.

Equilateral Triangles



Arrange the sticks to make four equilateral triangles. All of the ends of each "stick" must touch each other. (And, as engineers, we all know that an equilateral triangle has three sides of the same length.)

See the end of this chapter for the solution.

Finding Solutions: In this phase the team is not trying to find solutions, only ideas. To help this process the "leader" has some help; a simple paper and pencil — and of course, a form can be created from this idea (see Figure 11-14). The brainstorming or speculative process consists of two techniques: unassisted creativity and assisted creativity.

With unassisted creativity, one team member takes the creativity worksheet and is assigned one two-word definition for one of the functions. The individual lists every possible idea he/she has regarding that function, such as "create seal." Once the individual has put down whatever ideas he/she has, the worksheet is moved on to another team member who then adds his/her own ideas. The sheet is passed to each team member in turn.

The second step, assisted creativity, is nothing more than a group exercise where each participant "hitchhikes" on each other's ideas in order to create yet another "new" idea. To get started the team splits into 3 parts: one group has the worksheet for one of the two-word function definitions, one group has a set of "idea generators" or checklists to help the thinking, and the third group has reference sources such as a dictionary and thesaurus. As one sub-team reads the list, the second could find new words and ideas using the alphabet concept (take a word and think of another word with a different starting letter of the alphabet) and the dictionary, while the third worked the checklists continually questioning all the thought processes. Two sample checklists are shown in Figure 11-15A and Figure 11-15B.

There are a couple of important elements to using this process. The first is that the strong individual's habit of being judgmental must be abated. To do this, the group should decide beforehand how to indicate

Value Engineering Consultants
Creativity Worksheet

Reference Number: ________________ **Date:** ________________

Function: ____

1.	31.	61.
2.	32.	62.
3.	33.	63.
4.	34.	64.
5.	35.	65.
6.	36.	66.
7.	37.	67.
8.	38.	68.
9.	39.	69.
10.	40.	70.
11.	41.	71.
12.	42.	72.
13.	43.	73.
14.	44.	74.
15.	45.	75.
16.	46.	76.
17.	47.	77.
18.	48.	78.
19.	49.	79.
20.	50.	80.
21.	51.	81.
22.	52.	82.
23.	53.	83.
24.	54.	84.
25.	55.	85.
26.	56.	86.
27.	57.	87.
28.	58.	88.
29.	59.	89.
30.	60.	90.

Figure 11-14 Creativity Worksheet

How much of this is the result of custom, tradition, or opinions?	Can cause and effect be reversed?
Why does it have this shape?	Is one possibly the other?
How would I design it if I had to build it in my home workshop?	Should it be put on the other end or in the middle?
What if this were turned inside out? Reversed? Upside down?	Should it slide instead of rotate?
What if this were larger? Higher? Wider? Thicker? Lower? Longer?	Demonstrate or describe it by what it isn't.
What else can it be made to do? Suppose this were left out?	Has a search been made of the patent literature? Trade journals?
How can it be done piecemeal?	Could a vendor supply this for less?
How can it appeal to the senses?	How could this be made easier to use?
How about extra value?	Can it be made safer?
Can this be multiplied?	How could this be changed for quicker assembly?
What if this were blown up?	What other materials would do this job?
What if this were carried to extremes?	What is similar to this but costs less? Why?
How can this be made more compact?	What if it were made lighter or faster?
Would this be better symmetrical or asymmetrical?	What motion or power is wasted?
In what form could this be-liquid, powder, paste, or solid? Rod, tube, triangle, cube, or sphere?	Could the package be used for something afterwards?
Can motion be added to it?	If all specifications could be forgotten, how else could the basic function be accomplished?
Will it be better standing still?	Could these be made to meet specifications?
What other layout might be better?	How do competitors solve problems similar to this?

Figure 11-15A Creativity Checklist

1. Can the dimensions be changed?

Border
Converge
Deeper
Delineate
Encircle
Intervene
Invert (reverse)
Larger
Longer
Make slanted or parallel
More shallow
Place horizontally
Shorter
Smaller
Stand vertically
Stratify
Thicker
Thinner
Use crosswise

2. Can the quantity be changed?

Add something
Combine with something
Complete
Fractionate
Join something
Less
More

3. Can the order be changed?

Arrangement
Assembly or disassembly
Beginning
Focus
Precedence

4. Can the time element be changed?

Alternated
Anticipated
Chronologized
Faster
Longer
Perpetuated
Recurrence
Renewed
Shorter
Slower
Synchronized

5. Can the cause or effect be changed?

Altered
Counteracted
Destroyed
Energized
Influenced
Louder
Softer
Strengthened
Stimulated

6. Can there be a change in character?

Add color
Altered
Change color
Cheaper
Interchanged
More expensive
Resilient
Reversed
Stabilized
Stronger
Substituted
Weaker
Uniformity

7. Can the form be changed?

Accidents avoided
Conformation
Curved
Damage avoided
Delays avoided
Harder
Irregular
Notched
Regular
Rougher
Smoother
Something added
Softer
Straight
Symmetrical
Theft avoided

8. Can the motion be changed?

Admitted
Animated
Agitated
Attracted
Barred
Deviated
Directed
Lifted
Lowered
Oscillated
Repelled
Rotated
Slowed
Speeded
Stilled

9. Can the state or condition be changed?

Abraded
Coagulated
Colder
Disposable
Drier
Effervesced
Elasticized
Harden
Heavier
Hotter
Incorporated
Insulated
Lighter automatic electric blanket
Liquefied
Lubricated
Open or closed
Parted
Preformed
Pulverized
Resistant
Soften
Solidified
Vaporized
Wetter

10. Can the use be adapted to a new market?

Children
Elderly
Foreigners
Men
Physically Challenged
Women

Figure 11-15B Creativity Checklist

someone is being judgmental and thus can modify the behavior (e.g., slapping the table with a palm).

The two sub-teams switch roles from time-to-time until they reach the point of stagnation and agree that they are finished. The team will by now have created a unique creative list of “new’ and “old” ideas for each function under study. After the creative process, it becomes time for the evaluation phase. A possible result of this team effort for the two-word definition create-seal is shown in Figure 11-16.

Evaluation

The evaluation phase is a continuation of the creativity phase. It deals with a combination of appraisal, judgement, and selection to the qualitative and quantitative criteria and ideas developed for each function. In this phase, we go from divergent thinking to convergent thinking. Where, divergent thinking is problem identification and fact finding, convergent thinking is a mixing of appraisal, evaluation, judgement, selection, development, and implementation.

It is this phase that will create the final development of workable and meritorious alternatives. The introduction of appraisal, evaluation, and judgement will eliminate or reduce unnecessary costs and create a preferred recommendation or course of action.

Yet also in this phase it is all too easy to impart a cost-reduction spiral that does not result in value engineering, but simple cost reductions for budgetary reasons. It is in this phase that it is all too easy to degrade the product/system/material by reducing its quality, reliability, or maintainability.

Finally, in this phase ideas developed in the function and creativity phases will be refined and combined and evaluated by comparison. All of the costs of each function or idea will be established, and the team will continue to develop function alternatives. To do this will require a couple of new forms, an evaluation technique, and continuing the completion of the functional definition and analysis form.

In Concert With

Although this Evaluation Phase is shown as distinct from the Develpment/Investigation Phase, in reality in many cases, the two phases often overlap and there is really only one. It is up to the value engineering team to decide how many phases will be needed and what will be done when.

Refining, Combining, Evaluating by Comparison

Idea generation is a dynamic process that doesn’t ever really stop. The creative thought process is an ongoing series of judgements and evaluations. In the evaluation phase ideas that seem unusable may well be combined with other ideas to create a better solution. Some ideas will stand out as preferred solutions, while others may be found to be lacking information. It is important, however, that no idea be discarded out-of-hand, for whatever reason. All ideas have some merit, which is not always immediately obvious.

To get started, the team should use a worksheet to list the advantages and disadvantages of each function or idea that is an offshoot of a function. Figure 11-17A shows a sample of such a worksheet. The essence of this step is to be sure that no good ideas are overlooked, and that no efforts are misdirected. As the functions and ideas are refined, combined, and evaluated, it is important to be evaluating the time required to develop alternatives versus any potential gain. The gain is, of course, improvements in quality, maintainability, and reliability, as well as cost advantages. Similarly, any immediately perceived disadvantages may, with a little thought and creativity, be turned into advantages. Figure 11-17B shows the information included.

At this stage, the form is fairly self-explanatory: In the first column is a simplified and short statement of an idea from the functional development; in the second and third columns, every advantage and disadvantage, no matter how large, how important, or how small or insignificant is identified.

