The Geology of the Hudson River and Its Relation to Bridges and Tunnels

BY

GEORGE FREDERICK KUNZ, Ph.D., Sc.D.

APPENDIX B.

THE GEOLOGY OF THE HUDSON RIVER AND ITS RELATION TO BRIDGES AND TUNNELS.

By George Frederick Kunz, Ph. D., Sc. D.

THE GEOLOGY OF THE HUDSON RIVER AND ITS RELATION TO BRIDGES AND TUNNELS.

By George Frederick Kunz, Ph. D., Sc. D.

Introductory Note.

During the past decade, the question of more adequate means of communication between New York City and New Jersey has been acutely raised, partly by the proposition to construct extensive railroad and freight yard accommodations on the margin of Riverside Park, and partly by the development of the City, which calls for more adequate avenues for the transportation of freight and passengers across the Hudson River. With the commercial side of the question, the American Scenic and Historic Preservation Society is not directly concerned, its chief interest being in preserving, so far as possible, the scenic aspects of the river at New York. Whatever will most quickly and effectively remove the menace to the beautiful Riverside Park, therefore, is a thing to be desired, and in the following paper, the writer has aimed to point out what he believes to be the best way to accomplish that end.

For the geological and economic reasons hereafter stated, he is of the opinion that tunnels under the river afford such form of relief. This does not mean that he is opposed to bridges if they can be built,* for bridges can be made beautiful and monumental structures and need not necessarily disfigure the landscape. Indeed, there may be both bridges over and tunnels under the Hudson River as there are over and under the East River; yet the writer believes that the facts hereafter stated are worthy of consideration. The main object to be attained is quick relief for the congestion of population and traffic and the preservation of the picturesque river front of Riverside Park.

---

* The statement that there would be no bridge over the Hudson River near New York City was made by the present writer before the New York Academy of Sciences, Oct. 5, 1910.

I.

THE GEOLOGY OF THE HUDSON RIVER.

All the rocks of the Atlantic States have a general course, or "strike," approximately N. E. and S. W., parallel to the folds and ridges of the great Appalachian mountain-system which determines the geographical structure of eastern North America. Across these belts of rock, differing greatly in character and age, the drainage of the Atlantic slope makes its way to the sea, in a series of rivers whose prevailing course is from N. W. to S. E., or in some cases nearly north and south. Of the latter, the most important channels are the Hudson and the Connecticut; and it is of the first of these that we here propose to speak.

The early explorers called it "The Great North River," as contrasted with its next neighbor to the southwest, the Delaware, which was correspondingly termed "The Great South River." This last name has been little used and is almost forgotten, while the term North River is still much employed locally, in distinction from the name East River used for the tidal channel between New York and Long Island. But the name of its great discoverer has become that of the noble stream and is fixed in history, geography and literature; although in poetry and romance it is occasionally referred to under its aboriginal name of the Shatemuc.

For a long distance in its upper valley, above the gorge of the Highlands, the Hudson River flows almost due south, a little east of, and parallel to, the 74th meridian. Thence onward to New York City, the river follows the same general direction, but in a succession of marked variations and angles, determined by the geological character of the rocks which it traverses.

In its upper valley, the Hudson cuts for the most part obliquely across the strike of a great series of sedimentary rocks, mainly sandstones and shales, the latter more or less altered into slates of Palaeozoic age — Cambrian, Ordovician and Silurian. Of this portion we do not propose to speak, as this paper is concerned with the gorge of the Hudson from the Highlands southward, in relation to the great new aqueduct, and especially to the problems of bridging or tunneling the river near the City of New York.

As seen from the water, or from the railroad on either side, the Highlands appear as a lofty range of precipitous hills stretching up from the southwest to the northeast and crossing the river in a succession of imposing ridges rising steeply from the water to heights of some 1,500 feet. These are the northern end of the great line of mountains which extends over one thousand miles as the eastern member of the Appalachian system, and is known as the South Mountain in Pennsylvania and the Blue Ridge in Virginia.

This aspect, however, is somewhat deceptive. Instead of being a true mountain range, the Highlands are now regarded as more properly the eastern border of a great elevated plateau, carved out by erosion into ridges, peaks and valleys. This view, originated by Prof. William M. Davis and J. W. Wood, Jr.,* regards the whole mountainous area — when seen and studied from any point of elevation — as an ancient dissected peneplain, an area once worn down to an almost level surface through ages of erosion, and brought nearly to the level of the sea, but afterward raised and carved out by subsequent erosion into its present diversified contour.

The Highlands are composed of hard, highly crystalline and very ancient rocks, granitic and gneissic in character and of Archæan Age. The period in which they were leveled down to a peneplain is referred by some of our best authorities to the later Mesozoic age, coinciding with the Cretaceous.† Then began a new phase in the history of the river — an elevation of the whole region, with the carving out of the present system of hills and the excavation of the great valley of the Hudson. This coincides with the Cænozoic (Neozoic or Tertiary) Age of geologic time. Toward the close of this period, the elevation continued or was renewed, and went far above that of the present time, until the whole Atlantic seaboard (not to speak of regions further inland) was greatly uplifted, and the coast-line far extended to the east. As a consequence, the channel of the Hudson — as of all the

---

* Proc. Boston Soc. of Nat. Hist., xxiv, 365, 1890; xxv, 318, 1892.

† Kemp, J. F., Amer. Jour. Sci. (4) xxvi, 301, Oct. 1898.

streams of the Atlantic slope — was cut down far below the present bed of the river, into a deep and narrow gorge, subsequently filled up with later deposits, as we find now.

These latter phases, of great elevation and erosion, and then of depression and re-filling, belong to the latest of the geologic ages — the Quaternary (Pleistocene or Post-tertiary), and correspond in a broad and general way to the periods termed in the text-books Glacial and Champlain, respectively.

As a consequence of this succession of events, we find the Hudson River now flowing for the most part in a wide valley, excavated in Tertiary time; while within and beneath this lies a deep and narrow gorge excavated in early Quaternary (Pre-glacial and Glacial) time, which has been filled up with deposits in later Quaternary (Champlain) time. This last is the so-called " buried channel " of the Hudson. Thus the river now flows in a valley of its own formation, indeed, but at a level far above that to which it had cut down in the Glacial Period. The river-bed consists of soft deposits of late Quaternary origin, and the bed-rock lies beneath these at much lower depths. The bearing of these facts on the question of bridging or tunneling the Hudson River is of the utmost practical importance; and this paper aims to present these conditions, as now clearly brought to view, and to consider their meaning and indications.

Beyond the present mouth of the Hudson, and the bay and harbor of New York, it is of great interest to find that the old channel, belonging to the early Quaternary Period of elevation, is traceable far out to sea, first as a depression, and then as a veritable canyon deeply cut in the steep descent from the off-shore plateau down the slope of the " continental shelf." No other possible cause is known, or can be assigned for such a remarkable phenomenon, than a great elevation of the land above its present relation to the sea; and it coincides precisely with the fact already noted, that the Hudson valley of to-day has beneath it a deeply cut channel in the rock. No stream can possibly erode its bed below that of the body of water into which it discharges. Its eroding power depends upon its velocity, and its velocity is lost as it enters the sea, or lake; it then begins to deposit sediment and to form bars and deltas, instead of wearing its bed to a greater depth.

Nor is this feature peculiar to the Hudson. Similar submerged channels are found to extend a long way eastward from the mouths of all the important water-courses of the Atlantic slope, showing that the whole relation of land and sea was widely different from what it is now. The shore in early Quaternary time lay far out, at the actual edge of the continental plateau, and the rivers flowed across this now submerged border or "shelf," then a wide stretch of lowland, and carved out deep canyons when they came to the steep descent toward the ocean depths beyond.

A submerged channel of the Hudson, extending some eighty miles southeast from New York harbor, was first distinctly recognized by the late Prof. James D. Dana, as long ago as 1863, if not even earlier.* The United States Coast and Geodetic Survey, through Mr. A. Lindenkohl, followed up the investigation of it, with careful observations and soundings, and developed a much fuller knowledge of the subject in 1885,† and later in 1891.‡ Prof. Dana's data were few and imperfect, but Mr. Lindenkohl's work showed a canyon in the edge of the continental shelf, fifty miles off Sandy Hook, with the surprising depth of 2,400 feet below the general sea-bottom, there some 400 feet deep.

Between these two last-named dates, the general facts had been given to the public by the late Prof. J. S. Newberry, in the *Popular Science Monthly*,§ and also by Prof. D. S. Martin, in his Geological Map of New York and Vicinity. Both these publications appeared in 1888, though the latter was announced in 1887, as including this feature. Prof. Newberry's article gave a full and vivid presentation of the conditions indicated by the old channels, with a map of the submerged valley, and an ideal view of the lofty hills past which the Hudson then flowed where now are Manhattan and Staten Islands. A general statement of the facts as then recognized was given by Prof. Martin in the pamphlet accompanying his map,¶ in the following words:

"The existence of a great submerged valley reaching from the mouth of the Hudson nearly a hundred miles southeast to the edge

---

* Manual of Geol., 1st ed., 1863, p. 441.

† Amer. Jour. Sci. xxix, 475, 1885; (and embodied in Coast Survey Chart, No. 8a, elsewhere referred to.)

‡ Amer. Jour. Sci., xli, 489, 1891.

§ Pop. Sci. Mon.

¶ Privately printed, with the map, 1888.

of the 'continental plateau,' has been known and referred to somewhat, as one of the most marked evidences of great elevation of the land in the Glacial Age. Only the northwestern end of this valley lies within the field of the map, but enough appears to give some idea of its position and character. Its course is at first nearly north and south, but further on it turns more to the eastward; and the beginning of this turn can be seen at the lower edge of the sheet. All the evidence goes to show that before and during the Age of Ice, the whole northern part of the continent stood far above its present level; all the rivers and streams within the drift-covered area having cut their valleys down into the country-rock far below the present level of the ocean and the Great Lakes. At that time, as shown by Newberry, Manhattan Island was a lofty, rugged promontory, with the rivers on either side flowing in deep canyons or gorges to meet in what is now the Bay; that there a mighty stream was formed by the union of the Hudson with the rivers of New Jersey on the west, and with a river from the east that drained southern Connecticut and probably included the Housatonic; and that this combined body of water, after passing lofty hills where are now the islands and shores of New York Bay, flowed a hundred miles southeast through a low and level region, to reach the ocean. The channel of that great river is marked on our charts by this line of deeper soundings.

"The subsequent Champlain depression gradually carried the whole region below the present level, and has left the elevated beaches and stratified drift, which attest its reality and mark its bounds. The deep-cut river channels were filled up with drift-deposits, as is the case through most of the Northern States.

"The rise that followed in the Terrace Age, was marked by the partial re-cutting of their valleys by the rivers; but this work was done in the stratified filling, and does not reach at all down to the older and lower rock-channels. As an instance of this fact, it may be noted that the proposed Hudson River tunnel from Jersey City to New York is carried through hard clay with common marine shells, semi-fossilized, and nowhere touches the deeply-buried ancient rock-bottom.*

"The deep-sea soundings are enlarged from the Coast Survey Chart No. 8a, of the Approaches to New York Harbor, on which is shown with great beauty the long reach of the deep submerged valley that marks the glacial and pre-glacial channel of the Hudson, far out to sea. The limits of the present map include only the extreme northwestern portion of this remarkable depressed line, and so can furnish but a very inadequate idea of its striking extent."

---

* This was the so-called Morton Street tunnel, then in progress.

These announcements were followed by the second article of Mr. Lindenkohl already referred to, in 1891; and subsequently by the studies of Dr. J. W. Spencer, which greatly enlarged our conceptions of the subject. Dr. Spencer brought out and combined the whole body of observations as to the rivers of the Atlantic slope and their ancient sea-covered channels, showing the continental scale of the uplift, and moreover traced the depressed lines to far greater depths than had before been supposed, showing the elevation to have been enormous. The Hudson canyon at the edge of the continental plateau he finds to have reached the extraordinary depth of 9,000 feet. These remarkable studies, appearing in a number of articles, he summed up in 1905.*

Subsequent discussions relating to this subject have appeared in the Bulletin of the New York State Museum, No. 84, pp. 71, 72, 1905, by J. B. Woodworth, and in the *Scientific American*, Supplement, 1908, by H. W. Pearson. In these, attempts are made to avoid the difficulty of conceiving so great a land-elevation, by invoking other agencies; but the evidence of the entire system of eroded channels extending from the river-mouths of the present time across the shore plateau, and as canyons down its edge, is apparently complete and conclusive.

