The Technology Monthly
Engineering Journal

A MAGAZINE DEVOTED TO THE INTERESTS OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Vol. III — Contents, December, 1916 — No. 5

Entered as second-class matter at the post office, at Boston, Mass. Published monthly during the college year by the students of the Massachusetts Institute of Technology. Publication office, Massachusetts Institute of Technology, Cambridge, Mass.

Mail Address: Technology Monthly, M. I. T., Cambridge, Mass.

Subscription rate, $1.50 per year; 25c. per copy. Advertising rates upon application

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THE HANOVER STREET BRIDGE BALTIMORE, MARYLAND

By EDWARD CAMERON

THE construction of the Hanover Street Bridge, at Baltimore, Maryland, presents a good example of the methods used in constructing piers on an unfavorable river bed, and illustrates the tower and chute method of distributing a large yardage of concrete over an extended area.

This bridge, now practically completed, is about 2300′ long, contains upwards of 40,000 cubic yards of concrete, 1600 tons of structural reinforcing steel, and 800 tons of round steel reinforcing rods. The retaining walls, arcade, and river piers rest on yellow pine piles, while concrete piles carry the south abutment.

The north approach end consists of a retaining wall section 219′ long, and an arcaded section which is 423′ long. The retaining walls are of the counterfort type with concrete ties to the opposite wall. There are 20 longitudinal arches in the arcade section with 2 transverse arches every 20′. These arches carry a beam and slab system supporting the roadway.

There are eleven river piers extending to 25′ below mean low water, with 2 piers each side of the bascule span which extend to grade —35. Typical river piers have a 3′ base slab, 26′x69′, surmounted by the frustrum of a pyramid 5′ high. This supports a 4′ core wall and 12 buttresses which carry the cap of the pier, a solid block of concrete 8′ wide and about 12′ high. On this cap the super structure rests. The specifications called for 250 yellow pine pile for each typical river pier.

At this point the river bottom consists of a bed of mud beneath which there is a layer of iron ore which proved almost inpenetrable.

The method used to construct the river piers was as follows. First the site of each was dredged out to 4′ below grade. Then the piles were driven. The first few blows on each pile sunk it to the water level, after which a follower was used to drive it down to grade. In order to get the specified resistance it was found necessary to use piles up to 65′ in length. Next the piles were cut off with a submarine saw at grade minus 22 for typical piers and at grade minus 32 for the 4 bascule piers. After the piles were cut off, the cofferdam for the pier was built of Jones & Laughlin steel sheet piling. The river bottom was so soft that it was found necessary to support the sheet piling on temporary wood piles in order to keep the tops of the former above water.

The next operation was to seal the bottom of the cofferdam with a 2′-0″ slab of 1-2-4 concrete placed under water and resting on the pile heads. By plumbing down, the smallest dimensions of the cofferdam were found, and the bracing framed to this size, allowing a little play between bracing and sheeting so that when the cofferdam was pumped out the pressure would crowd the sheeting tight.

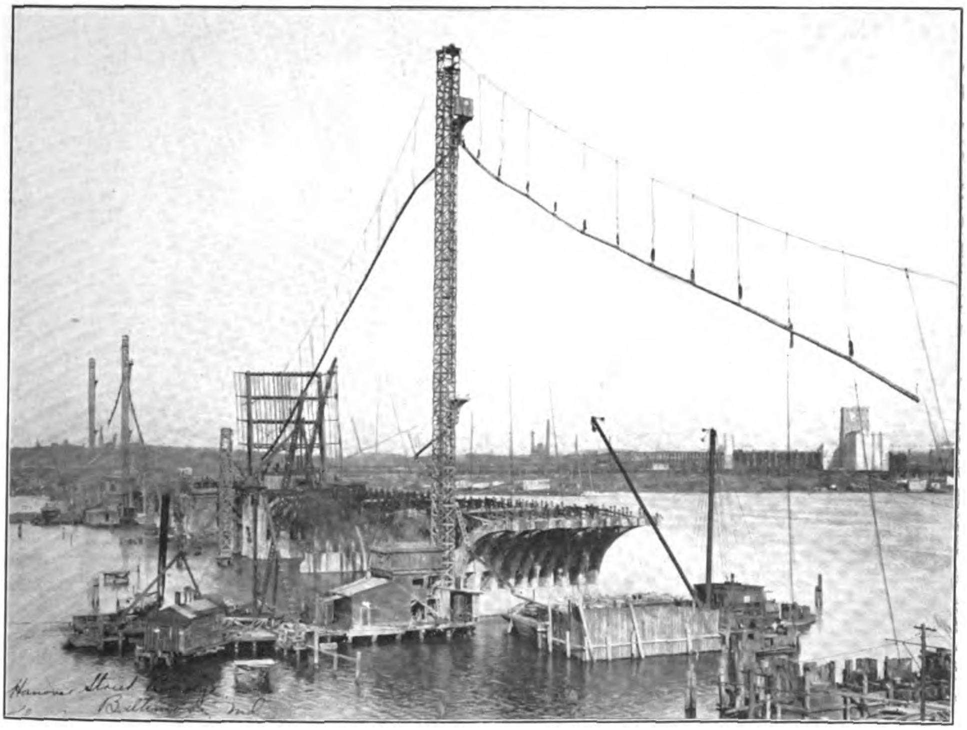
After the bracing was in place, the cofferdam was pumped out, an 8″ centrifugal pump being sufficient to unwater it in most cases, after which a 3″ pump was able to take care of the leakage. From this stage on, no great difficulties were experienced in finishing up the substructure.