If all this sounds a bit simplistic, it is. But, at the same time, it is an important step. Although we make evaluations, simple and complex on a daily basis, we often do so intuitively. With this structured methodology, the evaluation process will be seen to be more complex and exacting than simple intuition.

This worksheet is carried through the Development/Investigation Phase. In practice, this worksheet will be analyzed and evaluated twice — first in the evaluation phase by the value engineering team, and then in the Development/Investigation Phase, when similar forms will be used with other team components.

Cost Analysis and Evaluation

This step is also integrated into the development and investigation phase. In this initial evaluation step, a new worksheet is used to first draw a sketch of the function item being evaluated and then prepare a basic cost basis. Figure 11-18A shows the basic worksheets, and Figure 11-18B shows the same sheets with the information included.

In the sketch step, all that is needed is a freehand drawing that incorporates the essential items. With the parameters clearly defined and set there will be fewer tangential discussions and considerations.

Using the simple concept of the wall box, in this phase the requirement may be for an off-shelf-unit supplied out of a catalogue. It will be in the next phase, the Development/Investigation, when the team is expanded and a second review and evaluation made that advantages/disadvantages and cost savings can be integrated with each other.

Value Engineering Consultants
Creativity Worksheet

Reference Number: ______________ **Date:** ______________

Function: CREATE SEAL

1. PAINT	31. SPIGOT	61.
2. RUBBER	32. LABYRINTH	62.
3. RNG	33. WATER	63.
4. PLUG	34. DOVETAIL	64.
5. DRIED BLOOD	35. CORK	65.
6. VARNISH	36. FLANGE	66.
7. GLUE	37. PAPER	67.
8. PLASTIC	38. ROD	68.
9. EPOXUY	39. FOAM PLASTIC	69.
10. WAX	40. STOPPER	70.
11. PITCH	41.	71.
12. CHROME	42.	72.
13. WELD	43.	73.
14. RIVET	44.	74.
15. FIT	45.	75.
16. WASHER	46.	76.
17. SOAP	47.	77.
18. GASKET	48.	78.
19. LEATHER	49.	79.
20. GREASE	50.	80.
21. AIR	51.	81.
22. HEAT	52.	82.
23. FREEZE	53.	83.
24. COMPRESS	54.	84.
25. EXPAND	55.	85.
26. BRAZE	56.	86.
27. PLATE	57.	87.
28. SOLDER	58.	88.
29. GLASS	59.	89.
30. VACUUM	60.	90.

Figure 11-16 Creativity Worksheet

Value Engineering Consultants
Idea and Function Evaluation

Reference Number: ____________ **Date:** ____________
Team: ____________
Detail/Product/Material Specification: ____________
Function: ____________
Description (e.g., part number): ____________

IDEA FROM FUNCTIONAL DEVELOPMENT	ADVANTAGES	DISADVANTAGES

Plan(s)/Action(s) on Idea(s)

Figure 11-17A Basic Idea Evaluation Worksheet

Value Engineering Consultants

Idea and Function Evaluation

Reference Number: ____________ **Date:** ____________

Team: ____________

Detail/Product/Material Specification: ____________

Function: Wall Box; Confine and Secure Material

Description (e.g., part number): ____________

IDEA FROM FUNCTIONAL DEVELOPMENT	ADVANTAGES	DISADVANTAGES
Provide 2' by 2' 10 gauge polished aluminum wall box to confine and secure on/off regulator valve for hot water for each fixture in each bathroom	1. Secures and Hides valve	1. Hides valve
	2. Provides protection of material	2. Not easily visible in emergency
	3. Gives better appearance than plain valve	3. Requires identification on outside of box
	4. Quality Look and Finish	4. Requires secure latching mechanism
		5. Requires access to latch key or opening mechanism
		6. Additional Cost to Install

Plan(s)/Action(s) on Idea(s)

Figure 11-17B Initial Example — Idea Evaluation Worksheet

Value Engineering Consultants
Functional Development
Sketch

Reference Number: ________________ **Date:** ________________

Team: ____

Detail/Product/Material Specification: ______________________________

Function: ____

Description (e.g., part number): ______________________________

____

____

Figure 11-18A Functional Development Sketch Worksheet — Blank

Value Engineering Consultants
Functional Development Sketch

Reference Number: ____________ **Date:** ____________

Team: ____________

Detail/Product/Material Specification: ____________

Function: WALL BOX

Description (e.g., part number): STANDARD WALL BOX:
ABC MANUFACTURER
MODEL NUMBER 123456-A
SIZE 2' X 2'

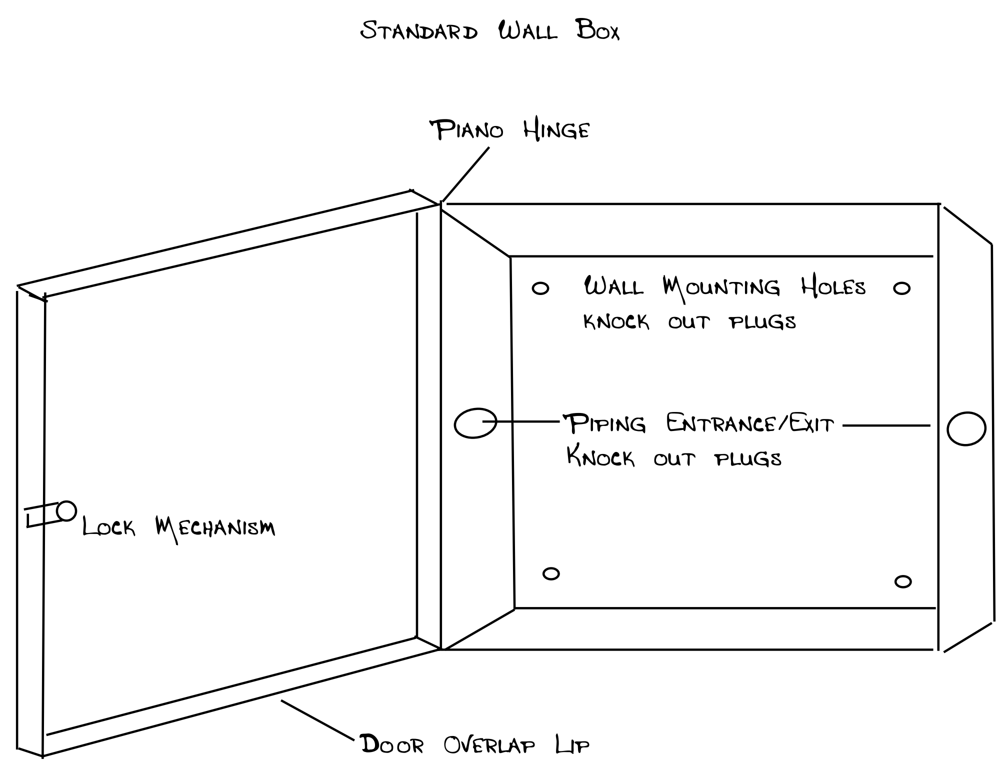


Figure 11-18A Functional Development Sketch Worksheet — Example

Value Engineering Consultants

Functional Development

Idea Development and Estimated Cost

Reference Number: ______________ **Date:** ______________

Team: ______________________________

Detail/Product/Material Specification: ______________________________

Function: ______________________________

Description (e.g., part number): ______________________________

____

____

FUNCTION	CREATIVE IDEA(S) & DEVELOPMENT	ESTIMATED COST	CUMULATIVE ESTIMATED COST
		Total	

Cost Summary

Material & Material Burden $ ______________

Direct Labor $ ______________

Direct Labor Burden $ ______________

Total $ ______________

Figure 11-18B Functional Idea Development and Estimated Cost Worksheet — Blank

Value Engineering Consultants
Functional Development
Idea Development and Estimated Cost

Reference Number: ____________ **Date:** ____________

Team: ____________

Detail/Product/Material Specification: ____________

Function: Wall Box

Description (e.g., part number): Standard Wall Box:
ABC Manufacturer
Model Number 123456-A
Size 2' X 2'

FUNCTION	CREATIVE IDEA(S) & DEVELOPMENT	ESTIMATED COST	CUMULATIVE ESTIMATED COST
Wall Box	Standard ABC Manufacturer Catalogue Wall Box	$12.75	$12.75
		Total	$12.75

Cost Summary

Material & Material Burden $ ____________

Direct Labor $ ____________

Direct Labor Burden $ ____________

Total $ ____________

Figure 11-18B Functional Idea Development and Estimated Cost Worksheet — Example

In this evaluation phase, everything from quantity purchases to custom designed and manufactured items should be taken into account. The value engineering team is: Establishing the first benchmarks of the functional and cost analysis; examining any secondary functions that should or can be considered; and ensuring that all of the project parameters have been met. The team must answer many questions: Are all the specifications and requirements met? Are all the two-word function definitions accounted for? Are all functions and needs being met? Is there duplication of effort or definitions that can be eliminated and, thus, reduce costs?

