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7 Additional Considerations

Chapters 5 and 6 discuss wind load and debris impact design criteria specific to wind shelters. This chapter discusses additional issues that should be considered in the design of wind shelters and buildings in general. These issues include flood and seismic hazards, fire protection and life safety, permitting and code compliance, and quality assurance/quality control,

7.1 Flood Hazard Considerations

The designer should investigate all sources of flooding that could affect the use of the shelter. These include floods up to and including the 500-year flood; any flood of record; flooding from storm surge (in coastal areas); and flooding from local drainages. If it is not possible to locate a shelter outside an area subject to the flooding described above, special precautions must be taken to ensure the safety and well-being of anyone using the shelter. The lowest floor of the shelter must be elevated above the flood elevation from any of the flooding sources described. All utilities or services provided to the shelter must be protected from flooding as well.

NOTE

The lowest floor of a shelter located in the SFHA must be elevated above the 500-year flood elevation or elevated to the BFE + 1 foot, whichever is higher.

A shelter in a floodprone area must be properly equipped to meet any emergency medical, food, and sanitation needs during the time the occupants could be isolated by flooding. Access to the shelter must be maintained during flooding conditions. If access is not possible by ground transportation during flooding, alternative access must be provided. An example of how alternative access can be achieved is the installation of a helicopter pad that is above the flood levels. In all cases, both the designer and the owner will need to work with local and state emergency managers to ensure that these special requirements are met, both in the shelter design and construction and in emergency operation procedures.

7.2 Seismic Hazard Considerations

When a shelter is in a seismically active area as defined by the IBC, ASCE 7-98, or FEMA's NEHRP provisions, the structure should be checked for resistance to seismic forces. However, wind loads, as described in this manual, and earthquake (seismic) loads differ in the mechanics of loading. The difference is created by how the load is applied. In a wind event, the load is applied to the exterior of the envelope of the structure. Typically, internal building elements that are not part of the MWFRS of the building will not receive load unless there is a breach of the building envelope. Earthquakes induce loads based on force acceleration relationships. This relationship requires that all objects of mass develop loads. Therefore, all structural elements and all non-structural components within, and attached to, the structure will be loaded. As a result, seismic loading requires both exterior building elements and internal building elements (including non-loadbearing elements and fixtures) to be designed for the seismically induced forces.

Another important seismic consideration for the designer is the assumed response of the structure during an event. Buildings are designed to remain elastic during a wind event—elastic in the sense that no permanent deformation of any of the structural members will occur. For earthquakes, this is not the case. Design for earthquakes is based on a two-earthquake scenario. The first earthquake is the common earthquake that can occur many times in the life of a structure and the second is the larger, rare earthquake. The design process requires that the structure remain elastic for the common earthquake. But for the rare earthquake, permanent deformation is allowed as long as it does not result in structural collapse of the building. Building elements that can "stretch and bend" give a structure the ability to withstand a large earthquake without the economic penalty of having to accommodate the rare earthquake without any permanent deformation.

7.2.1 Design Methods

After earthquakes in the 1920s and 1930s in California, engineers began to recognize the need to account for the lateral seismic-induced loads on structures. The first seismic codes calculated lateral seismic-induced loads using a percentage of the weight of the structure. This allowed common analysis procedures to be used. This method has been retained and is seen in today's building codes. It is commonly called the equivalent static force method. Over the years, this percentage coefficient has been refined and put on a more rational basis derived from the dynamic analysis of structures.

There are cases in which a more complicated dynamic analysis procedure is required. This dynamic analysis is common in the design and construction of very tall, irregular structures. The structures are considered irregular in that they are not rectangular or cube-like. They may have wings or appendages like an "L" or they may be "cross-shaped" structures. Figure 7-1 shows examples of buildings with an irregular shape.

The dynamic analysis procedure for these types of structures consists of three parts:

1. a time history analysis
2. a response spectrum is developed
3. a modal analysis of the final structure

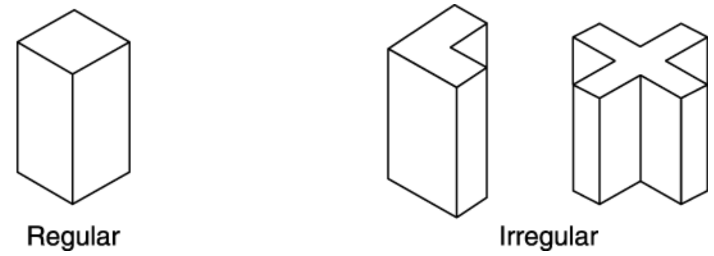


Figure 7-1
Examples of buildings with regular and irregular shapes.