The superstructure consists of 12

arch spans and a 150′ double leaf bascule span. The arches have a clear span of 95′ with a rise of 24′-9″. In fabricating structural steel, and for formwork for these arches, the rise was assumed as 25′-0″, thus allowing 3″ for camber. Each arch span is composed of 10 concrete ribs reinforced with structural steel trusses. The ribs are 2′-0″ thick, 2′-6″ deep at the crown and about 7′-6″ deep at the skewback, one rib being located under each car track, one under each sidewalk, and 2 under each roadway.

Strictly speaking the ribs are not arches, but act on the cantilever principle. The expansion joint occurs at the crown and the thrust is taken up by 2—7″x1 1-2″ steel eye bars which extend from the crown to a steel tower at the pier, being balanced by similar eye bars from the adjacent span. All steel work is encased in concrete, the eye bars being wrapped with wire lath and plastered.

18″x20″ spandrel columns outside ribs support the sidewalks, while 15″ square columns carry the system of roadway beams and slabs. The reinforcement for these columns was originally designed as steel rods, but a structural steel column with angles having an equivalent area was substituted, thus saving the labor of handling separate reinforcing bars. The roadway is 50′ wide, curb to curb with 8′ sidewalks.



THE HANOVER STREET BRIDGE, BALTIMORE, MARYLAND

The structural steel ribs were fabricated at the Maryland Steel Company's plant, at Sparrows Point, and were loaded on a lighter, 10 at a time, and towed to the site. They were made and erected in umbrella-shaped units each weighing about 10 tons.

Bottom forms for the ribs were made of 2″ yellow pine lagging spiked to 2″ joists sawed to the curve of the arch ellipse, and located under the lower chord angles of the steel ribs. Five-eighths inch bolts hung these forms from the chord angles. The side forms rested on the bottoms, and were spaced from the steel by spring steel wire clips which were snapped over the angles and spaced the forms 3″ from the former. These side and bottom forms were made up at a local mill according to detail drawings and were assembled in units of approximately 30 square feet.

While the concrete was green the 5-8″ bolts carrying the bottom forms were given a couple of turns to break the bond with the concrete. Later when it was time to strip forms it was found that practically all of these bolts could be unscrewed although a few had to be cut off.

Thus it will be seen that the structural steel ribs served the double purpose of providing reinforcement for the concrete and carrying the concrete forms, thus doing away with the expensive piling and false work in the middle of the river, which would otherwise be necessary.

To place the large amount of concrete required for this job, over such an extended area was a proposition which took a lot of study to decide. The system adopted was a tower and chute plant. One mixing plant was located on shore at the retaining wall end, one at pier 5, and one at pier 13; the latter two being supported on pile platforms in the river. Towers 200′ high were built at the mixing plants with elevators to raise the concrete to hoppers, from which steel chutes, hung by tackles from guys could place the concrete at any point within a radius of 450′.

By this means it was possible to place 350 cubic yards of concrete in a nine-hour day, and it was found that a carpenter gang of over 50 per cent of the whole working force were kept busy on forms in order to keep ahead of the concreting force.