Incorporating the Functional Definitions

In the information phase, the Functional Definitions Worksheet was initialized. The evaluation phase provides the information necessary to complete the final four sections of the worksheet: the Work versus Appearance evaluation, the estimated cost, the importance valuation of each element, and any notes or comments. The first step is to evaluate and compare the functional relationships and create a numerical weighting of the functions. This numerical weighting will provide a basis for determining value or levels of importance of the functions, as well as the magnitude of importance. To create a numerical evaluation, a Functional Evaluation Worksheet will be utilized as shown in Figure 11-19.

To start, use the function definition and analysis worksheet for detail/product/material. Continuing the Wall Box example, the worksheet identified eight functions for the wall box and listed them in order in the Functional Evaluation Worksheet—Part 1. This simply provides a list order for the items with appropriate alphabetic identification. See Figure 11-20A.

Comparison of Functions: The value engineering team must know and compare each function with every other function. Starting with the function delineated as “A” or *Confine Material*, it is compared to function “B,” *Store Material*. *Confine Materials* is determined to be more important than *Store Materials,* and is thus accorded a listing of “A” in the “A” line under the “B” listing in the Functional Evaluation Worksheet — Part 2.

At the same time that the relative importance is being determined, the magnitude of the importance must also be established. The numerical weights provided in Part 2 are then used to establish this importance difference. As seen, the *Confine Materials* is rated to be of major importance when compared to *Store Materials*.

Each of the remaining functions are evaluated and analyzed in a similar manner in relationship to all of the functions below it, as shown in Figure 11-20B.

With the evaluation and analysis complete, Figure 11-20B shows that the functions in importance as follows:

Prevent Loss	15
Protect Inside	10
Confine Material	9
Protect Material	9
Establish Privacy	5
Enhance Appearance	1
Store Material	0

From this analysis, the value engineering team would declare the Prevent Loss function to be the basic function. The final weighted list shows the relative importance of each of the functions to each other and to the project.

With this information, the Function Definition and Analysis Worksheet can now be completed as shown in Figure 11-21. Note that the basic and secondary functions have now been redefined based on the evaluation, and it can now be determined which of the elements are vital, essential, or would just be nice to have.

This analysis would continue to examine each of the system functions in relationship to the others and would, in turn, create a weighted evaluation of each of the separate products/systems/materials for the overall project being examined.

The Pencil: Another Look

An alternative evaluation and analysis could also be constructed by establishing idea criteria using a qualitative approach. In this method, each of the items of the function can be evaluated in the reverse of the function definitions and uses perscriptive connotations for expressing value. In this instance, the listing order might look like Figure 11-22A, the evaluation worksheet part 2 like Figure 11-22B, and the completed Evaluation worksheet part 1 like Figure 11-22C.

This alternate analysis can be conducted by the value engineering team or can wait until the next phase, Development/Investigation, and be conducted with an expanded value engineering team.

DEVELOPMENT/ INVESTIGATION

Consultation and Evaluation

The evaluation phase is continued here in the Development/Investigation phases as the value engineering team brings in other team members to provide additional creativity and energy to the process. All of the functional development worksheets are prepared for review by the advanced team. In Figure 11-23, the Idea Evaluation Worksheet is recreated with only the ideas of the function development filled in. As

Value Engineering Consultants
Functional Evaluation — Part 1

Reference Number: ____________ **Date:** ____________

Detail/Product/Material Specification: ____________
Function: ____________
Description (e.g., part number): ____________

Evaluation Summary

List Order	Functions	Weight
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
X		
Y		
Z		

Figure 11-19 Functional Evaluation Worksheet — Part 1, Blank

Value Engineering Consultants
Functional Evaluation — Part 2

Reference Number: ________________ **Date:** ________________

Detail/Product/Material Specification: ______________________________
Function: ______________________________
Description (e.g., part number): ______________________________
____
____

Numerical Evaluation:

Weight Factors

1 = Nice to Have — Minor Importance
2 = Essential — Medium Importance
3 = Vital — Major Importance

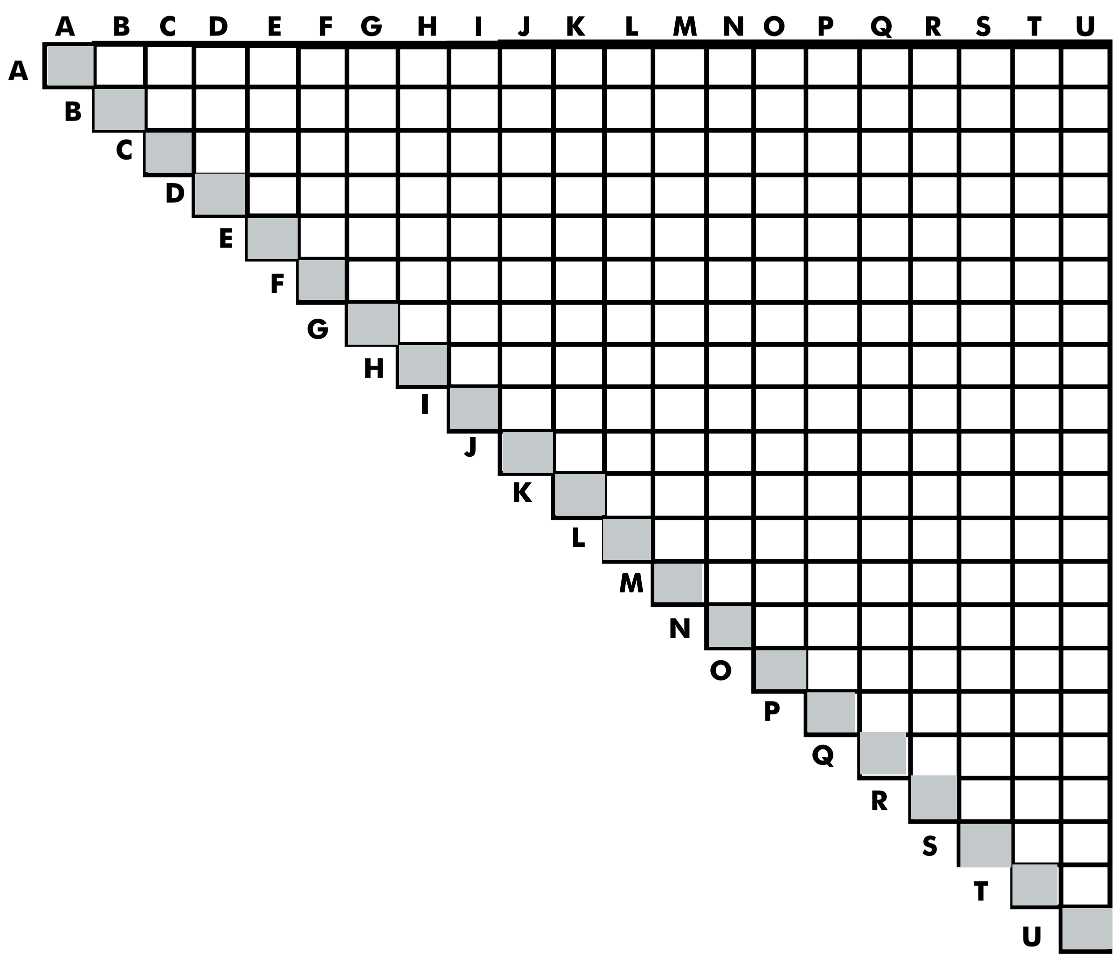


Figure 11-19 Functional Evaluation Worksheet — Part 2, Blank

Value Engineering Consultants

Functional Evaluation — Part 1

Reference Number: ________ **Date:** ________

Detail/Product/Material Specification: WALL BOX
Function: ________
Description (e.g., part number): ________

Evaluation Summary

List Order	Functions	Weight
A	CONFINE MATERIAL	
B	STORE MATERIAL	
C	PROTECT INSIDE	
D	PROTECT MATERIAL	
E	PREVENT LOSS	
F	ENHANCE APPEARANCE	
G	ESTABLISH PRIVACY	
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
X		
Y		
Z		

Figure 11-20A Functional Evaluation Worksheet — Part 1, Example

Value Engineering Consultants

Functional Evaluation — Part 2

Reference Number: ______________ **Date:** ______________

Detail/Product/Material Specification: WALL BOX

Function: ______________

Description (e.g., part number): ______________

Numerical Evaluation:

Weight Factors

1 = Nice to Have — Minor Importance

2 = Essential — Medium Importance

3 = Vital — Major Importance

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
A		A-3	C-1	C-3	E-2	A-3	A-3														
B			C-3	D-3	E-3	F-1	G-2														
C				D-2	E-2	C-1	C-2														
D					E-3	D-3	D-1														
E						E-3	E-2														
F							G-3														
G																					
H																					
I																					
J																					
K																					
L																					
M																					
N																					
O																					
P																					
Q																					
R																					
S																					
T																					
U																					

Figure 11-20B Functional Evaluation Worksheet — Part 2, Example

Value Engineering Consultants

Functional Evaluation — Part 1

Reference Number: ________________ **Date:** ________________

Detail/Product/Material Specification: WALL BOX

Function: ________________

Description (e.g., part number): ________________

Evaluation Summary

List Order	Functions	Weight
A	CONFINE MATERIAL	9
B	STORE MATERIAL	Ø
C	PROTECT INSIDE	1Ø
D	PROTECT MATERIAL	9
E	PREVENT LOSS	15
F	ENHANCE APPEARANCE	1
G	ESTABLISH PRIVACY	5
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
X		
Y		
Z		

Figure 11-20C Functional Evaluation Worksheet — Part 1, Example

Value Engineering Consultants
Functional Definiton and Analysis

Reference Number: ________________ **Date:** ________________

Detail/Product/Material Specification: ______________________________
Function: ______________________________
Description (e.g., part number): ______________________________

Qty	Item Descrp.	FUNCTIONS*						Cost per Function (Estimate)	Label Function V= vital E = Essential N = Nice to Have	Notes/ Comments
		VERB	NOUN	B	S	W	AP SL			
1	Wall Box	Confine	Material	X		X			E	
		Store	Material		X		X		N	
		Protect	Inside	X		X			E	
		Protect	Material		X	X			E	See Confine Mate-rial Above
		Prevent	Loss	X		X		12.75	V	
		Enhance	Appearance		X		X		N	
		Establish	Privacy		X		X		N	

Note: **B — Basic**
S — Secondary
W — Work
AP/SL — Appearance/Sell

Figure 11-21 Completion of Functional Definition and Analysis Worksheet

Value Engineering Consultants

Functional Evaluation — Part 1

Reference Number: ______________ **Date:** ______________

Detail/Product/Material Specification: Pencil

Function: Make Marks

Description (e.g., part number): ______________

Evaluation Summary

List Order	Functions	Weight
A	Elimnate Paint	
B	Reduce length of lead	
C	Remove eraser	
D	Stain wood in lieu of paint	
E	Make body out of plastic	
F		
G		
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
X		
Y		
Z		

Figure 11-22A Functional Evaluation, Part 1, Step 1

Value Engineering Consultants

Functional Evaluation — Part 2

Reference Number: ____________ **Date:** ____________

Detail/Product/Material Specification: Pencil
Function: Make Marks
Description (e.g., part number): ____________

Numerical Evaluation:

Weight Factors
- 1 = Nice to Have — Minor Importance
- 2 = Essential — Medium Importance
- 3 = Vital — Major Importance

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
A		B-2	A-1	D-1	A-1																
B			B-3	B-2	B-2																
C				D-1	C-1																
D					D-2																
E																					
F																					
G																					
H																					
I																					
J																					
K																					
L																					
M																					
N																					
O																					
P																					
Q																					
R																					
S																					
T																					
U																					

Figure 11-22B Functional Evaluation, Part 2

Value Engineering Consultants
Functional Evaluation — Part 1

Reference Number: ________________ **Date:** ________________

Detail/Product/Material Specification: PENCIL
Function: MAKE MARKS
Description (e.g., part number): ________________

Evaluation Summary

List Order	Functions	Weight
A	ELIMNATE PAINT	2
B	REDUCE LENGTH OF LEAD	9
C	REMOVE ERASER	1
D	STAIN WOOD IN LIEU OF PAINT	5
E	MAKE BODY OUT OF PLASTIC	Ø
F		
G		
H		
I		
J		
K		
L		
M		
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
X		
Y		
Z		

Figure 11-22C Functional Evaluation, Part 1, Step 2

Value Engineering Consultants
Idea and Function Evaluation

Reference Number: ____________ **Date:** ____________
Team: ____________
Detail/Product/Material Specification: ____________
Function: WALL BOX; CONFINE AND SECURE MATERIAL
Description (e.g., part number): ____________

IDEA FROM FUNCTIONAL DEVELOPMENT	ADVANTAGES	DISADVANTAGES
PROVIDE 2' BY 2' 10 GAUGE POLISHED ALUMINUM WALL BOX TO CONFINE AND SECURE ON/OFF REGULATOR VALVE FOR HOT WATER FOR EACH FIXTURE IN EACH BATHROOM		

Plan(s)/Action(s) on Idea(s)

Figure 11-23 Completed Idea Evaluation Form before, a Sketch is provided, as is the ideas development sheet.

Once again, the team sets down rules to follow similar to those that went before. In this phase additional team members might include the manufacturer, contractor, and owner representative. This phase can provide an intense critique of the function/idea under discussion. It is this value-added group that reestablished advantages and disadvantages, with the initial value engineering team providing input based on their initial worksheet.

Second Creativity, Evaluation, Cost Anaylsis

In this phase, the larger team will again do creativity and evaluation. As seen in Figure 11-24A and 11-24B, the sketch can be significantly modified, and a new, secondary approach to the idea development phase can result in a different evaluation that could result in significant cost savings.

As seen in Figure 11-24, in this development/investigative phase the emphasis was on alternatives to a catalogue box and a "new" brainstorming session with different expertises and viewpoints.

Final Alternatives

With additional idea evaluation and cost estimates worksheets and possible sketches, the expanded value engineering team is ready to redevelop the idea. The team would again establish advantages and disadvantages using Figure 11-23 worksheet. At this stage, all of the engineering diciplines, contractors, and even the owners would help in the final development and investigation to determine the best outcome.

With a workable and best-cost idea developed, the final step is to use construction supplies and industry standards to confirm the ability to meet the final engineering and design.

The Gut Feel Index

The Gut Feel Index is what engineers have developed from the original Delphia method of evaluation. The Delphia method attempts to achieve a consensus of opinion within a group using questionnaires regarding future events and technical expertise.

The Gut Feel Index is similar, but uses the intuitive qualification of each developed idea using the technical expertise of the individuals. Each team member scores each idea on a scale of 1 to 10 based on its technical merits and the economic expectations. Low technical requirements, low costs, and low risks get the highest mark.

High rankings by any individual are further explained to the other goup members so all understand the rationale behind the rankings. The average of the scores are then computed.

Finally, a Risk Guide is used to make the final determination as to each idea. Figure 11-25 defines a sample Risk Guide.

In this approach, the Risk 1 level can be implemented or accepted without much concern. All the other categories will require further investigation.

Cost Analysis, More

One of the major elements of value engineering is the final cost analysis that is done for the recommendations and alternatives. Cost considerations are an important element of the value engineering process. Up to this point, the process has relied on creative techniques, brainstorming, functional analysis, and comparitive analysis. The concentration has been on the technical side of the equation.

The result for value analysis must also incorporate the cost analysis side of value engineering. Interestingly, in many value engineering projects, a comparative-cost analysis is not often conducted. A cost analys will look at life-cycle costing, break-even analysis, and comparitive-cost analysis. For purposes of this basic overview, the details and in-depth review of the various cost-analysis methodologies are not included.

Are We There Yet?

The evaluation phase was intended to provide visibility to all ideas and flush out any constraints while offering alternative solutions. This phase, while seeming to repeat some of the evaluation phase, is the final organization and analysis phase. It is in this phase that the value engineering team prepares their final recommendations prior to presentation to the owners/clients.

The value engineering process reviewed here has used, depended and recommended the use of standardized worksheets. One major disadvange to this approach is the attempt to find a standardized process that is all encompassing for all situations and projects. Alas, that is not the case. So why then have worksheets?

The primary purpose is use as a tool, to help provide structure to the process and offer a presentation format. All of the worksheets help form a "picture" of the value engineering process and provide illustrative detail for support of the final recommendations. It is important that the end result show that there was depth to the engineering and analysis; that what is proposed is not "just" a suggestion or best guess but is based on engineering discipline.

Perhaps the best final step for the value engineering team is to have yet one more checklist; this one of questions that support the value engineering process.