As to a deflection of the Hudson channel back of Hoboken: Berkey has shown that the great angular bend of the East River, from about 25th Street down to Corlears Hook is due to a deflection of the river from its normal course in the line of strike of the rocks, doubtless due to a filling-up of its old channel by glacial drift, and that it "now flows across perfectly sound rock at a much greater elevation than the channel it once occupied." †

It is remarkable to notice how exactly the course of the Hudson River is deflected in the same southerly direction at a corresponding point. At about the line of 25th Street the course of both rivers is changed; while Manhattan Island bends in the same way, preserving about the same width, with its two shore lines keeping parallel to each other. Has the Hudson also been similarly deflected?

---

*Amer. Jour. Sci., Jan. 1905, pp. 1-15.

† "Areal & Struct. Geology of Southern Manhattan Island.", p. 282. Ann. N. Y. Academy of Sci., vol. xix, No. 11, 1910.

Just above the bend, the Bergen Ridge recedes somewhat toward the west, and then continues southward as Hoboken Ledge, with lowland east of it opening to the river, and then the serpentine and arkose elevation of Hoboken, south and east. The *map* affords a strong suggestion that either the Hudson or a part of it may have followed the base of the trap-ridge below this point, as it does above, leaving Hoboken an island, and emerging into the Upper Bay, somewhere about Communipaw, or else breaking through westward into Newark Bay (?)

All this, however, is theoretical entirely. No deep channel is now traceable back of Hoboken; all is filled up with shallow deposits. Extensive boring exploration would be necessary, under Hoboken and Jersey City, to furnish anything like proof.

That all rivers or tributaries contiguous to the ocean, or bodies of salt water where there is a tide, should be affected by the deposition of silt, is due to the chemical phenomenon that when salt water and water containing any sediment, whether sand, sewage, or otherwise, mingle, whatever is present in the water is deposited. Therefore, the amount of silt deposit is dependent upon the amount of fine matter, sand, or sewage existing in the water itself. At the mouth of every sewer the deposition of this material is greater than in the river itself.

The amount of such deposits depends to a great extent upon whether there is the regular average flow of water along the course of streams such, for instance, as the Peekskill or Esopus creeks or Sprout Brook, or whether these streams are in an abnormal condition, resulting from a spring freshet or an autumn storm. In this latter case there is often an exceptionally great deposit of sand, just as in a mill-dam, in ordinary times, there may be a deposition of various materials but usually of mud, while in times of storm a great quantity of sand is deposited in the course of a day or two. However, the deposition is much more rapid when fresh and salt water come into contact.

In the Hudson River we must take into account that one century of sewage has had time to be deposited there, and that since, as a result of the progressive deforestation of the hills and banks of this river a greater amount of silt and firm soil is now brought into it than ever before.

The great depth of the silt in the bed of the Hudson is shown by the result of borings made in the river at Storm King Mountain, in connection with the work on the new aqueduct. Here ledge-rock was first struck at 608.6 feet below the bed of the river, in the case of a boring made 800 feet from the east shore. Even at but 300 feet from the shore rock was only reached at a depth of 201.4 feet.[*]

Another diamond-drill boring, made about 700 feet from the east shore and some 300 feet north of the boring mentioned above, met granite at a depth of 507 feet, while still another, near mid-stream, when at a depth of 626 feet was still in fine sand and clay. Toward the west shore the conditions are evidently similar, for a boring 700 feet from that shore failed to get through the boulders at 580 feet, thus showing that bed-rock lies still deeper.

Some ten miles north of Storm King at the Pegg's Point crossing, in a boring made 720 feet from the west shore, the diamond-drill encountered the slate at a depth of only 223 feet, and Prof. Kemp believes that, according to the results obtained at Storm King, there must be a deep and narrow gorge in the stretch of 1,040 feet separating this boring from another one made near the east shore.[†]

As in Prof. Kemp's opinion the river has always flowed down grade to the sea through the channel it now traverses, he concludes from the data secured at Storm King that the depth at which bed-rock lies toward mid-stream opposite Manhattan Island must be 700 feet or more. A geological section-chart published by Dr. Berkey shows that between Hoboken and the foot of Bank Street, Manhattan, there is an unexplored tract 1,100 feet in width, extending from about the middle of the river half-way to the east shore. Between this tract and the west shore, for a considerable distance, rock is first met with at a depth of nearly 300 feet.[‡]

The evident fact that nowhere in the bed of the Hudson, between Storm King and the ocean, is there anything but silt, and

---

[*] Second Annual Report of the Board of Water Supply of the City of New York, 1907, p. 97.

[†] Kemp, J. F. "Buried channels beneath the Hudson and its tributaries." Am. Jour. Science, Fourth Series, vol. xxvi, No. 154, October, 1908, pp. 317-323.

[‡] Berkey, Charles P. "Areal and structural geology of Southern Manhattan Island." Annals of the New York Academy of Sciences. Vol. xix, No. 11, Pt. 11, pp. 247-282. Published April 21, 1909. See also J. Partsch "Die Neue Wasserleitung von New York und ihr Hudson-Tunnel," Zeitsch. d. Gesell. f. Erdkunde Zu Berlin, 1913, No. 5.

that this extends downwards to a great depth, constitutes an almost insuperable obstacle to the erection of a mid-stream pier and seems to indicate that we can never have a Hudson River bridge, unless the river be covered with a single span. This form of construction, although theoretically practicable, would entail enormous expense, as at no point where it has been proposed to build a bridge is the river less than three-quarters of a mile in width.

The foregoing general outlines lead us now to the practical aspects which it is the aim of this paper to present. The enormous growth of the City of New York of late, in commerce, manufacture and population, has made absolutely necessary the opening of new and much readier means of transit across the Hudson River. Three separate lines of tunnels have already been completed and opened; and there have also been various projects for the construction of magnificent bridges from shore to shore. It appears, however, that any hope of these is probably barred by the geological conditions. The existence of the deeply cut channel or gorge precludes the possibility of obtaining secure foundations for mid-river piers; while the width of the river is so great that no single-span structure is possible.

The following records of borings are given by William Herbert Hobbes:*

On or near Dock Line. — Hudson River.
[United States Datum] — New York Department of Docks.

No.				
149	Foot	Charlton St.	90′	Nothing as to *kind* of rock, merely "*to rock.*"
150	"	Houston St.	90′	Ditto.
151	"	Leroy St.	90′	"
152	"	Morton St.	100′	"
153	"	Barrow St.	124′	"
154	"	Perry St.	100′	"
155	"	Perry (extended)	150′	"
156	"	11th St.	60′	"
157	"	Bank St.	100′	"
158	"	Bethune St.	95′	"
159	"	12th St.	85′	"
160	"	Horatio St.	110′	"
161	"	22nd St.	180′	"
162	"	23rd St.	175′	"
163	"	26th St.	170′	"
164	"	35th St.	152′	"
165	"	36th St.	105′	"

(Above, and below, depths are less.)

---

* Nos. 149 to 1411, from his study "The Configuration of the Rock Floor of Greater New York," Washington, 1905, pp. 36-92.

DOCK LINE.

On or near Bulkhead Line. NEW YORK DEPARTMENT OF DOCKS.

[United States Datum]

No.			
189	Charlton St.	89′	Mica schist.
190	Leroy St.	88′	" "
191	Christopher St.	126′	" "
192	Bethune St.	160′	Granite 10′ west of pier.
193	13th St.	198′	*No rock*,—last, sand. 20′ west of bulkhead line.
194	23rd St.	177′	Granite.
195	30th St.	152′	Granite.

Other data, same source.

223 Foot of 132d St., 75 ft. west of pier end. 115′ Rock or b'lder.
222 Foot of 132d St., 200 ft. west of pier end. 130′ Rock or b'lder.
225 Foot of 158th St., 200 ft. west of Bulkhd line. 81′ Rock or b'lder.
922 Riverside Viaduct, 127th to 135th (all). *No rock* to 60′
and Riverside Viaduct, 131st & 12th Av. *No rock* to 75′.
923-928 Manhattan Viaduct, Broadway, 125th to 130th. *No rock* to slight depths.
929 Same near 131st St. Gneiss at 39′.
930 Same 131st to 133rd St. Gneiss at 38′ to 59′.
581 Bulkhead line at 32nd St. ("D-1"). Gneiss at 116′.

MCADOO TUNNEL, MORTON ST. TO 15TH ST., J. C.

CHARLES M. JACOBS, CHIEF ENGINEER.

From Borings.

[United States Datum.]

No.					Interval
250	515′ W. of "wall"	(Morton St.)	105′.	Rock or boulder.	515′
249	660′ W. of "wall"		80′.	Rock or boulder.	145′
248	800′ W. of "wall"		82′.	Rock or boulder.	140′
247	830′ W. of "wall"	(omitted on map)	76′.	Rock or boulder.	30′
246	960′ W. of "wall"		82′.	Rock or boulder.	130′
245	1030′ W. of "wall"		90′.	Rock or boulder.	70′
244	1120′ W. of "wall"		93′.	Rock or boulder.	90′
243	1215′ W. of "wall"		95′.	Rock or boulder.	95′
242	1260′ W. of "wall"		94′.	Rock or boulder.	45′
241	1380′ W. of "wall"		96′.	Rock or boulder.	120′
240	1480′ W. of "wall"		98′.	Rock or boulder.	100′
239	1570′ W. of "wall"		99′.	Rock or boulder.	90′
238	1640′ W. of "wall"		100′.	Rock or boulder	70′
237	1730′ W. of "wall"		105′.	Rock or boulder.	90′
236	1950′ W. of "wall"		154′.	Unknown obstruction	180′

(Distance from No. 236 to New Jersey shore, or location thereof on New Jersey shore, not stated.)

"Wall," as above used, apparently refers to New York bulkhead line. Greatest depth at New Jersey end, No. 236.

PENN., N. Y. & L. I. TUNNEL (33RD ST.)

NOBLE & JACOBS, CHIEF ENG'RS.

From Borings.

[United States datum]

No.		Interval.
262	3100′ E. of Weehawken pierhead line 149′ r'k or b'ld'r...	200′
261	2900′ E. of Weehawken pierhead line 183′ r'k or b'ld'r...	200′
260	2600′ E. of Weehawken pierhead line 255′ r'k or b'ld'r...	300′
259	2300′ E. of Weehawken pierhead line 269′ r'k or b'ld'r...	300′
258	2000′ E. of Weehawken pierhead line 274′ r'k or b'ld'r...	300′
257	1650′ E. of Weehawken pierhead line 268′ r'k or b'ld'r...	350′
256	700′ E. of Weehawken pierhead line 255′ r'k or b'ld'r...	950′
255	300′ E. of Weehawken pierhead line 237′ r'k or b'ld'r...	400′
254	200′ W. of Weehawken bulkhead line 129′ r'k or b'ld'r..	
253	Weehawken pierhead line 221′ gneiss.......	300′ (255 to 253)
252	750′ W. of Weehawken bulkhead line 93′ gneiss.......	550′ (254 to 252)
151	850′ W. of Weehawken bulkhead line 13′ gneiss.......	100′

The last three borings by drill; others "wash-borings."
Greatest depth to rock (or boulder) at No. 258,-274′.
Gap of 950′ between 257 and 256. (Room for cañon.)
Nos. 251 and 252 hardly in the *river*.

Length and relation of Weehawken pierhead and bulkhead lines not being known, the intervals from 255 W. are not exact.

LINE OF PROPOSED BRIDGE AT 59TH STREET.

CH. MACDONALD, ENG. NEWS, 33, 1895.

Wash Borings.

[United States Datum]

No.		Interval
263	460′ E. of N. Y. bulkhead 1, 28′ rock or boulder.	910′
264	450′ W. of N. Y. bulkhead 1. 123′ rock or boulder.	
270	2000′ E. N. J. bulkhead 1. 300′ rock or boulder.	?
269	1200′ E. N. J. bulkhead 1. 251′ rock or boulder.	800′
268	700′ E. N. J. bulkhead 1. 190′ rock or boulder.	500′
267	200′ E. N. J. bulkhead 1. 123′ rock or boulder.	500′
266	100′ W. N. J. bulkhead 1. 115′ rock or boulder.	300′
265	880′ W. N. J. bulkhead 1. 58′ rock or boulder.	780′

These had to be re-arranged, to give a continuous line from east to west. Only No. 264 and Nos. 266-270 are properly in the river.