Unless a seismic event has occurred and is documented at the exact building site, some sort of computed ground movement must be developed. This can be done in several ways. One is to use existing earthquake records and average several of them to produce a composite ground motion. Figure 7-2 is an actual graphical representation of a time response of the ground during a seismic event.

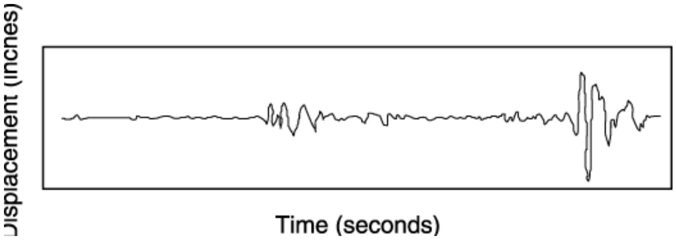


Figure 7-2
Time response of ground during seismic event.

Another way is to synthetically generate this motion using models of geologic phenomena and soil conditions. In either case, the result is a description of the movement and acceleration of the ground. Once this acceleration is defined, the acceleration is used as input in a single-degree-of-freedom system, illustrated in Figure 7-3. The single-degree-of-freedom system is a model of the building system with mass from floors and roof systems consolidated together to represent the building as a mass (M) supported by vertical building elements, with stiffness (k), acted upon by a lateral force (F) representative of the ground acceleration.

The stiffness (k) of the system can be varied to change the period of the building response to the applied lateral force. When this is done, a plot is made of the acceleration versus the period of the structure (see Figure 7-4). This type of plot is known as a Response Spectrum for the induced earthquake motion and illustrates the elastic structural system response to a particular earthquake motion.

Figure 7-3
Example of single-degree-of-freedom system.

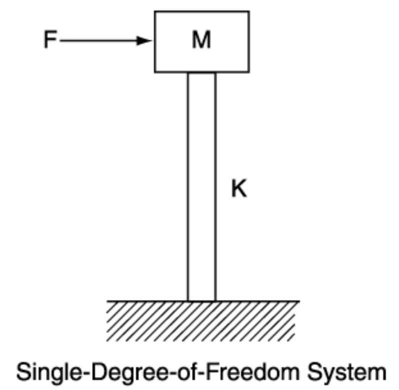
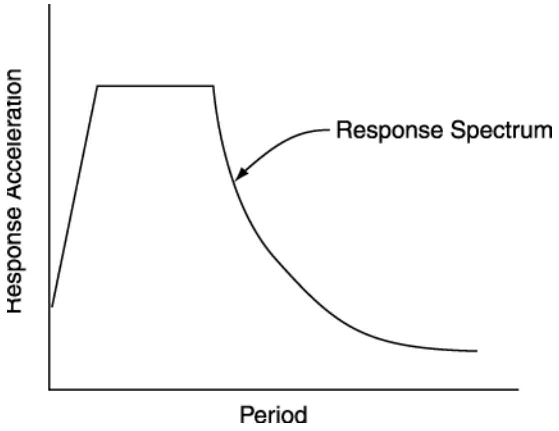


Figure 7-4
Acceleration vs. period of structure.



The last step in the dynamic analysis is to perform a modal analysis on the actual building. This type of analysis provides the motion of the building in terms of a single-degree-of-freedom system. Therefore, the response spectrum can be input into the modal analysis to give the building's response to the earthquake.

Both the static method and the dynamic method result in lateral forces induced on the structure. The geographic region of the country in which the shelter is located will dictate which analysis should be used. Once the forces are calculated, they can be input into the load combinations (as seismic load E) used for the design of the shelter.

7.2.2 Code Development

Earthquake codes are under continual refinement as new data become available. This continual refinement attempts to give more accurate models of how a structure responds to ground motion. Seismic events, like wind events, are constantly occurring and continue to test buildings constructed to recently improved codes and standards. An earthquake provides a test for the current procedures; after every event, those procedures are reviewed to ensure they are acting as intended.