Value Engineering Consultants
Functional Development
Sketch

Reference Number: ________ **Date:** ________

Team: ________

Detail/Product/Material Specification: ________

Function: WALL BOX

Description (e.g., part number): STANDARD WALL BOX:
ABC MANUFACTURER
MODEL NUMBER 123456-A
SIZE 2' X 2'

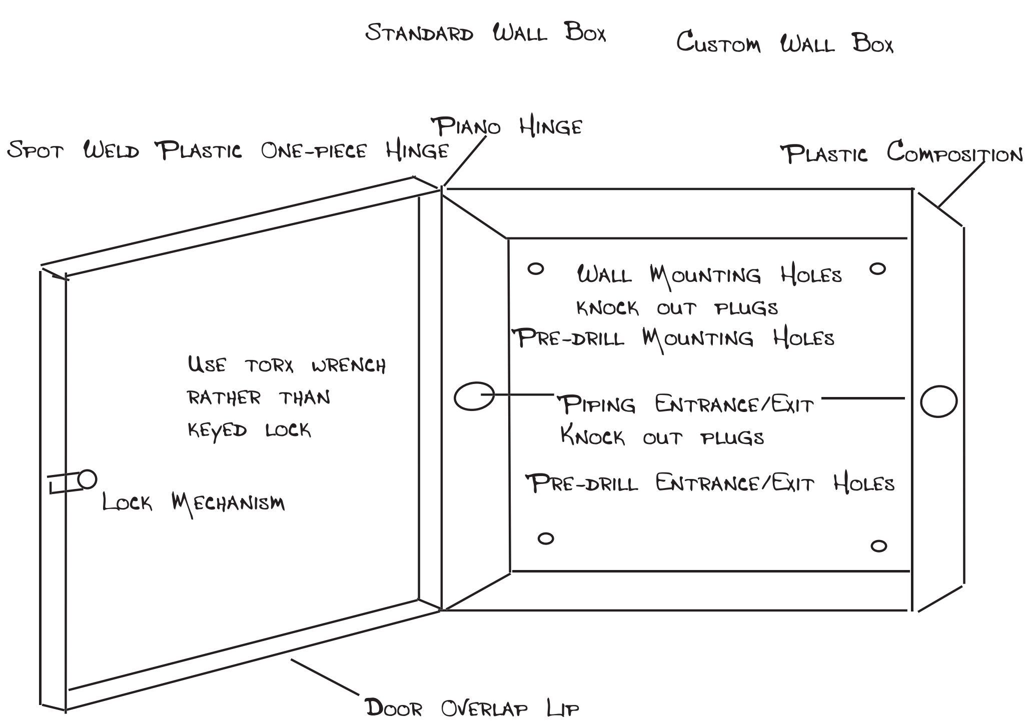


Figure 11-24A In-progress Alternative Sketch

Value Engineering Consultants

Functional Development
Idea Development and Estimated Cost

Reference Number: ______________ **Date:** ______________

Team: ______________________________

Detail/Product/Material Specification: ______________________________

Function: Wall Box

Description (e.g., part number): Standard Wall Box:
ABC Manufacturer
Model Number 123456-A
Size 2' X 2'

FUNCTION	CREATIVE IDEA(S) & DEVELOPMENT	ESTIMATED COST	CUMULATIVE ESTIMATED COST
Wall Box	Standard ABC Manufacturer Catalogue Wall Box	$12.75	$12.75
	Custom Box		
	Plastic Composition	$3.95	$3.95
	Plastic Composition – Vacuum Molded	$3.10	$3.10
	Spot Weld Single Hinge	$1.75	$5.70
	Use Two Hinges instead of One Hinge	$.75	$3.85
	Pre-cut Holes	$1.75	$7.45
	Drill Pipe Entrance/Exit on Site	$1.25	$5.60
	Drill Mounting Holes on Site	$.75	$6.35
		Total	$6.35 $7.45

Cost Summary

Material & Material Burden $ ____________

Direct Labor $ ____________

Direct Labor Burden $ ____________

Total $ ____________

Figure 11-24B In-progress Alternative Idea Development and Cost Estimates

Rank	Risk Description	GFI Range
1	Recommendation/idea has low risk, good payback, minimal cost or investment risk, and change will not be owner/client sensitive.	7.5-10
2	Recommendation/idea has some technical risk, payback and/or cost/investment is not fully defined, and change will not be sensitive to the owner/client.	6-7.4
3	Recommendation/idea is a new approach, needs some additional technical engineering/design work, cost/investment is not expected to be excessive, but change is a new approach to owner/client.	4.5-5.9
4	Recommendation/idea is whole different technical concept with attendant risks, unknown cost/investment requirements, and will be unknown to owner/client.	2-4.4

A Gut Feel Index of less than 2.0 would automatically be excluded.

Figure 11-25 Risk Guide

1. Does the proposed solution or alternative satisfy all of the original requirements and specifications?
2. Are there any issues or idea that remain unresolved prior to final recommendations?
3. Are all reliability requirements and specifications met by the alternative?
4. Are all of the recommendations and alternatives compatible with all other systems, processes and materials?
5. Do the recommendations or alternatives create any health or safety concerns?
6. Do the recommendations and alternatives meet the operational and maintainability requirements of the project/system?
7. Are the recommendations or alternatives able to be implemented within the guidelines of codes and regulations, and offer no additional delays or costs over the original engineering and design?
8. Do the recommendations and alternatives support the owners/clients requirements, specifications, and goals?

Everything is now in place and ready for the final step — the presentation of the results.

Recommendation/Presentation

The presentation and recommendation phase is the culmination of all the previous phases. Will the value-engineering-team reccommendations and alternatives be accepted or rejected?

In the end, it all boils down to "salesmanship." The recommendations and alternatives, no matter how they are couched, will be seen as an attack, repudiation, or rejection of another engineer's work. People react in different ways, but in the engineering/design profession a couple of things can be counted on occuring.

First, because it is human nature, change, no matter how slight or how right, will be resisted. Overcoming resistance will require patience and "proof." This requires that the value engineering team have all their worksheets for all aspects and phases of the process available for critical review.

Second, all recommendations and alternatives must be based on the same technical basis as the original specification. Not everyone will require exquisite detail to be convinced while, others will never be satisfied with whatever is provided.

To prevail, the value engineering team need only present two items: the facts and the truth. The presentation of the facts must be accomplished in the same deliberate manner that was followed throughout the value engineering process. Prepared with the worksheets and a written analysis, the presentation will be able to account for every requirement and specification, and be able to trace the path of the analysis from beginning to end with a clear understanding of the final recommendations/alternatives.

The worksheets used throughout the value enginering process will prove invaluable. They paint a picture for all to see and will provide a concise and complete visual explanation of the end result, along with compelling and unrefutable conclusion.

Present Costs

The whole exercise for value engineering is to provide cost savings on the total project. It is the presentation of exacting support details that will result in a successful and fully accepted modification. Because value engineering is a "team" approach and depends on a "Team Recommendation," an agreed-to consuensus result is the one most sought after by everyone involved.

Present Recommendation

The final step is to present a team recommendation. A recommendation worksheet is shown in Figure 11-26. This worksheet will be a summary of all the support worksheets and will spell out the findings and recommendations.

Making the Presentation

The final presentation should be both a written report of findings and a verbal description. Both need to be clear and concise, and the presentation confident and positive. The basic strategies for successful presentations are:

1. Expain the Whys: Provide the facts, detail the modification/changes, and describe and acknowledge any risks.
2, List the Benefits: It's important to concentrate on the benefits that will accrue because of the value engineering process. However, be sure not to exaggerate or oversell the results.
3. Make it a Participatory Presentation: Be sure to involve the audience in the discussion and presentation. Incorporate audience suggestions. Involvement is ownership.
4. Answer Questions Before They Are Asked: Be ready for the negativity that will be present by some individuals.
5. Be Prepared: Avoid surprises by being prepared, and don't let emotions interfere with the presentation.
6. Acknowledge Difficulties or Unknowns: Don't gloss over an obvious problem or a void in the presentation. Acknowledge the unknown and provide an interpretation or at least some alternative response.
7. Repeat, Repeat, Repeat: Repetition is the road to understanding. However, in repeating, be sure you are prepared with alternative road directions and maps. Repeating the same words over and over will not make the material understood any easier to be embraced.

Is It Value Engineering?

In the construction industry, the emphasis is constantly on the cost side of the equation. All too often the quality of the engineering and design are "attacked" under the rubric of "value engineering." As should be clear by this point, "true" value engineering can be an expensive undertaking. It is why value engineering invokes the Pareto principle: Only 20 percent of the product/project/system will produce 80 percent of the savings. It is for this 20 percent that a value engineering analysis is of value.