Greatest depth at No. 270, 300′.
Gap of 800′ between 270 and 269,— room for a cañon.
Interval between 270 and 264, unknown.
No. 1422, Weehawken, pier No. 7, no rock at 118′.

Eng. Record, v. 44, 1901, p. 260.

(Could not locate on map.)

HOBOKEN WATER-FRONT,

HOBOKEN LAND & IMPROVEMENT CO.

(Probably *wash*-borings, though not stated.)

[United States Datum]

No.		
1357	Pier foot Newark St., 132′ rock or boulder	The uncertainty as to rock or boulder shows these to be wash-bores.
1358	Pier foot 1st St., 134′ rock or boulder	
1359	2nd St. shore end, 47′ rock or boulder	
1360	2nd St. pierhead, 139′ rock or boulder	
1361	Pier betw. 2d & 3d at dock, 39′ rock or boulder	
1362	Ditto at pierhead, 134′ rock or boulder	
1363	Dock ft. 3rd St., 140′ rock or boulder	
	Then slight or moderate depths to	No. 1359, average of 4. No. 1361, average of 2. No. 1380, average of 2.
1374	Pier ft. 11th St., 73′ rock or boulder	
1376	Pier N. of 11th St., 93′ rock or boulder	
1377	Dock line, bet. 12th & 13th, 77′ rock or boulder	
1380	Dock line, bet. 13th & 14th, 77′ rock or boulder	
1385	Dock line, at 16th produced, 84′ rock or boulder	

(Could not locate on map.)

JERSEY CITY.

RUSSELL, ANN. N. Y. AC. SCI., II, PP. 76, 77.

From a point (No. 1416) at 9th and Henderson St.—

No.

1408. Pavonia Ferry, 2300′ E., 63′ Serp.
1409. Pavonia Ferry, 2850′ E., 120′ Serp.
1410. Pavonia Ferry, 3300′ E., 179′ Serp.
1411. 1450′ E. of Green St., on a line half way between 2d and 3rd Streets (produced).

(Could not locate on map.)

In 1910, under the direction of the New York Interstate Bridge Commission, a number of experimental borings were made in the bed of the Hudson from about the foot of 179th Street and also from the foot of 109th Street. At the first-named point nineteen borings were made, nine of them at a proposed site for a mid-stream pier, the others being in a continuous line to the New Jersey shore. The borings were all carried down 150 feet. Only near the New Jersey pier head line was rock met with, in this case at a depth of 80 feet below high water. Opposite 109th Street rock was struck 140 feet below high water at the New York pier head line and 97 feet below at the New Jersey pier head line. The mid-stream borings all failed to find rock within 150 feet from the river bottom, this being as far as the borings were carried down. Borings on a line midway between Fifty-ninth Street and Sixtieth Street, made in 1894 for the New York and New Jersey Bridge Company showed no hard bottom outside the pier head line at a less depth than a somewhat doubtful record of 222 feet below high water, other borings indicating a minimum depth of 296 feet.*

Wash-Borings for Proposed Bridge at 109th Street.

Boller & Hodge, Cons. Eng'rs.

[*Probably* calculated from high-water line, but no datum given as to water-level.]

Three sets of borings, for an E. center, and W. pier. Each set was numbered separately, 1, 2, etc., and here are marked E., C., and W., with the No.
The first three on a N-S line at pierhead; 635′ W. from shore.

Nos. E-4. N. Y. pierh. 1. 56′ water + 83′, 10″ mud = 139′, 10″ to rock.
Nos. E-5. N. Y. pierh. 58′, 6″ water + 84′ mud = 142′, 6″ to rock.
Nos. E-6. N. Y. 59′, water + 81′, 7″ mud = 140′, 7″ to rock.
Nos. C-3. 1575′ Wd. from last. 38′, 6″ water + 150′ in mud, no rock at 188′.
(No No.) 600′ Wd. from last.) 24′ water + 150′ in mud, no rock at 174′.
(No No.) 500′ Wd. from last. 20′ water + 150′ in mud, no rock at 170′.
Nos. W-2. 575′ Wd. at N. J. pierh. 6′ water + 90′ mud = 96′ to rock.

The borings above specified are the only ones actually sunk. Intervals as follows:

N. Y. shore to pierhead line, 625′ — (at 109th St.) E-4, 5, 6.
N. Y. shore to C-3 — 2210′; E-4 to C-3 — 1575′ interval.
N. Y. shore to W-2 — 3885′; C-3 to W-2 — 1675′ interval.
N. Y. shore to N. J. shore 4915′; W-2 to shore 1030′ interval.

Width from shore to shore, 4915′.
Wide intervals between bores.
No rock most of the way at 170′ to 190′.

Wash-Borings for Proposed Bridge at 179th Street, Fort Washington to Fort Lee. For N. Y. and N. J. Interstate Bridge Commission.

Boller & Hodge, Cons. Eng'rs.

Calculated from "high-water line," but no standard given. From rock-shore at each side.

No. 1. 1300′ W. of N. Y. shore, 40′ water + 150′ mud, no rock 190′.
No. 2. 1400′ W. of N. Y. shore, 40′ water + 150′ mud, no rock 190′.
No. 7. 1400′ (100 N. of 2)
No. 8. 1400′ (100 N. of 7)
identical in all respects. No rock 190′.
No. 11. 1700′ W. of N. Y. shore, 39′ water + 150′ mud, no rock 190′.
No. 12A. 200′ W. of N. Y. shore, 27′ 6″ water + 150′ mud, no rock 177′.
No. 14. 2200′ W. of N. Y. shore, 25′ water + 150′ mud, no rock 175′.
No. 15A. 2500′ W. of N. Y. shore, 21′ water + 150′ mud, no rock 171′.
No. 17. 2800′ W. of N. Y. shore, 19′ water + 150′ mud, no rock 169′.
No. 19. 3200′ W. of N. Y. shore, 13′ water + 67′ 1″ to rock.

---

* Fourth Report of the New York Interstate Bridge Commission to the Legislature of the State of New York, Session of 1911, Albany, 1911, pp. 9, 10; Plates I-III.

Add 200′ to shore at Fort Lee, and the total width at this narrowest point is 3400′.

One bore, but not stated which, was sunk in mud to 170′ without reaching rock, a depth from surface of + 200′.

Rock shelves steeply from New York shore, and forms the bottom at 150′ for about 1000′ W'd, when the mud begins to cover it. Obs. the steady shallowing of the mud (and sand) bottom W'd to the New Jersey shore. Rock 150′ deep on New York side, and then lost to + 200′ most of the way across.

B. H.	179th St. 2½ m.	8 bores, 150 feet in mud, save last W., which was 67 feet to R. (200 feet east of Palisade Park).
B. H.	109th St. 2½ m.	5 bores (E^{n} and W^{n} to R, 83 feet and 91 feet). 3 between,— 150 feet in mud only.
H.	59th St. 1¼ m.	5 bores between bulkheads 264, 267, 270, 123 — 300 feet to R or B. (?) E. 7 W.
H.	33rd St. 2 m.	8 bores between pierheads 255-262, 149 — 237 feet to R. or B. (?) W. 7 E.
N.	Morton St.	15 bores between bulkheads 236-250, 76 — 154 feet to R. or B. (?) W. 7 E.
B	Governors Is.	Well. n. hosp. — 60 feet to Manh. Sch. (pen^{d} 1725) 288. Well. Ft. Col. — 350 feet and no R. 289.

An attempt made to secure artesian well-water on the site of the new Woolworth Building at Broadway and Barclay Street, illustrates the great depth of solid rock at this point. The fact that an artesian well had been somewhat successfully sunk in the United States Post Office Building on the opposite side of Broadway, although with no great flow of water, seemed to promise well for the success of this work in the case of the Woolworth Building. However, although to a depth of thirty feet the usual surface drainage was present, the boring was carried down 1,574 feet without encountering anything but solid rock, and the attempt was finally abandoned. Possibly if a few sticks of dynamite had been exploded at the extreme depth, the surrounding rock might have been so shattered and fractured as to tap some subterranean water source.

II.

BRIDGES IN RELATION TO THE HUDSON RIVER.

Some years ago, the proposal to erect bridges across the Hudson River at several points between the upper part of Manhattan Island and the New Jersey shore was actively discussed, and plans were prepared for such structures. But more recently the successful construction of tunnels has been accomplished, while the difficulties in the way of bridge erection have come to be recognized; so that of late little has been heard of the latter project, and attention is being more and more directed to the former. Thus far, however, the tunnels opened have been made only for railroad cars. These are already introducing great changes and accommodating passenger travel on an extensive scale but there remains a vast and ever-increasing amount of freight and automobile traffic which is still dependent upon the ferries and liable to all the delays and interruptions of bad weather during the winter months. To meet this demand, either bridges or tunnels must be provided; the former involves great difficulties, even if possible at all, and their cost would be enormous; while tunnels can be built at far less expense — several, indeed, for the cost of a single bridge.

It is proposed in this section to present briefly a sketch of the several bridge-projects a few years ago under consideration. In the next section we will give an account of the three tunnel systems now in operation; and descriptions of plans for larger tunnels to be used for freight and automobiles, as now the next step in advance.

The New York Interstate Bridge Commission, for the systematic examination of the whole subject of trans-Hudson communication, was organized in 1906 and has done an enormous amount of careful and important work for the community, with judgment and economy. The President of the Commission, Hon. McDougall Hawkes, and his associates, are entitled to the gratitude of their fellow-citizens and to honorable recognition for their services.

In the attempt to bridge the Hudson the problem at once encountered is the breadth of the stream. With our present engineering experience, no bridge can be safely built with a single span exceeding three thousand feet. This is about double that of the suspension bridges over the East River to Brooklyn, and reaches the limit of security. The Hudson at New York exceeds this limit considerably even at its narrowest point. Supporting piers, one or more, between the ends of the span are therefore an absolute necessity, and these piers must of course rest upon rock. But the rock bottom lies so far down that it is impossible to use it for this purpose, on account of the enormous expense.

The narrowest part of the river within the City limits is at One Hundred Seventy-ninth Street, and plans were made and borings taken for a bridge at that point, from Fort Washington to Palisade Park, N. J. The Bridge Commission, in investigating that site, did so believing that the two banks of the river would act as supporting piers for the bridge, but even there it would be necessary to have intervening piers, as the width is a little over 3,900 feet.

Another investigation was made at a point some three and a half miles below, at One Hundred and Ninth Street, but here the width is 4,400 feet. Other proposed locations for bridges were at Fifty-ninth Street, Thirty-third Street, and Twenty-second Street. As the river widens below, no definite proposals have been made for bridge construction lower down.

For long bridges of single-span, two types alone are available — these being the suspension bridge and the so-called cantilever. A third type, known as the arched-rib, which is essentially a suspension bridge reversed, as shown by Prof. W. H. Burr in the Scientific American (Supplement No. 1252, December, 1899), while handsome and useful for many purposes, is less adapted to spans of very great length. The cantilever design has been employed in several noted structures, particularly the celebrated Forth bridge in Scotland, the finest example in the world; the ambitious but ill-fated Quebec bridge over the St. Lawrence river; and the Queensborough bridge from New York to Long Island. Of these, the first, built over the Firth of Forth by Sir Benjamin Baker, is constantly traversed by heavy railroad trains which pass over it without slackening their speed of fifty miles an hour, and has stood with perfect stability and security for over twenty years. It has a central pier, with two lateral spans of 1,710 feet, to the piers at either side.

The Quebec bridge was heralded as the longest of its kind in the world, having a clear span of 1,800 feet between piers — a central section being sustained by the cantilever arms on both sides. But, alas for human calculations! This structure collapsed under its own weight in August, 1907, falling in utter ruin before completion, with a loss of many lives. An elaborate investigation by the Canadian Government showed various defects in both the plan and the methods of construction.*

The immediate cause of the collapse, as determined by the Royal Commission appointed to investigate the matter, was "the failure of the lower chords in the anchor arm near the lower pier." The Commission found that this failure of the chords was neither due to the use of poor material nor to atmospheric conditions, but to defective design. Moreover, the unit stresses given were higher than any warranted by practical experience, and the dead load was estimated at too low a value. In the words of the report, "This error was of sufficient magnitude to have required the condemnation of the bridge even if the details of the lower chords had been of sufficient strength."