An example of code development is the recent acknowledgment that seismic events occurring on the west and east coasts are not expected to be the same type of seismic event. On the west coast, the difference between the common earthquake and the rare earthquake is small. Design codes assume that the rare earthquake is only 50 percent larger than the common earthquake. On the east coast, this is not the case. In this region, the rare earthquake can be as much as 400 percent larger than the common earthquake. Therefore, prior to the release of the 2000 IBC, western U.S. design codes did not fit well to eastern U.S. earthquake requirements.

This poor fit has led to refinements in seismic design procedures. The new procedures attempt to provide a process for evaluating the response of a building when it begins to deform from seismic loads. This approach is needed to ensure that the structure can stretch and bend to resist the rare earthquake. Whereas, in the western U.S. this is ensured because of the minimal difference betweem the two different earthquakes, this cannot also be assumed in the eastern U.S.

7.2.3 Other Design Considerations

All the elements of the structure must be evaluated for earthquake forces. Not only are the exterior walls loaded, but the interior walls can also receive substantial out-of-place loads. For wind loading, these interior building components are not usually considered, although most codes require interior walls to be designed for some lateral pressure. Often, seismically induced forces are larger than the code-specified lateral wind pressures and, as a result, govern the design. Therefore, the design of these elements and their connections to the main structure are essential to a complete design—one in which both non-structural and structural elements are considered.

Earthquake requirements considered in the design of a shelter can enhance the lateral resistance of the structure to wind loads. For example, seismic loads tend to govern the designs of “heavy” structures constructed with concrete or masonry walls and concrete slab or roofs. In “lighter” structures constructed from framing and light structural systems supporting lightweight (metal or wood) roof systems, wind loads tend to govern. But even if wind loads govern, consideration should be given to the calculated seismic loads to allow the structure to deform without immediate failure. This ability gives the structure reserve capacity that can be used in severe-wind events.

7.3 Other Hazard Considerations

It is important that the designer consider other hazards at the building site, in addition to the wind, flood, and seismic hazards already considered. One such consideration is the location of a shelter on a building site with possible physical hazards (e.g., other building collapses or heavy falling debris). These siting and location issues are discussed in Chapter 4, and design guidance is provided in Section 6.3.

Another consideration is the presence of a hazardous material (HAZMAT) threat on site. Older buildings that are retrofitted for shelter use should be inspected for hazardous materials that may be stored near the shelter (e.g., gasoline, chlorine, or other chemicals) or that may have been used in the construction of the surrounding building (e.g., lead paint or asbestos). For example, asbestos may become airborne if portions of the surrounding building are damaged, resulting in the chemical contamination of breathable air. Live power lines, fire, and gas leaks are also shelter design concerns that may need to be addressed at some shelter sites. For example, the case study in Appendix D (Sheet P-1) shows how a gas line, required for gas service to the shelter area when in normal daily use, was fitted with an automatic shutoff valve. This precaution greatly reduces the risk of a gas-induced fire occurring while the shelter is occupied.

CROSS-REFERENCE

The hazard associated with a live gas line servicing a shelter is addressed in the case study in Appendix D, on Sheet P-1 of the design plans.

7.4 Fire Protection and Life Safety

The shelter must comply with the fire protection and life safety requirements of the model building code, the state code, or the local code governing construction in the jurisdiction where the shelter is constructed. For single-use high-wind shelters, the model building codes, life safety codes, and engineering standards do not indicate square footage requirements or occupancy classifications. For multi-use high-wind shelters, the codes and standards address occupancy classifications and square footage requirements for the normal use of the shelter. The shelter designer is advised to comply with all fire and life safety code requirements for the shelter occupant load and not the normal use load; the shelter occupancy load is typically the controlling occupancy load. Chapter 8, Section 8.2, discusses the recommended square footage requirements for tornado and hurricane shelters.

Guidance and requirements concerning fire protection systems may be found in the model building codes and the life safety codes. Depending on the occupancy classification of the shelter (in normal use), automatic sprinkler systems may or may not be required. For many shelters, an automatic sprinkler system will not be required. However, when automatic sprinkler systems are not required and fire extinguishers are used, all extinguishers should be mounted on the surface of the shelter wall. In no case should a fire extinguisher cabinet or enclosure be recessed into the interior face of the exterior wall of the shelter. This requirement is necessary to ensure that the integrity of the shelter walls is not compromised by the installation of fire extinguishers. Finally, any fire suppression system specified for use within shelters should be appropriate for use in a closed environment with human occupancy. If a fire occurs during a tornado or hurricane, it may not be possible for occupants of the shelter to ventilate the shelter immediately after the discharge of the fire suppression system.