Unfortunately, most so-called "value engineering" it is simly the misappropriation of a term that connotes structured and scientific analysis to the evaluation of a product/system/material. In reality, it is nothing more than simple cost cutting or cost reductions for the sake of savings alone. This process is not value engineering, no matter what you may wish to call it. It is more appropriate to use the proper term for what all too often passes for "value engineering" — cost reductions. Or, if a analytical name needs to be used, **Cost Fitting** is appropriate.

Cost Fitting

Cost fitting is where engineers, designers, and the like are often left out of the process and the designs and mechanicals are turned over to a "value engineer," often nothing more than a contractor seeking the bid for the project. "The budget is the budget," as developers and owners like to say.

In this iteration of cost fitting, the Pseudo Value Engineer (PVE) will offer replacement products or designs that can be installed for less money or "To meet the budgetary needs of the project." There is no concern in cost fitting for the quality of the engineering or design. One problem with cost fitting is that there is always an alternative to anyone's choice of a product or design element. The PVE, knowing this, can offer cost savings over the design engineer's original work. All too often, the cost savings result in increased profits for the PVE as he/she garners the business with an on-budget bid—only to use inferior or less-desirable products/systems/materials with greater markups for the supplier.

Level the Playing Field

One option open to engineers is to have included in their contracts a series of clauses that would provide or require "true" value engineering to be performed on their designs. The role of the engineer is not to inhibit good value engineering of a project. As already shown, value engineering is a discipline that, when properly applied, will result in cost savings without any sacrifice in quality of design. The following example in Figure 11-27 is not intended to be exact legal language or offered as a instant contract addition. Rather, it is provided as a concept for insuring that proper value engineering is implemented on the engineers design and mechanicals.

The Déja Vu of the "Science" of Value Engineering

Does the "science" of value engineering seem very familiar? It should, because it contains many of the same elements followed in plumbing engineering and design. As you read about value engineering, you

Value Engineering Consultants

Team Cost/Improvement Recommendation

Reference Number: ____________________ **Date:** ____________________

Detail/Product/Material Specification: ____________________

Function: ____________________

Description (e.g., part number): ____________________

____

____

Team Members: ____________________

____

Original Design/Sketch	Recommended Design/Sketch

Expected Savings: ____________________

Life Cycle Costs: ____________________

Explanation of Savings or Cost Reduction(s) ____________________

____

____

FINDINGS AND RECOMMENDATIONS:

____

____

____

____

____

____

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____

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EXPLANATION FOR:
❑ **APPROVAL** ❑ **REJECTION:**

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Figure 11-26 Value Engineering Team Recommendation.

1. INTENT AND OBJECTIVES-This clause applies to any cost reduction proposal (hereafter referred to as a Value Engineering Change Proposal or VECP) initiated and developed by the Contractor for the purpose of changing any requirement of this contract. This clause does not, however, apply to any such proposal unless it is identified by the Contractor, at the time of its submission to the Owner, as a proposal submitted pursuant to this clause.

1.1 VECPs contemplated are those that would result in net savings to the Owner by providing either: (1) a decrease in the cost of performance of this contract, or; (2) a reduction in the cost of ownership (hereafter referred to as collateral costs) of the work provided by this contract, regardless of acquisition costs. VECPs must result in savings without impairing any required functions and characteristics such as service life, reliability, economy of operation, ease of maintenance, standardized features, esthetics, fire protection features, and safety features presently required by this contract. However, nothing herein precludes the submittal of VECPs where the Contractor considers that the required functions and characteristics could be combined, reduced, or eliminated as being nonessential or excessive for the function served by the work involved.

2. SUBCONTRACTOR INCLUSION—The Contractor shall include the provisions of this clause, with the pre-determined sharing arrangements contained herein, in all subcontracts in excess of $25,000, and any other sub-contracts which, in the judgment of the Contractor, is of such nature as to offer reasonable likelihood of value engineering cost reductions. At the option of the first-tier Subcontractor, this clause may be included in lower tier subcontracts. The Contractor shall encourage submission of VECPs from Sub-contractors; however, it is not mandatory that VECPs be submitted, nor is it mandatory that the Contractor accept and/or transmit to the Owner VECPs proposed by his Subcontractors.

3. DATA REQUIREMENTS—As a minimum, the following information shall be submitted by the Contractor with each VECP:

3.1 A description of the difference between the existing contract requirement and the proposed change, and the comparative advantages and disadvantages of each; including justification where function or characteristic of a work item is being reduced;

3.2 Separate detailed cost estimates for both the existing contract requirement and the proposed change, and an estimate of the change in contract price, including consideration of the costs of development and implementation of the VECP and the sharing arrangement set forth in this clause;

3.3 An estimate of the effects the VECP would have on collateral costs to the Owner, including an estimate of the sharing that the Contractor requests be paid by the Owner upon approval of the VECP;

3.4 Architectural, engineering, or other analysis in sufficient detail to identify and describe each requirement of the contract, which must be changed if the VECP is accepted, with recommendation as to how to accomplish each such change and its effect on unchanged work.

Figure 11-27 Example of Value Engineering Change Proposal Contract Clause

should have been aware that this discipline is very much like that of plumbing engineering and design. In fact, the elements described could just as easily be transported to, and applied to a plumbing design project. The elements techniques of value engineering are similar to most other engineering disciplines, and almost exactly the same as used by many other disciplines. Well then, if the plumbing engineer is already doing all this, why does it need to be done again?

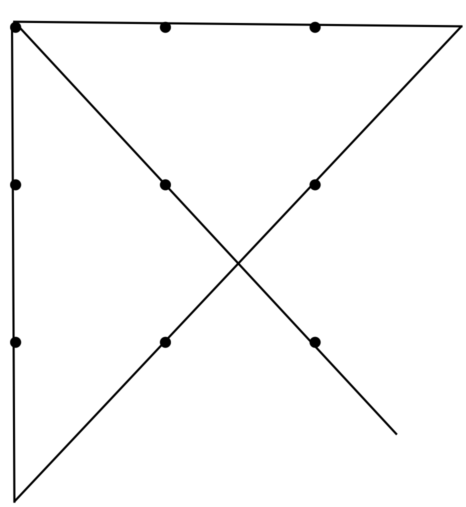
For the project's owner, developer, or manager it becomes an issue of perception. Each of the engineering and design disciplines used throughout the creation of a facility's project are always open to suspect and suspicion. Engineers and designers are often seen not just as "engineers" doing their necessary and important work, but as "engineering artists." The engineering artist is suspect as creating an enduring engineering work of art under the guise of "quality of design." A forever lasting engineered product that may well include redundancies will most likely include the most up-to-date and state-of-the-art products and materials available on the market — and therefore, by inference, the most expensive products and materials. The perception is of the engineering artist over-engineering a project. The engineer is suspect of using materials and products that have a longer life-cycle cost than may actually be necessary in order to provide an extra measure of safety, longevity, and quality of design.

It is this "quality of design" that is perceived by those financing the project to result in a more costly enterprise than is necessary, while still providing the safety and longevity desired. Enter the discipline of value engineering. This engineering step at each stage of a project is perceived to be nothing more than an oversight function protecting the economic interests of the owner and insuring quality of design at the best possible cost. It is not intended to be cost reductions simply for the sake of cost reduction.

What the engineer often "sees" as being the end result of value engineering, and why many object to its use, is the misconception that lower costs equate directly with reduced quality. The plumbing engineer, like all other engineers and designers, needs to remain flexible and open to the integration of other discipline's ideas and concepts. Value engineering is not a methodology designed to undermine the engineering, design, or specifications of a project. Nor is it intended to "outsmart" or "out-think" the engineers. Value engineering is not intended or designed to reduce quality, safety, professionalism or creativity. *It is an analysis to identify and stop waste, thus lowering costs while maintaining quality.*

Value engineering, when performed properly, will not affect performance and will not result in tradeoffs to reliability, quality, or maintainability. And this may well be the crux of the conundrum inherent in the discipline. Value engineering is only as good as the process followed, the experience of the engineers, and like any project, subject to various obvious and hidden agendas by numerous parties involved. Moreover, it is not unheard of for many "value engineered changes" to be nothing more than an owner-mandated cost reduction disguised under the rubric of "value engineered." Which is not much different than having a carefully engineered and specified product substituted by a contractor as something deemed "equal," often for nothing more than increased profit potential and no real savings for the owner. Despite the negative connotation often is improperly designated with the value engineering label, the concept needs to be looked at as an adjunct to a project's engineering, and each other engineering discipline needs to embrace the concept and use it effectively within his/her discipline.