Three sets of arch forms were made up in advance. All the form-work for this job had to be particularly well braced due to the speed with which concrete was placed by the chutes in contrast to the slower method of placing with wheelbarrows, as practised on smaller jobs. By the former method a relatively greater depth of concrete is poured at one time so that there is no chance for the lower layers to get the slight set which ordinarily relieves the lateral pressure of the concrete to some extent.

Exposed surfaces of the piers and ribs were given a very coarse bush-hammered finish, while the balustrade received a carborundumed rubbed finish.

The accompanying pictures show the general design of the bridge and give a good idea of the layout of the construction plant. The frontispiece shows sections at all stages of construction. At the extreme left, the retaining wall and arcade sections may be seen. South of these several spans are shown, completed except for the balustrade. One leaf of the bascule had been erected at this stage of the game. The cantilever construction of the bays is shown at pier 13, just in front of the tower at the right, while the cofferdam and substructure of pier 14 appear just south of pier 13.

In the illustration on the preceding page we see the concrete tower at pier 13, also the suspended chutes. A hopper is shown part way up the tower with a chute delivering concrete to the substructure of pier 14, the cofferdam for which appears in the foreground. The mixing plant for this tower may also be seen in the foreground. On the shore at the right is a pile of bottom forms for the arch ribs, all ready for erection, while a relay tower is seen south of the tower at pier 13.

The Hanover Street Bridge was designed by the State Roads Commission of Maryland, H. G. Shirley, Chief Engineer, and J. E. Greiner, Consulting Engineer, and was erected by H. P. Converse & Co., General Contractors, of Boston, during 1915 and 1916.

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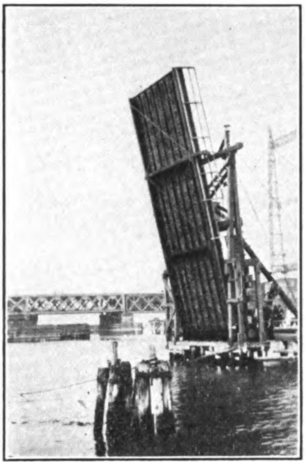

Fig. 7—Temporary draw ready to operate. Washington St. Bridge, Norwalk, Conn.

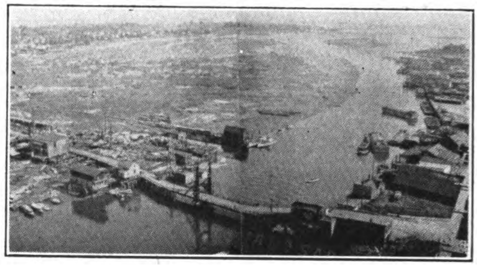

Fig 10—Temporary bridge in service: old bridge removed. Washington Street Bridge, Norwalk, Conn.

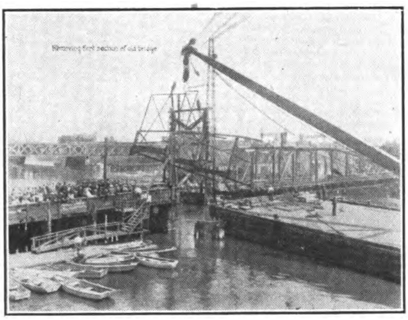

Fig. 8—Removing old swing span. Washington St. Bridge, Norwalk, Conn.

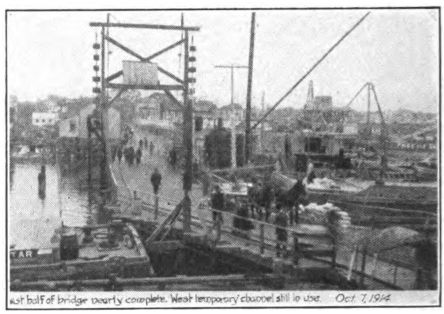

Fig. 11—Washington Street Bridge, Norwalk, Conn.

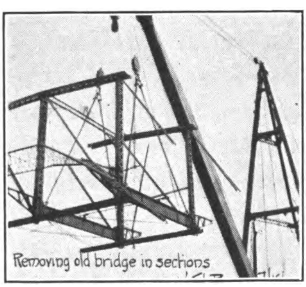

Fig. 9—Removing old swing span. Washington Street Bridge, Norwalk, Conn.