In conclusion the Commission state that in their opinion "the professional knowledge of the present day concerning the action of steel columns under load is not sufficient to enable engineers to economically design such structures as the Quebec Bridge. A bridge of the adopted span that will unquestionably be safe can be built, but in the present state of professional knowledge a considerably larger amount of metal would have to be used than might be required if our knowledge were more exact." †

As to any bearing upon the question of bridging the Hudson by a cantilever structure, it is enough to note that the entire length of this bridge was 2,800 feet, and the length of the main span 1,800 feet, the latter extending across the St. Lawrence, with two "anchor spans" of 500 feet on each side, from the shore to a main pier; while the narrowest part of the Hudson at New York, as already stated, is 3,900 feet, at Fort Washington.

---

* Royal Commission Quebec Bridge Inquiry, Report, Ottawa, 1908.

† Royal Commission's Report, p. 10.

It is true that at least one design was made for a cantilever bridge over the Hudson, of 3,100 feet span between piers; but this was only for comparison with a suspended structure of equal length, and showed that the latter would be much less heavy and less costly.

Several designs were made for suspension bridges in the years between 1896 and 1900, and a brief account of these may be given here, as matter of history.

The type employed in all these designs is that known as the "stiffened suspension" bridge, viz., a suspended structure with strengthening trusses extending along each side, to give greater rigidity and to distribute the strain of what is called the "live" or moving load, such as railroad trains, etc. The strains or stresses upon a bridge are of three principal kinds: (1) The actual weight of the structure itself, which is of course, constant, and vertical; (2) the effect of wind, which is chiefly lateral, and varies greatly in both amount and direction; and (3) the moving or "live" load, which likewise varies constantly, and also acts unequally at different points. The truss-work, although it adds very materially to the weight of the whole structure, tends nevertheless so much to equalize and distribute the stresses of the second and especially of the third class, that it is now employed in all, or nearly all, long suspended structures. It is usually carried along the line of the roadway, as well shown in the three suspension bridges over the East River, but may also be combined with the cables themselves, as a bracing connecting an upper and a lower set. This latter, known as the "trussed cable" type, may be developed in several ways, and was proposed in one or more of the designs for bridging the Hudson.

The board of engineers charged with the consideration of proposals for such structures, adopted for them a length of 3,100 feet, believing that suitable tower foundations could be obtained far enough out from each shore to make this the limit of the clear span.

One striking and beautiful design was that prepared by Mr. Gustav Lindenthal, the eminent bridge-builder, for a bridge from Twenty-second Street to Castle Point at Hoboken.* It had at

---

* Sci. Amer. Suppl't, No. 1252, Dec. 30, 1899, fig. 8, and Sci. Amer. Suppl't, No. 1253, Jan. 6, 1900, fig. 1.

the ends, 3,100 feet apart, two double towers, each curving upward from a spreading base, in the form of the Eiffel Tower at Paris. One system of truss-work extended, as in the Brooklyn bridges, along the roadway from shore to shore; while another was provided with the cables. These were double for their whole length, forming on each side two parallel curves one above the other, connected vertically by cross-bracing. Between the towers and the shore ends these trussed cables passed from above the roadway to beneath it, crossing the other system at this point, and then were carried on to the anchorages. This type of construction had already been used by Mr. Lindenthal at Pittsburg and St. Louis, and has been employed somewhat also abroad.

Another design was one that received the approval of the Secretary of War.* This had a simple cable system extending from the towers, which were 3,220 feet from center to center, and vertical suspenders carrying a horizontal roadway flanked by a large, high and powerful truss system 3,100 feet long. The trusses were not continuous, as in the Brooklyn bridges, or the Lindenthal design, but double — two joined at the center of the bridge. From the towers to the shore ends, about 1,000 feet, extended a smaller system of trusses, beneath the roadway, with three small supporting towers some 250 feet apart.

Another design, somewhat similar but with important differences, was prepared by Mr. George S. Morison, of the American Society of Civil Engineers.† Like the last, this had a simple system of four cables, sustaining a nearly horizontal roadway by vertical suspenders. But the truss system was different; it was not only continuous, but was made 1,000 feet longer than the span, being carried back 500 feet from each tower. The trusses were thus 4,100 feet long, their extremities resting upon small supporting piers, whereon they would be free to move in expansion and contraction, and there connected with a shore-span at each end in the form of a cantilever some 500 feet in length, supported, of course, on a small pier of its own. Mr. Morison laid much stress on the superior advantages of the continuous truss, as com-

---

* Sci. Amer. Suppl't, No. 1253, Jan. 6, 1900.

† Scientific American Suppl. No. 1001; Nov. 28. 1896.

pared with the double one hinged at the center, and on the cantilever connection at the ends.

A fourth design,* more like the second described, presented yet a different appearance. Four heavy cables, not in two sets as in the last, but about equidistant laterally sustained the roadway by vertical suspenders. But a striking aspect was given by the truss system; this was joined at the center, but instead of being parallel throughout, extended from tower to tower in the form of two low arches, rising to half the height of the towers at a distance midway from each to the center of the bridge. The light and lofty character of these arched trusses and the intersection of their upward curves with the catenary of the cables, presented a peculiarly elegant and graceful aspect.

Either of these designs, if carried out, would have yielded a beautiful and impressive structure, of magnificent proportions — a very triumph of engineering skill. A bridge of such unprecedented length, spanning so noble a river, would have been a matter of not only local but national pride. Its construction was desired and hoped for by many citizens of New York for years, but appears now to be improbable. It is not indeed impossible; but the cost of constructing foundations at the depth necessary to reach the rock is practically prohibitive. It has been calculated that such a bridge would cost from one to two hundred millions of dollars — a sum which would equal a tax of ten or twenty dollars on every man, woman and child in the States of New York and New Jersey.

Although not directly a Hudson River bridge, reference should be made here to the magnificent arch which is to cross Hell Gate to connect the Pennsylvania and New Haven railroad systems, instead of the long ferry trip around New York Island as now involved. From Long Island City to the Bronx is to extend a great steel viaduct over three miles long, crossing the islands and channels of the upper East River, and passing over Hell Gate by a bridge of 1,000-foot span, the largest arch in the world.† This noble structure was planned by Mr. Gustav Lindenthal, already referred to, and was approved by the Municipal Art

---

* Scientific American Suppl. No. 1252; Dec. 30, 1899, fig. 6.

† Scientific American, vol. xcvi, No. 23, June 8, 1907, p. 468.

Commission. The East River will thus be crossed by bridges representing the three types of construction — the "stiffened suspension" type in the Brooklyn, Manhattan, and Williamsburg bridges; the cantilever in the Queensborough bridge; and the "arched rib" type in the one at Hell Gate. At the shore-ends will be handsome massive towers of granite and concrete, between which will extend a very graceful but most powerfully built double arch of steel truss-work, 1,000 feet long, 140 feet high at the towers, and 40 feet high at the center. From this (truly a reversed suspension bridge, as Prof. Burr expresses it)* the roadway will be hung by suspenders, carrying the four tracks of the viaduct in a straight line about a hundred feet above the water.

The following table gives the principal data concerning the bridges over the East River:*

---

* Scientific American, Supplement, No. 1252, Dec. 30, 1899, p. 20,070.

* This table was furnished to the author through the courtesy of Hon. Arthur J. O'Keeffe, Commissioner of Bridges, April, 1913.

BRIDGES OVER THE EAST RIVER — GENERAL DATA.

	Brooklyn Bridge.	Manhattan Bridge.	Williamsburg Bridge.	Queensboro Bridge.
Type	Suspension	Suspension	Suspension	Cantilever
Length, river span	1595.5 ft.	1470.0 ft.	1600.0 ft.	1182 and 984 ft.
Length, main bridge	3455.5 ft.	2920.0 ft.	2793.0 ft.	3724.5 ft.
Length, Manhattan approach	1562-5 ft.	2067.0 ft	2650.0 ft.	1052.0 ft.
Length, Brooklyn approach	998.0 ft.	1868.0 ft.	1865.0 ft.	2672.2 ft. (Queens)
Width, over all	86.0 ft.	122.5 ft.	118.0 ft.	89.5 ft.
Tracks, elevated railway (or subway)	2	4	2	2 (Dec. 31, 1912)
Tracks, surface railway	2	4	4	4
Roadway	Two 16 ft. 9 in. wide	One 35 ft. 0 in. wide	Two 19 ft. 11 in. wide	One 53 ft. 3 in. wide
Footwalks	One 15 ft. 7 in. wide	Two 13 ft. 7 in. wide	Two 17 ft. 8 in. wide	Two 16 ft. 4 in. wide
Main trusses, height, c to c pins	17 ft. ¾ in.	24 ft 0 in.	40 ft. 0 in.	45 to 185 ft.
Main trusses, panel length	7 ft. 6 in.	18 ft. 1 3-16 in.	19 ft. 11 in.	43 to 80 ft.
Elevation above M. H. W.—cable at tower	+272.0	+322.5	+333.0	+323.0 (top chord pin)
Cables, number of wires	5,296	9,472	7,696	....
Cables, diameter, each wire	0.165 in.	0.192 in.	0.192 in.	....
Cables, total diameter	15.75 ft.	21.25 in.	18.625 ft.	....
Cables, length c to c anchorage pins	3578.5 ft.	3224 ft.	2985 ft.	....
Total steel in main bridge	11,920 tons	41,680 tons	28,700 tons	54,200 tons
Total steel in Manhattan approach	10,200 tons	8,150 tons	10,500 tons	6,000 tons
Total steel in Brooklyn approach		7,620 tons	6,085 tons	13,600 tons (Queens)
Total masonry, main piers	85,160 cu. yds.	79,600 cu. yds.	45,500 cu. yds.	53,000 cu. yds.
Total masonry, anchorages	56,620 cu. yds.	228,500 cu. yds.	112,800 cu. yds.	
Cost of construction, including terminals	$16,091,580	$14,104,900	$14,181,560	$13,496,500
Construction of masonry piers started	Jan. 3, 1870	Oct. 1, 1901	Nov. 7, 1896	July 19, 1901
Construction of steelwork started	May 29, 1877	April 30, 1908	Feb. 21, 1899	Nov. 20, 1903
Roadways opened	May 24, 1883	Dec. 31, 1909	Dec. 19, 1903	Mar. 30, 1909
Cars first operated, Brooklyn surface	Jan. 23, 1898	Sept. 4, 1912	Nov. 3, 1904	10-4-09, N.Y. & Q. Co.
Cars first operated, New York surface	....	Nov. 14, 1912	Feb. 9, 1905	Jan. 24, 1912
Trains first operated, elevated	Sept. 24, 1883	....	Sept. 16, 1908	....
Travel, both directions for 24 hours, 10-24-12				
Elevated railway cars	7,490	....	1,944	....
Surface railway cars	8,017	482	9,088	2,796
Vehicles	3,913	4,823	5,924	3,644
Passengers, elevated railway cars	211,117	....	72,648	....
Passengers, surface railway cars	119,893	4,798	155,195	50,852
Passengers, vehicles, including driver	5,976	8,314	10,878	7,819
Pedestrians	7,282	1,498	2,168	1,153
Total number of people crossing	344,268	14,610	240,889	59,824
Per cent. of total of 4 bridges	52.2%	2.2%	36.5%	9.1%
Cost of property	$7,100,000	$12,470,000	$9,096,000	$4,635,000

To build a bridge of any of the types proposed for the Hudson River, it would be necessary to have one or more piers; either two piers one-third of the distance from each shore, or one pier in the center of the river. An absolutely essential condition for this is that the river-bed should be of sufficient compactness to yield a firm foundation — a condition that could only be satisfactorily fulfilled if rock were present at a reasonable depth. An illustration of the difficulties involved may be found in the case of the bridge across the Firth of Forth, where the single span requires for its support two structures similar to the Eiffel Tower. Therefore the Bridge Commissions, and all those who for the past twenty-five or thirty years have hoped and dreamed that the Hudson River would be bridged, are probably doomed to disappointment.

In the meantime, however, it is perfectly possible to construct many tunnels under the river, and that brings us to the third division of our subject.

III.

THE TUNNEL SYSTEM.

Within the last half-decade, the transportation of passengers to and from the City of New York has entered upon an entirely new phase — one equally remarkable from both an engineering and a practical viewpoint. Although New York is built upon an island, it is possible now to enter or to leave it without the use of ferries, by a system of tunnels beneath both the rivers that confine it. There have been constructed and opened no less than three tunnels under each river, all of them for the passage of railroad trains. Of these six tunnels, five have two tubes and one has four, making fourteen tubes in all. Their dimensions vary widely, as did also the conditions under which they were constructed, owing to differences in the nature of the material penetrated, so that the engineering problems to be met have been highly complicated and varied.

