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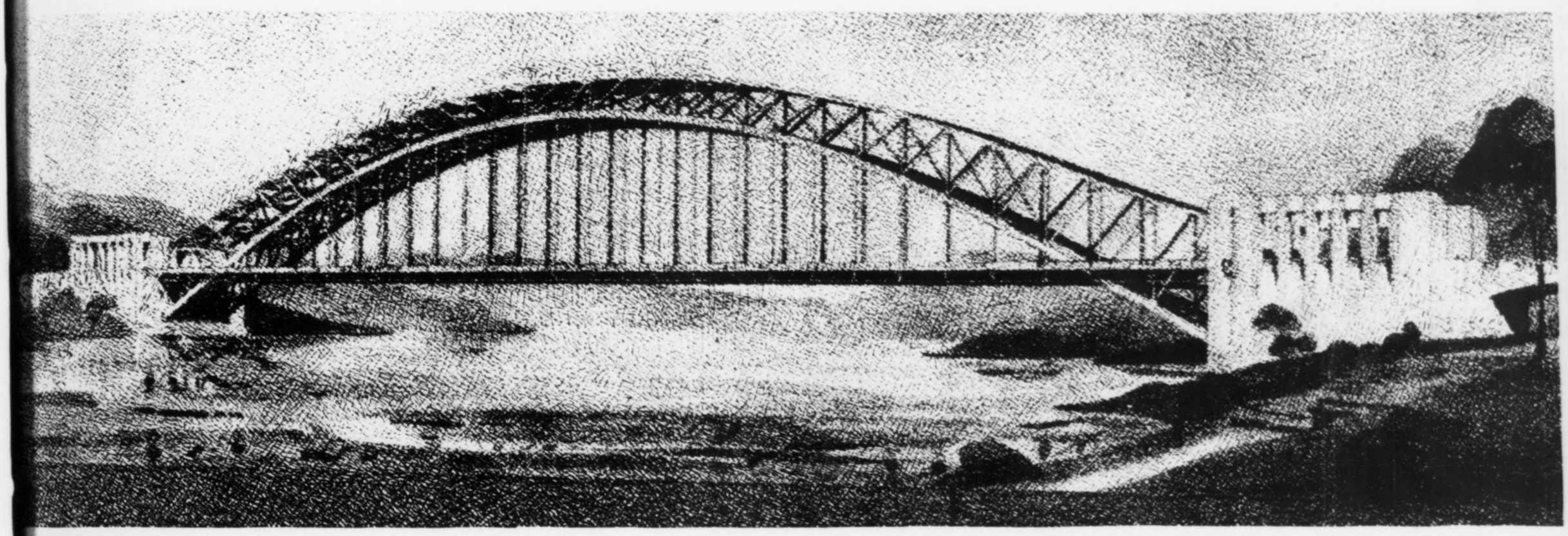

New Croton Lake crossing for Westchester County parkway
is a three-hinged arch of notably long span

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Erecting a 750-Ft. Steel Arch Without Falsework

Contractor utilizes cable tiebacks and temporary cable-bent towers to build each half as a cantilever arm on Croton Lake structure in Westchester County, N. Y., longest three-hinge design on record

By W. FREDERICK WELSCH
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THE NEW steel arch over Croton Lake in northern Westchester County, N. Y., is the largest of the many bridges in the county's extensive highway system. It is also believed to be the longest three-hinged arch yet built. In addition to features of architectural and technical interest, it was erected by a cantilever method involving the use of temporary cable tiebacks, utilizing hydraulic-jack adjustment. The bridge is 750 ft. c. to c. of end pins, 44 ft. c. to c. of trusses and carries a 40-ft. roadway and a 6½-ft. sidewalk on each side. The bottom chord has a parabolic outline with a rise of 125 ft. The bridge required 1,400 tons of carbon steel, 600 tons of silicon steel, 60 tons of cast steel and 300 tons of reinforcing steel.

The location of the bridge on the new Bronx River Parkway Extension is shown in Fig. 2. Croton Lake is a part of New York City's water-supply system and is located in the foothills of the Catskill Mountains. Because of the topography of the surrounding country a monumental structure was desirable, and the steel arch was selected as best meeting this requirement. Conditions at the site also were somewhat unusual and influenced both the character and the erection of the superstructure. The parkway crosses the lake at its narrowest point, the distance between shore lines being about 700 ft. at normal water level; the water is about 90 ft. deep for a large part of the width. This latter condition dictated a single span, and the desired alignment of the parkway brought the span length to 750 ft. The possibility of some settlement of the north abutment made a three-hinge design advisable.