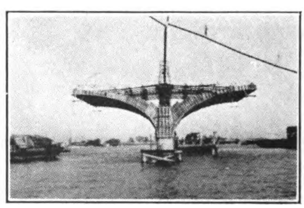

Fig. 12—Cantilever arch construction. Constructing first unit. Hanover St. Bridge, Baltimore.

span could operate freely above it, and the handrailings and tower bracing, which would have interfered with the draw, were not placed until after its removal. Without this bracing the tower was not sufficiently strong, hence the west temporary leaf could not be placed until the old draw was removed and the bracing placed. This west leaf was, therefore, constructed on a barge and floated into place when needed. This operation was performed on a falling tide so that the span was slowly lowered into position, after which the barge was floated out from beneath it. The hoisting cable and counterweight chains were then connected and the temporary bridge placed in service, with only about 24 hours obstruction to the river traffic. Other figures show how the hoisting cables and tower bracing were reversed to permit the channel to be shifted to the east opening.

(3) Methods Employed to Overcome Difficulties in the Design of the Hanover Street Bridge, Baltimore.

(Fig. 12.) When the Hanover Street Bridge in the City of Baltimore was being designed, it was decided by the State Roads Commission that it must be an arched structure. The foundations, however, had to be built in sand and silt of such depth as to require 100-foot piles in some places. With such foundations an arch of the usual type was out of the question. To meet these two requirements, I invented a modified form of arch which does not produce any horizontal thrust against the foundation, and which at the same time will permit any foundation to settle without causing cracks in the structure. The methods of construction and design are clearly shown in the figures. It will be seen that in appearance it is a true arch, but at the crown the arch ring is cut through so that from the crown of one arch to the crown of the next the pier and arch rings and roadway are a unit, which can settle in any way without affecting either adjacent unit. Each of these units is exactly balanced under the weight of the structure alone, but when a street car or other load passes over the bridge, each unit receives this load in passing, first on one side and then on the other. Under such conditions there is a tendency to rock back and forth, hence the foundation is very much widened out to give the necessary stability, the amount being relatively very small, however, because the ratio of live to dead load is small in a concrete bridge. (Figs. 13, 14, 15.)

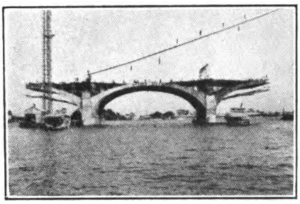

FIG. 13—Two adjacent units, nearly complete. Hanover St. Bridge, Baltimore.

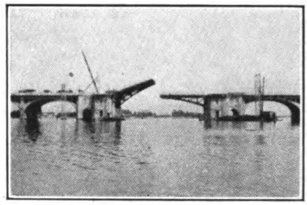

FIG. 14—Arches and bascule. Bascule piers are widened to provide anchorage for adjacent arch. Hanover St. Bridge, Baltimore.

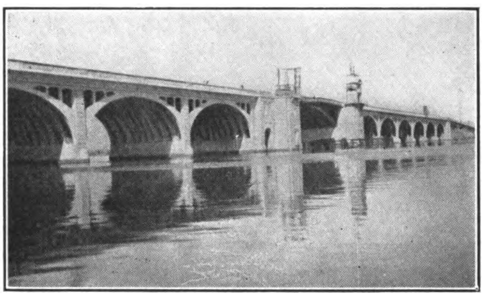

FIG. 15—Hanover St. Bridge, Baltimore, complete except for operating towers.

The method of construction of these units is as interesting as the design, for after the pier was completed, a steel frame or rib was set on the center line of each concrete rib of the arch. These frames were fabricated complete at the Sparrows Point plant of the Bethlehem Steel Co., and then placed upright on scows and towed to the bridge site, where they were lifted by a derrick and set directly in place. After they had been bolted down to the pier, the forms for the concrete were built around the steel frames, and then the concrete was poured in, completely surrounding the steel. During the process the forms were supported by the steel, hence no scaffolding or centering was necessary to support the concrete while it was still unset. Of course, it was necessary to place the concrete simultaneously on both sides of the pier so that the whole was balanced, otherwise the unit would have overturned. (Figs. 13, 14, 15.)

This design is an excellent illustration of a structure which was adapted to meet the conditions of the site, and of a method of construction invented to overcome the expense and uncertainties which would have resulted from the conditions had the usual method of construction been followed. The method is original, but the principle has been recognized for several thousand years and can be found in bridges still standing in Persia and China.