The great example and precedent for a sub-aqueous tunnel has long been the celebrated one beneath the Thames at London. The construction of this tunnel was easy in comparison with those at New York, from the fact that its course lay mostly in a stiff compact clay, which kept its place firmly around the tube and held the tube in position; while at New York there was a great variety of material to be traversed — solid rock, decomposed rock, sand, boulders, mud, and soft river silt — in some places even quicksand. All manner of devices and modifications had to be adopted, to meet these diverse conditions; and it is no small triumph of technical skill that all the obstacles have been overcome and all the tunnels are now in successful operation.

There remains, however, a very important question, which only time can decide, viz., whether the constantly moving loads passing through these tunnels, and the vibration thereby caused, may not after a while produce strains or deflections in the long reaches of the tubes that traverse soft or almost semi-fluid material. Upon this point engineering authorities differ widely in opinion. Thus far, no indication of any such tendency has been detected; but it may yet be too good to regard the problem as permanently solved.

A sub-aqueous tunnel-tube for rail-cars has two distinct functions to perform — not only to provide an elongated chamber for the trains to traverse in safety, as in a land tunnel, but also to support their weight. For the former — to resist the pressure from without — strength of construction is all that is necessary; but if the tube lacks proper support as a whole, no strength of construction can assure its absolute security. The question is as to a tube 1,500 or 2,000 feet long and 15 to 20 feet in diameter — a ratio of 100–1 — firmly supported at both ends, but resting on and surrounded by soft or semi-fluid silt for most of its length. So serious did this problem appear to some of the engineers engaged upon the earlier of the New York tunnels that they advocated, and began, a system of supporting pile-work to form a basis for the tube, by which the tube would become simply a water-tight chamber for the cars to pass through. This method was adopted in the first East River tunnel opened — the Subway tube from the Battery to Brooklyn — and was planned also for the Pennsylvania Railroad system under the Hudson. But the first Hudson tube, that known as the Morton Street, or later as the McAdoo tunnel, which was many years in construction, with long intervals of suspended work, showed no trace of anything like displacement under long-continued and most careful tests; and hence the pile-foundation project was given up as unnecessary in the construction of the Pennsylvania tubes.

With various modifications of detail, the general character of all the tunnels is similar — a tube, ranging in diameter from 15 to 23 feet, and consisting of a succession of rings 2½ feet wide of strong iron plating, bolted on from one to another, by flanges, and then lined with some two feet or more of brickwork or concrete. Each track has a tube, and the two may be separated and entirely independent, or may be close together and almost united.

A few words may be given to the East River tunnels, before considering those under the Hudson. There was a small tunnel carried across under the East River some years ago, from about Sixty-ninth Street to Ravenswood, for the Long Island City Gas Company. This, however, was but a small affair, though it was very interesting to students of local geology, as giving the first definite information as to the exact character of the rock underlying the river.

The passenger tunnels beneath the East River are three, as already stated. The first of these, opened in 1907, was the Rapid Transit tunnel from the Battery, New York, to Joralemon Street, Brooklyn, designed to connect the subway systems of the two boroughs. It consists of a pair of tubes 15 feet in diameter within and runs about half way through rock on the Manhattan side — some 2,000 feet — and then through mud, gravel and sand to Brooklyn.

Next above this come the tunnels of the Pennsylvania Railroad Company at Thirty-second and Thirty-third Streets. In view of the great prospective demands of travel between Long Island and the Pennsylvania system of roads it was decided to construct four tubes here, instead of the usual pair. These have an outside diameter of 23 feet — four feet less than the Blackwall (Thames) tunnel — and are in two sets or pairs, some sixty feet apart, those of each set being closely adjacent. On passing out from the rock of Manhattan Island into the soft material of the river channel, quicksand was entered and serious difficulty was found in carrying the shield and machinery along the true line of direction. About half the length of these tubes is in rock, which rises in two ledges (though entirely buried) with deep channels between.

The third set is that known as the Belmont, or New York and Long Island Railroad, tunnel, crossing the river from East Forty-second Street to Long Island City. Here there are two tubes, with a diameter of 15½ feet. The work at this point was mainly in rock, much of which, however, was decomposed and soft. Advantage was taken of a reef — really a southern extension of Blackwell's Island — to sink a shaft whence borings could be run in both directions, as well as from the two shores, thus giving four headings. Only about one-quarter of this tunnel lies in soft river-filling, in the deep channel east of the reef.[*]

This tunnel is intended to connect with the New York Central Railroad system, at the Forty-second Street terminal, as the pre-

---

[*] As to the general characteristics of the East River bottom, see Charles P. Berkey, "Geological Features Affecting the Plan of Construction of the City Tunnel of the Catskill Aqueduct," New York, 1912, pp. 144, 166-168, Report of the Board of Water Supply . . . on the City Tunnel.

vious set does with the Pennsylvania station at West Thirty-second Street, both being carried from the river to the terminals by rock-tunnels beneath the city.

The tunnels beneath the Hudson River are also three, one being that of the New York and New Jersey Railroad Company, often called the McAdoo tunnel, from Fifteenth Street, Jersey City, to Morton Street, New York; and the other two, one above this and one below it, both connected with the Pennsylvania Railroad system and leading to and from its up-town and down-town terminals, at Thirty-second Street and Cortlandt Street respectively.

The McAdoo tunnel calls for particular notice, as being not only the first to be opened (February, 1908), but by far the first begun or even attempted. Its inception goes back a full generation — to 1874 — when Mr. DeWitt Clinton Haskin, who had been connected with the building of the Union Pacific Railway, undertook the project of carrying a tunnel beneath the Hudson. A working shaft was sunk, a little back from the foot of Fifteenth Street, Jersey City, and another near the foot of Morton Street, New York — somewhat over a mile apart — 5,400 feet. The shaft was a circular pit 30 feet in diameter and 65 feet deep, enlarged into a chamber at base, whence the parallel tubes of the tunnel were started on a gentle grade. Little was then known as to the nature of the material filling the river-bed, and the shield-method was employed; it was thought that the material could be excavated by hand-labor, and would retain its position, with the aid of compressed air, while the steadily advancing tube could be lined with thin iron plates and then with brickwork 2½ feet thick laid in hydraulic cement. The work progressed slowly for several years, until in July, 1880, a terrible accident occurred. The overlying silt at the point then reached was only a few feet thick, and unable to withstand the force of the compressed air; the result was a "blow-out," followed by an inrush of water, which disarranged the air-lock and cost the lives of twenty laborers. The work was resumed, however, and went on for two years, when it was suspended from lack of funds, after about 2,000 feet of the north tube had been constructed.

Eight years then passed, until the enterprise was taken up by an English company in 1890, with Sir John Fowler and Sir

Benjamin Baker of the Forth bridge as consulting engineers. The shield system was now introduced, and progress was much more rapid. But in 1891 the work was again abandoned, after 2,000 feet more had been traversed, in less than two years — as much as in the eight years at first.

The tunnel then lay abandoned for several years, in which time it filled with water, while public interest in the attempt had completely died out. It is greatly to the credit of Mr. W. G. McAdoo, that he saw the possibility of once more taking up this work, already two-thirds completed, although twice given up, and of not only finishing the tunnel itself but developing it on a much more important scale.

Mr. McAdoo undertook this great task in 1896; a new and strong company was formed, known as the Hudson and Manhattan Company, and Mr. Charles M. Jacobs was placed in charge as chief engineer. The old tunnel was pumped out, and found to be mostly in good condition. It was kept in order and carefully watched until 1902, when work was actually resumed. The shield used by the English company was readjusted and used for the north tunnel; and a new shield was built and equipped with new machinery for the south tube. A novel and peculiar difficulty was now encountered in the form of a ledge of rock on the New York side which rose only partially above the floor of the tunnel, thus necessitating simultaneous excavation in rock below and in silt above. Special additions and modifications had to be devised, to meet this new obstacle; but it was successfully overcome and the whole work accomplished without accident, to the great credit of Mr. Jacobs. The unfinished portion of the north tube (1,400 feet) and the greater part of the south tube were completed in about five years, and formally opened on February 25, 1908.

Unlike the other tunnels, the two tubes of this one differ somewhat in size; the northern one having a diameter of 19 feet 5 inches outside and 18 feet 1 inch within, while the southern tube is smaller, being 16 feet 7 inches without and 15 feet 3 inches within. This difference is due to the fact of their being constructed, as above stated, by different companies, a number of years apart.

The tunnel thus described, however, is but a small part of the work — only that beneath the river. It is extended much further, under the cities on both sides of the Hudson, to form very important railroad connections. In New York it is carried as a rock tunnel for over half a mile, to Sixth Avenue and Ninth Street, and there it divides into two branches, one going across to Fourth avenue, to connect with the Rapid Transit Subway, and the other continuing under Sixth Avenue to Nineteenth Street, and ultimately to connect with the main Pennsylvania Railroad Station at Thirty-second Street. On the New Jersey side a tunnel has been built parallel to the river, to connect all the railroad terminals on that side with each other and with New York. This system consists of two tubes of 15 feet internal diameter, and extends from the D. L. & W. terminal in Hoboken southward to the Pennsylvania Railroad station in Jersey City, taking in the Erie Railroad between, and is to go on to that of the New Jersey Central Railroad below. At Fifteenth Street this tunnel (or subway) meets and joins the river tunnel, with its New York connections. This junction is itself a most remarkable piece of engineering work; it consists of three immense caissons, or subterranean chambers, made of reinforced concrete, 45 feet wide and high and 106 feet long, the largest ever constructed. In these, the tubes of both tunnel systems are made to connect in a most ingenious manner without any crossing of tracks by a two-story construction of each caisson.

But this remarkable achievement did not exhaust the energy and foresight of Mr. McAdoo. He perceived the importance of a tunnel that should meet the needs of the great downtown district of New York; and hence the Hudson and Manhattan Company undertook the construction of another pair of tubes, a mile or more south of the old tunnel, to connect the Pennsylvania Railroad station in Jersey City directly with the great new Terminal building in Manhattan, at Cortlandt and Dey Streets. This is the second Hudson tunnel, opened on July 19, 1909. It consists of two tubes of larger size, 23 feet in external diameter, and not running side by side, as in the other. From Jersey City they diverge slightly, the southern one being used for trains to New York, and going under Cortlandt Street into a station excavated beneath the great

Pennsylvania downtown terminal. There the track turns northward, and then, curving to the west, under Fulton Street, returns through the other tube to Jersey City. The length is a little over a mile.

The stations at both ends of this tunnel are again very notable structures — great subterranean chambers, excavated in rock to a depth of 80 or more feet, and lined with concrete — one beneath the Pennsylvania terminal in Jersey City and the other beneath that in New York. The former also connects directly with the subway already described, beneath Washington Street in Jersey City, and the latter with the Rapid Transit Subway at Cortlandt Street, New York. All the great lines of passenger travel, therefore, both local and distant, are linked together in this remarkable manner.

The third tunnel under the Hudson, opened in 1910, was constructed by the Pennsylvania Railroad Company to bring its whole body of passenger trains directly into the great station recently erected in West Thirty-third Street, and to connect with the Long Island extensions of the same road.

The change of policy on the part of the Pennsylvania Railroad from a bridge to a tunnel was brought about by an investigation and computation made by the late J. J. Cassatt. On his return from Europe in 1900, he said in regard to the bridge projected from Hoboken to Twenty-third Street, New York, which had been planned by Lindenthal, that as it would cost at least $200,000,000, it would be impossible to entertain the proposition and that the subject of tunnels must be investigated.

The Pennsylvania Railroad Tunnel consists of two tubes having an outside diameter of 23 feet, but running side-by-side. Their actual under-water length is about three-quarters of a mile, but their extensions and approaches are very much longer. The tubes have, of course, the usual iron casing, but of extra strength, and are lined with two feet of concrete. On each side of the track, moreover, the concrete is carried up vertically to a level with the car-windows, where it then forms a horizontal platform extending to the wall on either side, wide enough for a person to walk upon and affording a means of exit for passengers in case of accident or breakdown. The original plan was to sink a series of piles — cast-iron tubes 2 feet 3 inches in diameter and 1½ inches thick — to a bed-rock, as a foundation for the tunnel. These were to sustain the weight of the heavy trains, which it was thought might cause strain or deflection in the tubes. This feature was given up, however, in view of the perfect stability shown by the other Hudson tunnels, after some months of operation. Had this been undertaken it would have proved a Herculean task, and probably an impossible one. The same difficulty that has already been emphasized as to piers for bridges would have been speedily encountered. The contractors would have found themselves engaged in attempting to sink piles from one to two hundred feet, and then to unknown depths before rock could be reached. How far, indeed, the present stability of the unsupported tunnels may prove permanent, is a question of possible concern, though we must hope that it may never become actual. The much vaunted "mastery of man over nature," however, has limits.