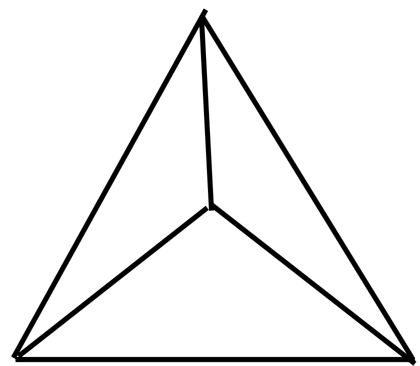
Solution to Nine Dots



The solution calls for thinking "Outside the box."

Solution to Equilateral Triangle

The solution calls for thinking off the two-dimensional surface of a table and into three dimensions. The solution shown is as viewed from above. It's a Pyramid shape. The base is, of course, one of the equilateral triangles.



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12 Green Design for Plumbing Systems

INTRODUCTION

An important part of a sustainable design plumbing system is the conservation of water. Seventy percent of the earth's surface is covered with water, but only 0.5percent of that water is fresh water that is available for drinking water and is relatively easily obtainable. Of that 0.5percent, only 2percent is potable without some form of treatment. With such a limited resource, it only makes sense that we should be trying to limit the consumption of water.

Sustainable design is gaining popularity in the building community, offering new and innovative ways to improve the built environment. The basic premise of sustainability is to reduce the use of non-renewable resources, and the amount of waste discarded, and provide a healthier environment to live and work in. Sustainability is gaining acceptance from a wide variety of places and is a required design philosophy by many governmental agencies such as the General Services Administration (GSA). The GSA requires all of the new buildings they are involved with to meet certain sustainable requirements defined by the U.S. Green Building Council.

The U.S. Green Building Council was formed in 1993 and is the nation's foremost coalition of leaders from across the building industry working to promote buildings that are environmentally responsible, profitable and healthy places to live and work. The U.S. Green Building Council (USGBC) is leading a national consensus for producing a new generation of buildings that deliver high performance inside and out. As the leading organization representing the entire industry on environmental building matters, USGBC's unique perspective and collective power provides its members with enormous opportunity to effect change in the way buildings are designed, built, and maintained.

One of the methods the USGBC has developed for maintaining consistency in sustainable guidelines is through the development of a certification program for buildings known as Leadership in Energy & Environmental Design (LEED™).

LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN

The LEED (Leadership in Energy and Environmental Design) Green Building Rating System™ is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. LEED provides a complete framework for assessing building performance and meeting sustainability goals. Based on well-founded scientific standards, LEED emphasizes state-of-the-art strategies for sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality. LEED recognizes achievements and promotes expertise in green building through a comprehensive system offering project certification, professional accreditation, training, and practical resources.

The LEED program is based on a rating system that is divided into six main areas of design. These areas are Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Environmental Quality, and Innovation & Design Process. Each of the areas has specific requirements and prerequisites that must be met in order to qualify for any certification levels. The certification levels and minimum points for each level in the LEED program are as follows:

Certified	26-32 points
Silver Level	33-38 points
Gold Level	39-51 points
Platinum Level	52+ points with a possible 69 points available.

A complete listing of the LEED Rating system and other requirements of the certification system are available from the USGBC at www.usgbc.org.

One of the listed areas in the LEED program is Water Efficiency. The area is broken down into three sub areas that allow points to be earned by achieving certain criteria established to reduce water consumption. The first credit available is for utilizing water-efficient landscaping to reduce the amount of potable water used for irrigation by 50 percent. This is typically accomplished by using a highly efficient irrigation system, capturing rainwater, or using recycled site water to reduce the consumption of potable water. Additionally another credit is available for the elimination of the use of potable water for irrigation purposes.

WASTEWATER TECHNOLOGIES

For water efficiency, the area of credit is Innovative Wastewater Technologies. Reduction of the use of municipally provided potable water for building sewage conveyance by a minimum of 50 percent or treating 100 percent of the wastewater on-site to tertiary standards is required. This is typically accomplished by the use of storm water or grey water for the conveyance of sewage in the building drainage system. Additionally, the use of high-efficiency plumbing fixtures or dry fixtures can reduce the amount of potable water used in the plumbing system.

Ideas for ways to accomplish this point:

1. Automate the operation of equipment.
2. Connect cooling water for equipment to a closed-loop chilled water system instead of using potable water.
3. Monitor the water consumption of the equipment.
4. Use ultra-low-flow fixtures in the plumbing system.

WATER-USE REDUCTION CREDIT

Closely related to the reduction in wastewater through Innovative Wastewater Technologies is the Water-Use Reduction Credit. There are two of these credits available, one for reducing the use of potable water by 20 percent over and above the requirements of the Energy Policy Act of 1992 (EPACT), and another credit for reducing the potable water usage by an additional 10 percent for a total reduction in potable water usage of 30 percent.

Ideas for ways to accomplish this point:

1. Select equipment that provides for maximum water efficiency.
2. Provide ultra-low-consumption plumbing fixtures.
3. Use metering or infrared faucets.
4. Use infrared flush valves.
5. Eliminate one-pass cooling for equipment.
6. Reduce cooling-tower drift losses and other equipment losses to save on the amount of makeup water.

CAUTIONS

Many factors should be considered when sustainable designs are required or even contemplated. For example, the reduction in the amount of water used in the system needs to be verified, and the effects on the system need to be considered. Reduction in the amount of wastewater generated can have another impact on the sizing of the water and drainage piping in the building. Waste piping, in particular, needs to be sized based on a flow velocity of two feet per second; reducing the flow rate of the fixtures changes the tables and information commonly used by the plumbing designer and code officials. The model plumbing codes have been modified to reduce the number of fixture units attributed to the plumbing fixtures in the pipe-sizing calculations based on the reduction in water mandated by EPAC. Communication between the code official and designer is imperative to minimize potential problems in the plumbing system.

EPACT requires all manufacturers of plumbing products in the United States to meet or exceed water-usage requirements for plumbing fixtures as follows:

Faucets:	2.5 gallons per minute (9.5 liters per minute, lpm)
Metered Faucets:	0.25 gallons per cycle (0.9 liters per cycle, lpc)
Shower Heads:	2.5 gallons per minute (9.5 liters per minute, lpm)
Water Closets:	1.6 gallons per flush (6.1 liters per flush, lpf)
Urinals:	1.0 gallons per flush (3.8 liters per flush, lpf)

It should be noted there are millions of plumbing fixtures installed in existing buildings that have not been modified to meet the requirements of EPACT and represent a significant opportunity to reduce the amount of water used by the plumbing system.

PLUMBING PRODUCTS

Reductions in water usage beyond what is required by EPACT can be obtained by using products such as lavatory faucets with flow rates of 0.5 gallons per minute (1.9 lpm), showerheads with flow rates of 1.5 gallons per minute (5.7 lpm), and water closets that use dual-flush technology. Use of these ultra-low consumption fixtures should be cautioned without taking appropriate measures in the sanitary drainage system to accommodate the lower volume of water in the piping system. Usually, reducing the pipe size or increasing the slope of the pipe—thereby increasing the velocity of the water flowing through the piping system–accomplishes this.

The use of infrared faucets and flush valves in the plumbing systems can reduce the amount of water consumed. The exact amount of reduction in water usage varies depending on the type of building and occupancy, but can be a significant amount upwards of 75 percent over conventional faucets.

Waterless urinals have been developed to use a biodegradable, immiscible fluid that is less dense than normal liquid waste and allows the waste to pass through a special trap and then to the drainage system. These products do not connect to the building water supply and do not use water. There is quite a bit of controversy about the use of these products and their potential for increased maintenance costs. Some areas have provisions in the plumbing code that would prohibit the use of these fixtures and require special permissions or variances in order for the fixtures to be used. Care should be taken by the designer to fully understand the advantages and disadvantages and discuss these items with the building owner prior to using this type of fixture.

Composting water closet systems use little or no water, are not connected to a conventional plumbing system, and convert wastes into compost by means of an aerobic decomposition process carried out by micro and macro organisms. Another type of fixture that does not use water is an incinerating water closet, which utilizes a combustion chamber in order to incinerate wastes. Use of these units is typically limited to remote locations or locations where water availability is limited. Again, the limitations of code should be investigated prior to using these units.

Dual-flush water closets are available with controls to provide a reduced volume of water when a full flush is not required. These fixtures are becoming more common in the United States. Several manufacturers currently have units available.

ADDITIONAL LEED POINTS—ENERGY SAVERS

Another area where LEED points are available is energy efficiency and energy-use reduction. There are many ways energy consumption can be reduced in a plumbing system. While the most common ways to conserve energy have to do with heating, ventilating, and air-conditioning systems in a building, there are still ways to conserve energy in the plumbing system.