7.5 Permitting and Code Compliance

Before construction begins, all necessary state and local building and other permits should be obtained. Because model building codes and engineering standards do not address the design of a tornado or hurricane shelter, the design professional should meet with the local code official to discuss any concerns the building official may have regarding the design of shelter. This meeting will help ensure that the shelter is properly designed and constructed to local ordinances or codes.

Complete detailed plans and specifications should be provided to the building official for each shelter design. The design parameters used in the structural design of the shelter, as well as all life safety, ADA, mechanical, electrical, and plumbing requirements that were addressed, should be presented on the project plans and in the project specifications.

Egress requirements should be based on the maximum occupancy of the shelter area. This will likely occur when the designer calculates the occupancy load based on the 5 ft^2 or 10 ft^2 per person recommended in Section 8.2 for tornado and hurricane shelters, respectively. For multi-use shelters, reaching the maximum occupancy will be a rare event. For life safety considerations, egress points for the shelter area should be designed to the maximum possible occupancy until a code or standard governing the design of shelters is developed. As a result, the design professional will likely have difficulty providing doors and egress points with hardware (specifically latching mechanisms) that comply with code and resist the design missile impact criteria presented earlier in this chapter. Design professionals who are limited to door hardware that is acceptable to the building official but that does not meet the impact resistance criteria should refer to Section 6.4.4 and Figure 6-8 for guidance on the use of missile-resistant barriers to protect doors from debris impact.

Regarding code requirements not related to life safety or structural requirements—typically those for mechanical, electrical, and plumbing systems—the designer should design for the normal use of a multi-use shelter unless otherwise directed by the authority having jurisdiction. It would not be reasonable to consider the additional cost of and need for providing additional mechanical, electrical, and plumbing equipment and facilities for the high-occupancy load that would occur only when the shelter is providing protection from a tornado or hurricane. Shelters designed to the criteria in this manual are for short-duration use, and the probability of their use at maximum occupancy is low.

NOTE

The square footage recommendations for shelters designed to meet the criteria presented in this manual are as follows:

Tornado shelters: 5 ft^2 per person

Hurricane shelters: 10 ft^2 per person

These square footage recommendations are discussed in Section 8.2.

7.6 Quality Assurance/Quality Control Issues

Because a tornado or hurricane shelter must perform well during extreme conditions, quality assurance and quality control for the design and construction of the shelter should be at a level above that for normal building construction. Design calculations and shop drawings should be thoroughly scrutinized for accuracy. When the design team is satisfied that the design of the shelter is acceptable, a registered design professional should prepare the quality assurance plan for the construction of the shelter.

The quality assurance plan should be based on the Special Inspection Requirements listed in Sections 1704, 1705, and 1706 of the IBC; however, because of the design wind speeds involved, exceptions that waive the need for quality assurance when elements are prefabricated should be not allowed. The IBC recommends using these special inspections and quality assurance program when the design wind speeds are in excess of 110–120 mph (3-second gust), depending on exposure or if the building is in a high seismic hazard area. Sufficient information to ensure that the shelter is built in accordance with the design and the performance criteria of this manual should be provided by the design professional. The quality of both construction materials and methods should be ensured through the development and application of a quality control program.

A typical quality assurance plan should require that special inspections be performed on the following building elements:

- roof cladding and framing connections
- wall-to-roof connections and wall-to-floor connections
- roof and floor diaphragm systems, including framing, collectors, struts, and boundary elements
- vertical and lateral MWFRS, including braced frames, moment frames, and shearwalls

- connections of the MWFRS to the foundation
- all prefabricated elements and their connections to other shelter components during on-site assembly
- fabrication and installation of components and assemblies required to meet the missile impact resistance requirements of this chapter

To ensure that the elements described above are properly inspected, the quality assurance plan should identity the following:

- the elements and connections of the MWFRS that are subject to inspection
- the special inspections and testing to be provided according to IBC Section 1704, including the applicable references standards provided referred to in the IBC
- the type and frequency of testing required
- the type and frequency of special inspections required
- the required frequency and distribution of testing and special inspection reports
- the structural observations to be performed
- the required frequency and distribution of structural observation reports