On the New Jersey side, which the tunnel reaches at a point some three-quarters of a mile south of the D. L. & W. terminal at Weehawken, connection is made with the subway running parallel to the river, already described. The tunnel itself, however, is continued in a straight line northwestwardly, for a mile or more, under the Bergen Ridge, the southern extension of the Palisades. On emerging from the portal on the further side of this ridge the tracks are carried west upon an elevated embankment, over the meadows and the Hackensack River, as far as Harrison, N. J.— nearly to Newark — where they join the main line of the Pennsylvania road. Here the electric traction used in the tunnel system is exchanged for steam; and there are also great yards for the distribution of freight, etc.

At the New York entrance, or "portal," at Thirty-third Street and Tenth Avenue, the two tracks pass into a system of switches, and increase in number until they become twenty-one in the great Seventh Avenue Station. Here begins then the eastward extension — the tracks being reduced to four, which are carried in a rock-tunnel across the City to First Avenue, where they enter the four-tube tunnel under the East River, previously described, leading to Long Island City. The total distance between the end or "portal" of the tunnel here, and the Bergen portal beyond the Hudson, is 5.3 miles — crossing under both rivers and the whole breadth of Manhattan Island between them.

Here again are immense yards, and two most important connections. One of these is the branch of the Pennsylvania Railroad extending north to Port Morris, and passing over Hell Gate by the magnificent arch bridge previously described. This will give short and direct rail connection with the whole New Haven system, and thus between all New England and the South and West. The other is the Long Island Railroad, with its network of branches, now affiliated with the Pennsylvania road. This will not only place the great suburban population of the island, present and prospective, in direct touch with the Pennsylvania system, but may acquire extreme importance in another way entirely. If the project recently suggested, although still in the future — of making a port for the mammoth Atlantic liners at or near Montauk Point — shall ever be carried out, the Long Island Railroad would become the carrier of most of the passenger traffic to and from Europe. The question of piers at New York long enough for the giant steamers even now building, is already assuming a serious aspect, and the Montauk proposal may well develop into a reality ere many years. If it should, this connection would become of national, or even international importance.

Such is the tunnel system of New York City — unique in its extent and in its variety, in its engineering difficulties and triumphs, and in its practical relations to the conditions and needs of the metropolis of the Western World. This paper is concerned mainly with the sub-river tunnels, especially those beneath the Hudson, but these have to be considered in their relations to the whole system, of which they form an integral and most remarkable part. The problem of crossing the Hudson, impracticable in respect to bridges, from the geological conditions of the channel, has been solved by means of tunnels, apparently with complete success.

From the foregoing account of the system of tunnels thus far developed under the Hudson and East Rivers, it will be seen that all of them are, as already stated, made and used for railroad service alone. All are constructed on the same plan — that of a tube containing a single track; and with no provision or space for any other use, save the limited footpath in the Pennsylvania tunnels for exit in case of accident. The great volume of travel and traffic that does not or cannot use the railroads, must still cross the Hudson by ferry alone. This state of things cannot continue long, now that railroad tunnels have been successfully constructed, and the method is shown to be so feasible. The latter part of this section will review briefly some of the schemes proposed for traffic tunnels under the rivers, and also for subway routes to connect them with each other and with the principal thoroughfares.

In the first place, we may note that this latter idea has already been carried out on the New Jersey side of the Hudson, in the subway of the McAdoo system already described, connecting the several railway termini and the river tunnels. Something of the same kind will surely be needed on the Manhattan side — a subway near and parallel to the river. But of this, more will be said later.

The congestion of the business streets and of the waterfront by vehicles of all kinds carrying freight has reached a point where it has become very serious, and threatens to restrict the further development of commerce at this port. Besides the railway terminals, some of the most important steamship lines now dock on the New Jersey side, and hence vast amounts of freight must be taken over the ferries both ways, and handled on both sides of the river to load and unload. The cost and the delays involved by these conditions are enormous, the former alone rising into many millions annually.

To meet this grave necessity for relief there has been proposed by Mr. C. Wilgus — a leading engineer connected with the New York Central Railroad system — and laid before the Public Service Commission,* a plan consisting essentially of a subway road for the carriage and delivery of freight along the waterfront. It is proposed to have branches beneath the main business streets, and a belt line under South and West Streets, the latter connecting with the New York Central yards at West Sixtieth Street and with tunnels under the Hudson and East Rivers, and so with the

---

* Sci. Amer.; vol. xcix, No. 23, Dec. 5, 1908, p. 413.

opposite water-front on each. The freight is to be carried on these roads in cars of standard guage, which thus can run directly into the yards or stations of any connecting railroad for reception or delivery. There will also be tracks leading out on the principal steamship piers. The larger transfers of freight are to be made at points distant from the crowded parts of the City; and the subways are planned on a scale to handle nine-tenths of the freight that is now slowly and laboriously carted through the streets. The scheme also contemplates an elevated railway for passengers in the space over the belt tracks, in the river-front streets relieved of their present congestion. The project is a most elaborate and extensive one, but is very carefully and skillfully wrought out.

Another plan is to construct a passenger subway parallel to the river fronts, connecting with new tunnels at several points, as well as with the railroad tunnels already built, and also with the existing subway lines at the various stations. This would be a reproduction on a greater scale — and with transverse branches to connect with the present subways — of the McAdoo line on the New Jersey side.

Whatever system shall be adopted, however, for passenger and freight distribution in the City, we are brought back to the problem of tunnels beneath the Hudson; and here some interesting and important questions arise as to the manner of their construction.

All the tunnels before described have been circular tubes, excavated essentially by a process of simple boring. Indeed, it is said that Mr. Greathead, the inventor of the "shield" method that bears his name and has been used in almost all the work herein described, derived his idea of the iron "shield" for tunnel construction from the method by which the boring mollusk, Teredo (commonly known as ship-worm) makes its tubular burrowing in timber, protected by its small cylindrical shell in front, and lining the tube as it proceeds, with a calcareous coating.

This form of tunnel has some disadvantages, however. If enlarged sufficiently to take two tracks, or roadways, much waste space remains above and below them. The Pennsylvania tunnels are 23 feet in diameter, and are lined with $2\frac{1}{2}$ feet of concrete, leaving 18 feet of clear width. A slight enlargement would allow room for two roadways for vehicles, and a footpath. Such a tunnel could be built, according to Mr. Davies, the engineer who constructed the East River tunnels for the Pennsylvania road, at a cost not exceeding $3,000,000 a mile — about the length necessary for the Hudson. But a further enlargement would afford much greater advantage proportionately in regard to space. The latest proposition is one made by Messrs. Jacobs and Davies, for a Hudson tunnel of 31 feet diameter outside and 28 feet 9 inches within, to accommodate four roadways, two above and two below, with a foot-path on each side of the upper level. The tube is divided at its middle by a horizontal partition of concrete; above this are two roadways for slow traffic — trucks, vans, etc. — 12 feet high and 9 feet wide; and below it are two roadways for rapid vehicles — automobiles, etc. — 9 feet high and 8 feet wide. The concrete lining, somewhat as in the Pennsylvania Railroad tubes, is carried up vertically to the partition; above this is a footway in the semi-arch on either side, of 4 feet 6 inches width, alongside of the truck-way; beneath this is a passage or gallery in the concrete filling, for pipes, electric wires, etc.; and provision is made for air-passages and drainage in like manner. The whole is a most complete and systematic plan, and seems admirably adapted to meet the requirements of such a tunnel, with remarkable economy of space.

Another tunnel has been built, however, in a wholly different manner — that beneath the Harlem River at One Hundred and Forty-fifth Street, for the Rapid Transit Subway. This was constructed by Mr. Duncan D. McBean, and he has proposed to the Public Service Commission to use the same method for tunneling the Hudson and East Rivers, with certain advantages of construction over the tube form, and at less expense. The Harlem River tunnel was built without any mishap, and has served its purpose perfectly. Can the same process be applied to the Hudson?

The McBean method is essentially the following: A wide trench is dredged in the river-bed to about half the depth of the tunnel, and walled off from the water with timber casing. The upper half of the tunnel is built outside, in semi-cylindrical segments; and these are lowered into place one by one. The ends are closed by temporary partitions so as to make the upper half serve as a work-chamber, in which compressed air can be used, while beneath, the lower half of the tunnel is excavated, and then lined with concrete. Later, concrete and filling are added externally, the trench filled up and the cross-partitions and outside casing removed. In this method, the tube is not of necessity a cylinder; and two or several roadways may be built side by side, without increasing the height; while two side-walls only are necessary for the whole to withstand the external pressure — the several roadways being separated simply by partitions or bracing. The whole rests upon a strong foundation of piling, driven from the trench to rock.

This last statement carries with it the entire case, as regards the Hudson. The plan worked well in the Harlem River, where the rock lies at very moderate depths; but it is needless to repeat here what has been already emphasized in this article — as to both piers for bridges and pile-work for tunnels — that the depth to rock in the Hudson is prohibitive for either.

In Mr. McBean's proposal to the Commission, after describing the advantages of his method and its successful application to the Harlem tunnel, he offers to construct several tunnels of 100 feet wide, giving two double roadways — one for trains and one for automobiles — four car-tracks, and a footway, all side by side, with an interior height of 18 feet. The cost for any of these tunnels, he specifies as $1,000 per foot of length.

After reading this account, and examining the careful drawings that illustrate the plan, it is very disappointing to recognize the fatal difficulty in the way. In a published letter to the Mayor of New York (September 19, 1910), as to a proposed new tunnel under the Harlem River, Mr. McBean says that in his method "the pile foundation is an integral part of the structure (which cannot be omitted in soft ground), thus insuring the integrity and permanency of the foundations at every point." (P. 5.)

Still another method has been used, at Detroit, Mich. In this, which is known as the Wilgus, or Trench method, some of the features of the last are united with the tube form. A trench is dredged, to the full depth of the tunnel, and into this are lowered sections of iron tube which are joined on to each other to form a roadway or track-way. Several such tubes may be laid nearly side by side, with bracing between; and when finished, the whole lower part of the trench is filled with concrete, encasing and embedding the tubes, beneath, around, and above. The concrete is laid under water, through pipes, under the supervision of divers. This method gives a very solid concrete structure, enclosing the iron tube-ways. All these are on one level, as in the McBean system. The Wilgus method has been proposed for the new four-track subway tunnel under the Harlem River, but we are not aware that it has been suggested for the Hudson. It is possible that such a firm concrete structure might dispense with the pile foundation. In calling for proposals for the new Harlem tunnel, the Public Service Commission have not positively required this feature in a structure of the Wilgus type, but have left it optional, apparently with the view that, as in the Pennsylvania Railroad tunnels, a foundation is not essential to stability. In that case this method might be applicable to the Hudson; but the dredging of a wide trench to the necessary depth, with all the crib-work, etc., requisite, would be a matter of great difficulty and great cost, in a river so broad and deep.

One other suggestion may be noted here, as bearing on the Hudson problem. Mr. Alexander E. Dandridge, in a recent letter, has taken the ground that engineers in general have erred in assuming that they must accept whatever kind of material Nature has provided in a river-bed, and penetrate it as best they can. He advocates instead the formation of an artificial bed, through which a tunnel can afterwards be bored. His plan is to use crushed traprock, mingled with a suitable proportion of stiff clay to give it firmness and coherence. This he would dump from scows into the river for a space several hundred feet wide and bring it up to near the surface, from the shore outward for a thousand feet. The weight of this load would press the lower portion of the mass into a very compact condition. Then the upper part would be dredged off, leaving a water depth of say fifty feet, and the material dumped onward for another thousand feet, and the same process repeated until a basement of this kind had been laid across the whole distance. Then, through this submerged causeway ,as it might be called, the tunnel would be made by boring, with a firm stiff bed and wall instead of the loose river silt.

This suggestion is ingenious, and seems at first sight very feasible. The question would be, however, as to such a dense mass retaining its position amid and upon the silt. A causeway or embankment built across swampy ground is liable to settle, sometimes even causing the ground to rise in ridges parallel to it, at considerable distances. On land, where the road or track is on the top of the causeway, repairs and addition are easy; but in a tunnel enclosed within such a causeway, and beneath a deep river, settling would be a very serious matter. This question is probably impossible of determination save by actual experiment, and after considerable time; and this uncertainty seems to bar the way to Mr. Dandridge's well-reasoned scheme being attempted.