Using high-efficiency water heaters to heat domestic water is one of the first steps in saving energy in a plumbing system. Using solar water heating systems or photovoltaic technology and generating electricity to heat water can also be an option in some cases; capture an alternative energy source and reduce the amount of other types of energy used. Many of the alternatives for heating water will depend on the type of building being designed and the quantity of hot water your system requires. The use of a solar water-heating system may be an option for some buildings. However, if there is a high demand and you require a quick recovery on the water heating system, then a solar water-heating system may not be advisable. The use of photovoltaic receptors to generate electricity to heat water can also be a viable option if your situation only requires a limited amount of hot water.

The use of small electric or natural gas-fired instantaneous water heaters, which only use energy when the water is flowing, is very much a viable option--especially when the fixture is remotely located from the rest of the building, or the hot water demand is only needed for a short period of time. Understanding how the building uses hot water and accurately determining the demand of the building are prerequisites to providing a water heater that is not oversized, and, therefore, an energy-wasting device.

Reducing the amount of standby heat loss from the water heater or storage tank is all part of saving energy. Not storing quantities of hot water and using an instantaneous water heater may provide a great solution—if you have the right circumstances. However, other types of facilities may need to have a large quantity of water stored for use during high-demand periods. It is important to have conversations with the client and understand the constraints the design will need to conform to.

Opportunities for the application of different water heating technologies are endless. Depending on the type of building you are designing, there may be multiple solutions for providing hot water to the building fixtures.

Hot-water recirculation systems conforming to ASHRAE 90.1 should also be provided. These systems require that the piping system be insulated with a minimum insulation thickness and the circulating pump be controlled by a temperature-sensing device or a time clock. This standard should be consulted prior to the design of a recirculation system. Another consideration to limit the energy lost in a hot-water recirculation system is the routing of the supply and return piping. Using the shortest route for the distribution system will provide a more-efficient piping system, thereby saving energy from the heat loss of the system. These systems should also be balanced to provide uniform heat loss throughout the system and limit the temperature drop in the system.

In certain building types and installations, consideration may be given to using a central-chilled drinking-water system for energy conservation. The amount of energy consumed by electric water coolers spaced throughout a facility may actually be greater than the amount of energy consumed by a central chiller with a looped piping system to the drinking fountains and the recirculation pump—keeping the water in the system moving and cool. As with a hot-water recirculation system, a chilled drinking-water system should also have the piping insulated to prevent heat gain and also prevent condensation on the piping system. Of course, using drinking fountains instead of electric water coolers would also save energy, piping, and insulation costs associated with the system. The building owner should be consulted prior to providing a non-chilled drinking-water solution for their building.

The possibilities are numerous for energy conservation, and taking the time to stop and review the building being designed can provide some interesting ways to save energy. The use of a waste-heat-recovery system to preheat the inlet water to domestic water heaters can to limit the amount of energy used to heat the domestic water. If a building system is connected to a central steam system where the condensate is not returned, using the heat remaining in the condensate is advisable. It is common to provide heat-recovery systems on large laundry and car-wash facilities, but common to apply them to other types of buildings.

Recovering the heat from dishwashers, glass washers, showers, and other devices that use hot water has not been utilized on a wide basis. One technology that allows heat recovery from these types of uses is the gravity-film heat exchanger. This device utilizes a vertical counter-flow heat exchanger that extracts heat from waste water and uses it to preheat the cold water to the water heater. The heat exchanger consists of a copper drainage pipe with small-diameter copper piping coiled around the drainage piping over a given length. The heat is transferred from the drainage piping to smaller coils on the outside of the piping. The unit is installed in the vertical position so waste water in a vertical stack flows down the entire perimeter of the waste piping with a center core of air in the middle. This type of configuration would not be as efficient installed in the horizontal position, as water in the drainage piping would only be in contact with the coiled piping over half of the piping system perimeter.

INNOVATIVE IDEAS

When thinking about sustainable design and portions of the plumbing system that could be modified to provide a more ecological solution to the installation of plumbing systems, there are several things that could be investigated.

Considering the use of mechanical joints or press joints with o-ring gaskets to limit the use of flux and solder and reduce the potential negative health effects of the byproducts of making soldered joints could be shown to be sustainable. While the use of lead pipe has declined to almost nothing, the retrofit of any system containing lead would be considered sustainable—even to the point of not using lead and oakum for joining cast-iron hub and spigot piping. Not many areas still use this method of joining piping, but there are some areas where lead and oakum are still prevalent today.

GREEN ROOFS

One portion of some sustainable designs is the use of green roofs or roofs that have a thin layer of soil, which contains vegetation and helps provide additional insulation and a thermal break for the building occupants. There are several types of these systems available, each with its own specific criteria and method of installation. Common to many of the different types of green roofs is the requirement to be able to provide some type of irrigation water for the plants.

Typically, the preferred solution in sustainable design would be to use some type of water other than the potable water supply to the building. Many of the potential solutions for how much water will be needed for the irrigation systems, as well as the type of irrigation system to be used, should be verified with the architect or landscape designer. It is recommended the plantings used in this type of situation be more drought resistant than conventional types of plants. This assists with the premise to save as much water as possible. Whether rainwater or clear water wastes from the building is collected to water the plants, there are several options available. The use of other types of water, not drinking water, will assist in the reduction of water use for the building.

It is common for the irrigation system of a green-roof installation to be a drip-type irrigation system. Other types of systems exist to limit the amount of run-off water into the roof-drainage system. The designer of the landscape portion of the green roofing system should be consulted on the type of irrigation system to be provided. The type of irrigation system used may depend on the type of vegetation planted on the roof, and whether or not water must be in a specific area for a predetermined length of time, or if another type of system is recommended.

The roof-drainage system used in a green roof setting is designed as a conventional roof drainage system would be. The plumbing code should be consulted regarding the amount of rainwater anticipated and the requirements of storm durations. Pipe sizing for the storm-drainage system remains the same as it would for a conventional system. If a secondary drainage system is required for a conventional roof, and the green roof being designed contains the same attributes, (such as parapets) then a secondary drainage system with overflow drains or scuppers would also be required on the green roof. Green roofs are designed in many shapes and sizes, and each will be different depending on the designer and the area with which they are working.

To help keep soil and other plants away from the roof drains, usually a small area around the drain is separated from the remainder of the green roof. Care should be taken when designing these systems to keep debris and other portions of the plantings from getting into the roof-drainage system and potentially creating a problem. Additional screening of the roof-drain strainers may be necessary.

GREY WATER SYSTEMS

One of the technologies becoming more prevalent in the design of sustainable plumbing systems is the use of grey water systems. The systems reuse previously used water for another. Typically, grey water systems are used to flush water closets and urinals and should not come into any human contact. The collection of rainwater for use in this type of system is also gaining acceptance and can reduce the amount of potable water used for things other than drinking.

Typically these systems gather water from various uses (allowing the water to be classified as grey water) and bring that water back to a central location. Once the water is gathered into a tank, it can then be sent back to the system to be used again. The water must be filtered prior to distribution to water closets and urinals to remove substances from the water that may cause the flush valves or other components to fail. For example, small particles of sand or other matter can clog the diaphragms of flush valves so they run continuously. Distribution pumps are required to pressurize the system and allow it to function properly.

Grey water systems are commonly found in laundry facilities, car washes, and other such facilities. Treatment of the waste water from these systems is usually required before the water can be used again. Various manufacturers of these systems are available and should be consulted regarding the specific requirements of their systems.

Another potential resource for grey water usage is condensate gathered from high-efficiency condensing-type water heaters, and boilers, and from fan-coil units, air-handling units, etc. That water can be used to provide makeup water to the boiler or chiller makeup water systems. Condensate gathered from high-efficiency water heaters and boilers should be tested and potentially treated to reduce corrosive properties that may restrict it from being reused for another purpose. The condensate gathered from cooling coils or fan-coil units is generally water relatively free of impurities and can also reduce the amount of chemical treatment of the makeup water required for the other systems.

Rainwater-collection systems are becoming more prevalent for use in irrigation systems. These collection systems require the storage of the rainwater, usually in underground storage tanks that can be quite large. The amount of storage depends on the requirement for irrigation water, as well as the amount of rainwater anticipated. Some amount of water treatment and filtration should be anticipated to keep the sprinkler heads from fouling and becoming clogged with debris, but not to the same extent as the water used to flush water closets and urinals.

If rainwater collection is being considered, the designer needs to investigate its potential impacts. Certain areas of the country prohibit the collection of rainwater because the rainwater serves other areas of the country as their primary water supply. Thus, rainwater collection in one area could create a significant shortfall in another water supply if the rainwater is not allowed to flow downstream.

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