(4) Possibilities in the Use of Concrete Caissons for Bridge Piers.

One of the strongest objections raised against the design just described was the fact that it required a width of footing greater than would be required for an arch of the usual type. This was only true to a limited extent, because the use of piles in either case would require an excessively large footing. The result of this width is, of course, to very greatly increase the cost of cofferdams, pumping, excavation, etc. The great softness of the river bottom increased the difficulties, for it was anticipated that there would be considerable inflow of water through the bottom of the dam, the water working its way under the lower edge of the sheeting.

(Fig. 16.) In order to eliminate this element of increased cost, I suggested the use of concrete open caissons, and the discarding of the cofferdams. Construction by this method would be as follows: The lower portion of each pier would be built on shore on slipways provided for the purpose, and when completed to such a height that it would float, this would be launched just as a timber caisson or a ship is launched. The amount completed on shore could be only such that the structure could be floated out into place without grounding on the shallow bottom near shore, and such that it could be conveniently handled. When the caisson had been floated into its final place and secured to

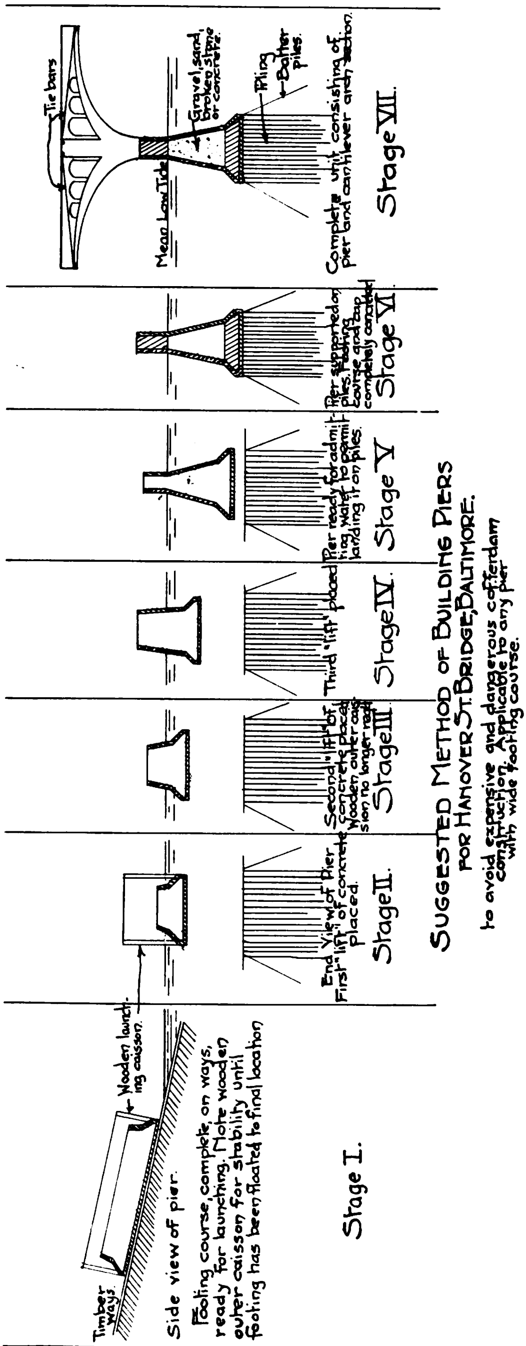
Tie bars
Gravel, sand, broken stone or concrete.
Piling
Batter piles.
Mean Low Tide
Complete unit consisting of pier and cantilever arch section.
Stage VII
Pier supported on piles. Footing course and cap completely concreted.
Stage VI.
Pier ready for admitting water to permit landing it on piles.
Stage V
Third "lift" placed
Stage IV.
Second "lift" of concrete placed. Wooden outer caission no longer needed.
Stage III.
End View of Pier. First "lift" of concrete placed.
Stage II.
Wooden launching caisson.
Timber ways.
Side view of pier.
Footing course, complete, on ways, ready for launching. Note wooden outer caisson for stability until footing has been floated to final location
Stage I.
SUGGESTED METHOD OF BUILDING PIERS FOR HANOVER ST. BRIDGE, BALTIMORE.
to avoid expensive and dangerous cofferdam construction. Applicable to any pier with wide footing course.

FIG. 16