The tube-method, however, has already been used with apparently complete success, in the river bottom as it is; and if no tendency appears to settling or other weakness in the railroad tunnels, with their extremely heavy and rapidly-moving trains, none need be feared for tunnels used for ordinary traffic and for the slow carriage of freight. The objection as to waste of space in a circular tube has been eliminated in the Jacobs-Davies plan of a two-story tunnel, above described; and there seems no reason to doubt that ere very long the Hudson River may be traversed by several tunnels constructed on some such plan. If these should then be combined with a freight-subway in the City, such as the Wilgus system proposed, or something similar, and with the existing subway for passenger travel, a very comprehensive scheme would be developed, for the relief of the congestion that has now become so serious, and for the further development of the metropolis of America.

London is now traversed by a great connected system of subways and river tunnels, amounting to a total of many miles, and now approaching completion after years of experiment and construction. New York will surely be similarly provided in the near future.

The first Thames tunnel, between Rotherhithe and Wapping, was planned by Marc Isambard Brunel. A shield of timber having several independent sections was used. The work was begun in 1825 and completed in 1843, the cost being about £1,300 per linear yard. In part this tunnel was carried through almost liquid mud. The Blackwall tunnel, for which Sir Alexander Binnie was engineer, is 3,116 feet in length by 24¼ feet interior diameter. In this case the passage was made through clay and about 400 feet of water-saturated gravel. Operations were begun here in 1892, the work being finished in 1897. The third and largest of these Thames tunnels, that known as the Rotherhithe tunnel, has a cross-section larger than that of any other similar construction. Maurice Fitzmaurice was the engineer and designer of this tunnel, which was carried through sandy and shelly clay overlying a seam of limestone resting upon a stratum of pebbles and loamy sand; for 1,400 feet it runs directly under the river bed. Four years were required for its completion, from 1904 to 1908.

Of the two later constructions, the Blackwall tunnel measures 4,470 feet from portal to portal (6,200 feet between grade points), the tube has an external diameter of 27 feet and an internal diameter of 25 feet 4 inches; through it runs a roadway 16 feet wide and 17 feet 7½ inches high at centre, and two footways each 3 feet 1½ inches in width. The corresponding dimensions for the more recently built Rotherhithe tunnel are: length from portal to portal 5,200 feet (between grade points 6,883 feet); roadway 16 feet wide with a height at centre of 18 feet 6 inches; two footways each 4 feet 8½ inches wide. The number of vehicles that passed through this tunnel in 1911 was 896,629 and in 1912, 973,336; the volume of traffic through the Blackwall tunnel is stated to be nearly as large.*

In some of the tunnel plans it has been proposed to do away with the difficulty of approaches, which involve a great expenditure of space, by a system of elevators. The tunnel would terminate at the actual river-front, in a spacious chamber, in which would be installed elevators large enough to take vehicles of any size up and down between the tunnel and the street-level. Something of this kind will undoubtedly be a feature of the new tunnels for automobiles, carriages and freight.

That it is perfectly practicable to construct a large tunnel at a relatively small outlay is shown by estimates submitted for such a

---

* To the New Jersey Inter-State Bridge and Tunnel Commission, a Presentation in the Matter of Tunnels or Bridges for Highway Crossing of Hudson River, by Jacobs & Davies, Inc., Feb., 1913, p. 12.

tunnel, to be built on the McBean method. Here elevators placed at the bulkhead line at each termination would lower and raise cars, vehicles and pedestrians, to and from the tunnel. The entire width of the whole structure would, as we have already stated, be about 100 feet, and the total cost of building such a tunnel between Manhattan Island and the New Jersey shore would be about $5,000,000.

The great difference in the expense of maintenance must also be considered in comparing the total expenditure for a bridge with that entailed by the building of a tunnel. The up-keep of a cement-like tunnel would be almost nominal, whereas the cost of a bridge, with its tendency to rust, the cracking of bolts, etc., is enormous. One single item of expense for the Queensboro Bridge, the painting of the structure, amounted to $33,000.

The cost of building a bridge would be from ten to twenty times as great as that of tunneling the river; and as we can now estimate closely both the time and the expense required for the construction of a tunnel, we can safely assert that within a comparatively short period there could be three or four large enough for traffic, special ones for automobiles, and also others for railroads. A notable advantage would be that these various tunnels could be located at a number of different points along the river, at Fifty-ninth, Eighty-sixth, Ninety-sixth, One Hundred Tenth, One Hundred Thirtieth, One Hundred Thirty-seventh, One Hundred Fifty-seventh, and One Hundred Eighty-first Streets, to connect with the main thoroughfares and subways — thus satisfying the requirements of those who have advocated these different sites for the construction of a bridge, and who have been forced to agree upon a single site. There is little doubt that we could have a double tunnel at each and every one of these streets for the cost of one bridge.

In making any of these improvements, however, one thing should always be borne in mind, the necessity of preserving intact, as far as possible, the beauties of Riverside Park, one of the great ornaments of our city. Hence the laying of surface tracks and the establishment of extensive freight-yards within the boundaries of the park should be avoided. All the requirements of the railroad can be satisfied and the park preserved by placing the tracks under cover, and to this there can be no objection. The successful operation of our subway transporting under comfortable conditions 1,200,000 passengers daily, renders any objection to underground means of transit certainly unreasonable, especially as all trains within the greater metropolis will certainly be and should be operated by electricity. An important consideration in favor of this plan is the fact that it would remove all danger of injury from passing trains to anyone not immediately connected with the operation of the railroad, as only employees of the railroad would be permitted to have access to the subway; moreover this provision would also do away with the petty thieving now possible. An ideal plan, and a perfectly feasible one, would be to lay the main freight tracks on the Jersey side of the river, where within a comparatively short distance of the river front land can be acquired at a very reasonable cost. Tunnels could then be built across the river at points in a line with St. John's Park, 30th Street, 59th Street, 72d Street, and 130th Street, conveying the freight directly to these distributing points, the main yards to be on the Jersey side. For a two-track road running from 59th Street to 210th Street, the New York Central Railroad now occupies about thirty acres of ground or forty-five acres for a three-track and sixty acres for a four-track road. And they are much hampered for lack of proper freight yard facilities. It would not cost much to purchase an area of 3,000 or 4,000 acres in the Jersey meadows. This, to say nothing of the obligation which ought to rest upon any truly representative corporation, to respect and preserve one of the greatest heritages of New York City, the banks of the noble and beautiful Hudson.*

In carrying out the contemplated extension of the New York Central's tracks, the proposition of having them pass by an open cut on either side of Spuyten Duyvil Creek has been urged, but it seems as though there were no sufficient reason for defacing or cutting into either Inwood Heights or Spuyten Duyvil Heights, as there would be no difficulty in constructing a tunnel beneath the heights on either side of Spuyten Duyvil Creek and beneath

---

* International conference relating to Project for celebration of centenary signing of Treaty of Ghent and One Hundredth Anniversary of Peace among English speaking Nations. New York, Friday, May 9, 1913. pp. 1-12.

the creek itself. If at the same time the New York Central would modify the course of its present line by carrying its tracks in a direct line from a point east of Spuyten Duyvil in a northwesterly direction to the Hudson, they would in this way accomplish a distinct saving both in time and in distance and consequent expense.

The New York Central Railroad has received more direct benefit from the beauty asset of the Hudson River than any other corporation. But it has failed to realize the supreme and permanent value of this asset, and no corporation has done less to preserve the beauty and, indeed, none has done more to obliterate it than this great corporation, its natural guardian and conserver. This failure to act has perhaps arisen from lack of interest, but it is not too late to preserve Fort Washington, Inwood Hill and Spuyten Duyvil Creek.

There should be a system of covering up scars of railroad cuts by means of vines or rose bushes, such as those used by Edward Bok, who planted 3,000 rose bushes — pink and yellow — at a single Pennsylvania Railroad cut, with a resultant 100,000 roses in bloom.

The Pennsylvania Railroad has paid more attention to beautifying its line, perhaps because here there is no great river asset. But the New York road should introduce the same method. It would have a double attraction to its patrons, and furthermore increase the value of the entire real estate adjoining the railroad tracks.

A reward of $1,000 to $2,000 a year, divided into three to five or more prizes and medals to encourage fine and well-kept stations and the yards of small owners and fine estates, would mean much in toning up the entire line from New York to Albany.

In the report of the New York State Bridge and Tunnel Commission submitted to the Legislature in April, 1913, the commissioners favor the construction of tunnels instead of a bridge. This preference is based on the drawbacks of the proposed bridge apparent from a consideration of a tentative plan proposed by Boller, Hodge and Baird, consultant engineers to the Commission. As the opinion prevailed that the neighborhood of Fifty-seventh Street would be the best point for the New York end of the proposed bridge the estimated length of the main structure and its approaches refer to a bridge constructed there. The entire length, including approaches, from Ninth Avenue and Fifty-seventh Street, Manhattan, to the Boulevard in Weehawken would be 8,330 feet, and the great central span would measure 2,730 feet in length between pier-head lines and 2,880 from one tower centre to the other. Accommodations would be afforded for eight lines of rapid transit trains, as well as for two driveways, each thirty-six feet wide, so that four vehicles could travel abreast, and also for two footways, each eight feet in width. The supporting towers would rise to the unexampled height of 745 feet from bed rock, but 239 feet less than the height of the Eiffel Tower. In view of the altogether exceptional character of the structure, the eventual cost would probably greatly exceed the original estimates, and hence even the large sum of $42,000,000 given by expert engineers may be much too low. There is, therefore, every reason to commend the present preference of the commission for tunnels, two of which would cost but $11,000,000, and the changed attitude of the members in this respect from that assumed a few years since proves that they were open to conviction and impartially anxious to recommend the course best calculated to further public interests and welfare.

Not only would large tunnels of this type aid most powerfully in the development of the commercial interests of lower Manhattan, at the same time helping largely to relieve the present congestion, daily growing worse, but it has been figured that they might bring in a very satisfactory percentage on the money invested in them. Putting the annual interest charges on capital at $550,000 and the yearly cost of maintenance at $90,000, we have $640,000 to be provided for. Should 5,000,000 vehicles use the tunnels in the course of the year, as is indicated by the volume of ferry traffic, and should the average toll be received as is now collected by the ferries (about 24 cents per vehicle) there would be an annual revenue from this source of $1,200,000, showing a profit about equal to the amount of the interest charges.*

---

* To the New Jersey Inter-State Bridge and Tunnel Commission, a Presentation in the Matter of Tunnels or Bridges for Highway Crossing of Hudson River, by Jacobs and Davies, Inc., Feb., 1913, pp. 5, 6, 9.

The legal status of the land beneath the Hudson has been partially defined in a recent decision by Supreme Court Justice Arthur S. Tompkins. He was called upon to determine whether the New York Central Railroad Co. could condemn land under water near Peekskill which the company wished to fill up so as to straighten out their tracks and enlarge the road here in establishing the projected fourtrack system to Peekskill. Several private owners laid claim to this sub-aqueous land under a charter granted June 17, 1697, by King William III to Stephanus Van Cortlandt, and it was also contended by the Attorney-General that as the State held the land under water in trust for the people, such lands could not be acquired from it by a corporation. However, Judge Tompkins decided against this latter contention, holding that where there was proof that the land was necessary for railroad purposes it might be acquired for this use, noting that in case of an attempt to thus acquire all the lands under the river — a contingency suggested in the Attorney-General's brief — the claim could be successfully resisted with the argument that no legitimate railroad use could require the entire river bed of the Hudson.

A comprehensive plan for the improvement of the facilities for freight handling on the west front of New York City has been proposed by D. C. Willoughby, of Boston, and submitted to the consideration of the Board of Estimate. Although the requisite capital, estimated at $85,000,000, would be provided from private sources, the title to the subway, warehouses and tunnels projected, would be from the outset vested in the city, only the equipment being regarded as the company's property; the latter also would be accorded a twenty-five years' franchise, with one renewal for a like period.

The plan provides for the construction of a six-track subway, running beneath a marginal way along the river front from Cortlandt Street to Twenty-third Street, two of the tracks being brought into connection at this point, by means of a cross-over, with the New York Central's tracks. The other four tracks would connect with a freight tunnel to be carried beneath the North River at about Twenty-third Street, passing out into a freight classification yard in New Jersey. Above the marginal way, on the New York side of the river, immense warehouses would be erected, one for every four blocks, in which space could be rented by merchants in the neighborhood for the reception of freight consigned to them. It would thus be possible, after proper classification of the freight in the New Jersey yard, to transmit by mechanical means the lots consigned to each merchant directly to the warehouse wherein he had reserved space, obviating the necessity of long cartage from a distant point to the merchant's place of business. There would also be a small classification yard in Manhattan for the distribution of fractional parts of a carload. Should this plan be put in operation it is estimated that as many as 2,642 cars could be loaded or unloaded simultaneously. Of the $85,000,000 to be expended in all, the Manhattan subway would cost $16,486,000, and the warehouses, the subsidiary yards, etc., in Manhattan, $25,000,000, making a total of over $40,000,000 to be expended within that borough.

In St. Louis it has been found practicable to run complete freight trains through a tunnel into the basement of the building occupied by a great hardware concern. The cars, loaded with consignments from the manufacturers, are here divided into so many different groups and labeled to the different firms to which the hardware is to be shipped, whether a single carload, five carloads, or ten carloads, no unloading and reloading being requisite.

A proposition for a four-tube, or a six-tube tunnel under the East River has been submitted by Duncan D. McBean to the consideration of the Public Service Commission, with the claim that a four-tube tunnel of this type could be built for but 50 per cent. more than the cost of one of the three two-tube tunnels to be constructed on the shield method as proposed by the Public Service Commission. Two of the four McBean tubes would constitute a roadway 39 feet in width and 15 feet 9 inches in height. A marked advantage over a tunnel built on the shield method would be a lesser depth, 65 feet beneath the river surface instead of 95 feet, thus considerably shortening the necessary approaches, which might be made to begin respectively at Broad Street, Manhattan, and Montague Street, Brooklyn. Should a six-tube tunnel of this type be constructed, Mr. McBean suggests that two of the tubes be used by the Interborough Broadway subway line and two by the

Brooklyn Railway, leaving the present tunnel under the East River for the Seventh Avenue subway line.

A further extension of one or more of the traffic tunnels may also be considered, viz., that instead of terminating at or near the river-front, on the New Jersey side, it should be continued westward under the Palisade ridge, so that traffic of all kinds could pass through the hill and have access to roads in the open region beyond. This, it will be remembered, is the case already with the tunnel of the Pennsylvania Railroad, which emerges at some distance west of the Palisades. As with that one, there should be of course also a north and south connection near the river, for vehicles and freight; but a continuation beneath the ridge would open up large added possibilities.

One of these should be noted in particular. By such a tunnel from the upper part of Manhattan Island to a point like Edgewater or Fort Lee or even higher up, the whole park system of New York could be brought into direct connection, for automobile travel, with the great Interstate Park west of the Hudson, which begins only a few miles above. Central and Morningside Parks and Riverside Drive in Manhattan, and Van Cortlandt Park and Lafayette Boulevard in the Bronx, could all thus be united with the magnificent Interstate Palisade Park, and brought within a few minutes' ride thereof, by automobile, the whole forming a park and parkway system unequaled in the cities of the world.

A tunnel connecting with the subway at 130th Street, going direct to the Palisades Park and through the hill to the region beyond, would do more to open up the country than a bridge, because the traffic between Westchester and central New Jersey would not be great enough in twenty years to warrant an expense that would amount to more than the value of the entire real estate of Bergen County.

As a recognition of the growing sentiment in favor of tunnels we may note that by chapter 189 of the Laws of 1913, the name of the New York Interstate Bridge Commission was changed to that of the New York State Bridge and Tunnel Commission.

In the report submitted to this Commission on February 25, 1913, by J. V. Davies, it is recommended that the first tunnels be constructed on "a line from the foot of Canal Street, Manhattan, to intersect the shore line of Jersey City at approximately the extended line of Twelfth Street, Jersey City, which is the line of division between the properties of the Erie and Lackawanna railroads, and extending thence to a portal in the block between Twelfth and Thirteenth Streets and Provost and Henderson Streets, so that the surface of the street is reached at Henderson Street, which is the first continuous street parallel to the river connecting Jersey City and Hoboken."* The approach would reach grade in Manhattan at the line of the new extension of Seventh Avenue and widening of Varick Street.

The estimated cost of a Hudson River Bridge seems high enough, but the lessons of past experience have almost invariably shown that the real and final cost is far in excess of the sum originally named. As an instance we may note the Manhattan Bridge over the East River, the original estimate for which was \$15,800,000, while the actual cost was \$26,500,000, an increase of 67.8 per cent. The difference in the cost of the Queensboro Bridge, though not so great, was notable enough, the original estimate here providing for \$12,500,000, a sum which had to be increased to \$18,100,000 to cover the eventual cost of this bridge.†

The conditions as to buried channels which we have noted as obtaining on the Atlantic Coast of the United States have been shown to exist from the Arctic Sea to beyond the center of the African Continent, and also in the Mediterranean Sea, thus providing at once a confirmation and an extension of the theory advanced. It has been assumed that the general uplift of the now submerged land must have been from 6,000 feet to 7,000 feet, as gauged by soundings.‡

In the channel between France and England, an "English Channel River" has been traced out from its rise somewhere near the Strait of Dover for nearly 300 miles through a deepening channel to the point of its discharge into the ocean at about

---

* Fifth Report of the New York State Bridge and Tunnel Commission to the Legislature of the State of New York, 1913, Albany, 1913; Appendix B. p. 15.

† Efficient Citizenship (Bureau of Municipal Research), No. 632, July 6, 1913.

‡ Edward Hull, "Monograph on the Sub-oceanic Physiography of the North Atlantic Ocean," London, 1912, p. 3.

7° W. long., on the margin of the now submerged Continental Platform. The waters of the Seine probably flowed into this stream somewhat north of Cherbourg, and it also had for tributaries the streams entering the Solent. After receiving their accessions it passed along what is marked on the chart as "The Hurd Deep," a clearly marked channel 70 miles long, the depth of 186 feet at the upper end increasing to 336 feet toward the middle of its course, and then lessening to 162 feet at the end. Here the submerged channel has been kept clear by the strong tidal current, but above and beyond this point it has been silted up: the original entrance to the ocean was between lofty walls of rock.*

On the French Atlantic Coast the Adour may be selected as a typical stream. Having its source in the Upper Pyrenees, it enters the ocean at the foot of these mountains, Bas Pyrenees, near Bayonne. A characteristic feature of the submerged channel of this stream is that it is continuous from the present mouth of the river to the point of former entrance into the ocean 100 miles out from the shore line of to-day. At a distance of five or six miles from the shore the channel already has a depth of 1,050 feet (700 feet below the surface of the platform); after being joined about fifteen miles out by another channel, the bed sinks rapidly and the banks, rising to a height of from 4,000 to 6,000 feet, become so precipitous that it assumes the form of a deep canyon; when it finally reaches the original shore line, it has a depth of 7,200 feet.†

In Africa the Congo shows similar phenomena. This mighty river enters the ocean in latitude 6° S.; at this point, at Banana Creek, it is 49 fathoms (294 feet) deep; but on tracing out the submerged channel, at a distance of five miles from the shore, the soundings reveal a depth of from 1,368 to 1,452 feet, the width being here about two miles and the sides steep and precipitous. Still farther out, 50 miles from shore, the channel has widened to ten miles and a depth of 4,878 feet has been attained, the maximum depth of 7,200 feet being reached at a distance of 57 miles; the total length of this submerged channel to the point of its original entrance into the ocean is 122 miles.‡

---

* Ibid., p. 7.

† Ibid., pp. 8, 9.

‡ Ibid., p. 13.

Some years since, when several gentlemen were interested in producing arguments for the preservation of the Palisades, we realized that for strategic purposes the Palisades from Bayonne northward ought to be of great value to the Government. Then, as now, there is not a single soldier stationed there. If an enemy should land on the Jersey coast, march up along the rear of the Palisades and seize these heights, the entire city would be at their command. We realized at that time, upon investigation, that on the whole island of New York there was not a single soldier of the United States bearing arms to protect the city of two and a half million inhabitants. This matter is again brought to mind when we read of the quibbling in regard to the height of the subway tunnels. We have here the greatest city on the American continent. In case of war it might be of supreme importance to connect the northern part of Manhattan Island with Long Island, and to make this practicable there should be a proper standard-size track under the city. Should not facilities be provided by which, in case of necessity, a train load of soldiers could be run to the upper part of Manhattan Island, or to Long Island, over these tracks, or train loads of munitions of war, or supplies for the army or for the inhabitants of the city? And with tunnels an army could safely cross from shore to shore without an enemy being aware of their presence. From this viewpoint alone it seems that for strategic purposes it is most important that one or more, if not all the subway lines should be made of adequate size, and should have a standard-guage track, such as the railroads of the United States use, as otherwise the same trouble that made itself felt before the standardization of the railroads would arise.

We know that all the railroads interchange freight cars, and that these can be shipped from one part of the United States to another; but can any good reason be adduced to explain why passenger cars are not similarly shipped? How many realize the time it takes to go from Yonkers to Newark, or from Yonkers to Garden City? Why this great length of time? Simply because what we might term a financial boundary line runs between these points. Is there any reasonable excuse for not having an interchange of cars, when this could be accomplished by building not more than from ten to twenty miles of underground road in New York City, and by a little more co-operation between the great systems that terminate here?

It is difficult to find any good and sufficient reason for laying any other than a standard-gauge track, no matter for what purpose, except under very rare conditions. The fact that Russia had only a single-track, narrow-gauge road through Siberia had as much to do with her defeat by Japan as any other cause. A double-track, standard-gauge road was originally advocated, but certain of the high officials objected, stating that the road was built only for sentimental considerations.

When merchants in cities like Chicago can send from ten to twenty carloads of dry goods directly into their cellars, as do, for instance, Marshall Field & Company, or when a concern such as the Simmons Hardware Company can receive 150 carloads of nails for reshipment without repacking, this is a pretty good sign that Chicago is far in advance of New York City in aiding the development of wholesale business. The cost of hauling freight from a dock to a store often exceeds the cost of hauling for several hundreds of miles by rail. Why should we not exchange freight cars from through lines to municipal roads, just as they are now exchanged between the different railroads?

There is no doubt that the present subway system runs its cars in the smallest possible tubes, in order to carry the greatest number of passengers at the least possible expense. To this economy in the cost of transportation there would be no objection, if it did not work injury to the passengers; but when, as frequently happens, there are from 125 to 150 human beings in a single car, and that car has practically no air space above it, what is the meaning of the inactivity of the State Board of Health, or the City Board of Health, and of our various medical societies? Why is nothing done to prevent this? Let us have a high subway with plenty of trains, and let us have tracks permitting an interchange of cars, for the greater advantage of the people of this community.

The ease with which tunnels are driven even in rock under the river is shown in the new gas tunnel which was opened July 17, 1913, from 132d Street, Bronx, south to Astoria. It is 5,176 feet long, 21 feet high, 19½ feet wide and 150 feet below the river — 4,622.04 feet without a shaft opening. The total cost was $5,000,000.

The author and others have stated that a bridge across the Hudson River, at the end of One Hundred and Seventy-ninth Street, could not be built at a reasonable cost, because a sufficiently good foundation for the piers could not be obtained at that site. This statement has remained unchallenged, and is probably generally believed. It is therefore only proper to state that a group of engineers who claim that they are qualified to express an authoritative opinion, by long experience in the design and construction of deep and heavy bridge pier work, believe that the statement that piers could not be properly sunk, is incorrect.

The engineers of The Foundation Company state that piers for the longest projected spans at the 179th Street site can be so constructed and so sunk to a depth of about two hundred feet below the river bed that they will be absolutely stable and secure. As at no place in the Hudson River has a true bed been reached, and as it may be as much as 1,000 feet below, there is a geological as well as an engineering problem to solve here. They state further that the piers for the shorter spans can be founded with like security with less difficulty still; and that the two larger piers will cost not to exceed one and one-quarter million dollars each, while the smaller piers will not exceed in cost one-half of a million dollars each.

The projected larger piers would be the largest and deepest ever built, but they claim that their wide experience with deeply founded piers for important bridges across large rivers amply justifies the opinion that modifications and amplifications of known methods are all that is necessary to secure for the proposed bridge an absloutely solid and rigid superstructure.

The above statement is made by the company with the full knowledge of the soft materials encountered in the borings, and with a full appreciation of the difficulties involved.

In conclusion it gives me great pleasure to avail myself of this opportunity to thank Hon. McDougall Hawkes, of the New York Interstate Bridge Commission, who has afforded me every privilege and all the information it was in his power to extend.