The monumental character of the abutment design is indicated in Fig. 1, on achitect's wash drawing. These abutments as well as the flanking spans on the approaches are of concrete, unfaced, but with accentuated formmarks (Fig. 4). All pilasters and columns in the abutments are precast concrete blocks, and the concrete blocks for the balconies are made of cast stone of approximately the same color as the wall concrete.

Design

At the south abutment, rock is very close to the surface, but near the north abutment it is from 80 to 150 ft. below the water, rising toward the north and overlain with sand, gravel, clay and boulders. The latter material, however, was so densely compacted that it was deemed suitable for foundation material. During excavation the dense character of the material shown by the borings was verified. Indeed the sides of the excavation remained vertical enough to be utilized as forms against which the abutment concrete could be poured.

Although the material at the abutment sites was found to be satisfactory, the possibility of a slight settlement of the north abutment indicated the desirability of a three-hinge arch, as a small movement of the supports of this type of bridge does not alter the stresses as it would with a two-hinge type. Freedom from temperature stresses and from the delicate adjustment at closure are additional advantages of the three-hinge design. The effect of a range of 100 deg. in temperature on this structure was estimated to move the crown pin vertically only 10 in.

Fig. 1—New Croton Lake crossing of Bronx Parkway Extension in Westchester County, N. Y.

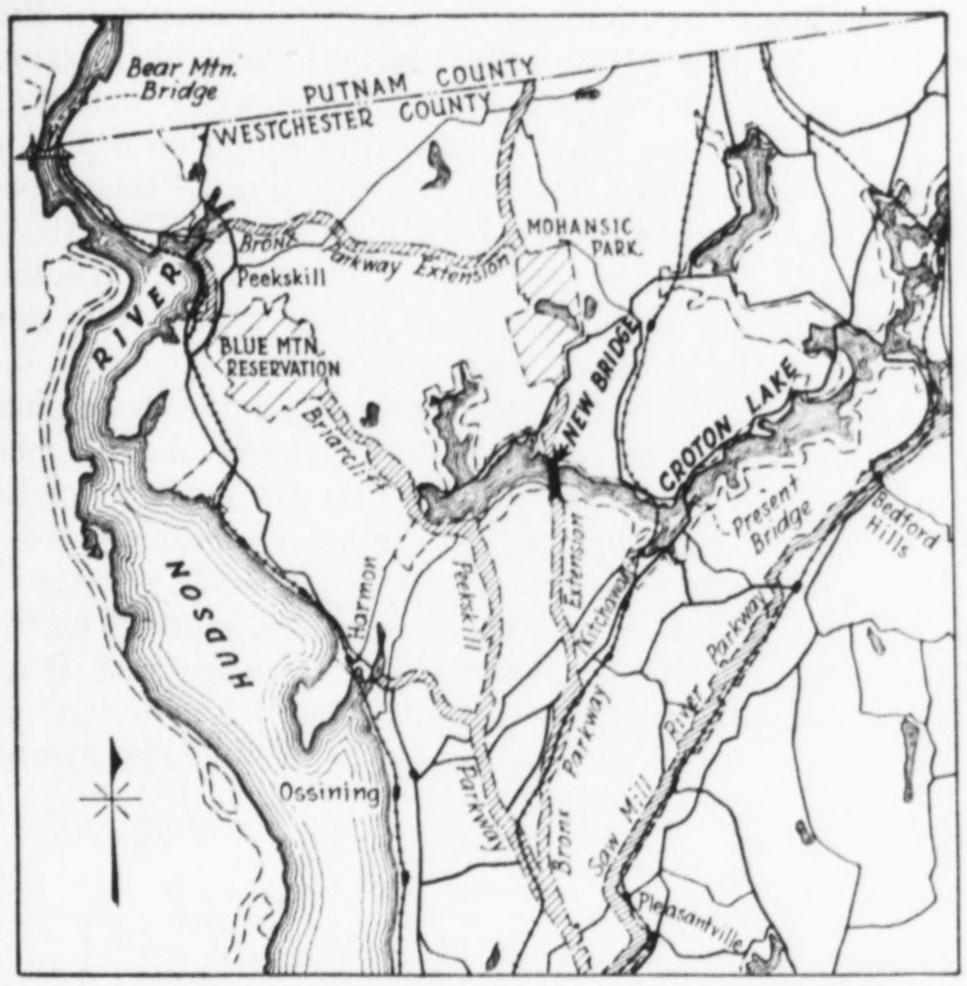

Fig. 2—Upper Westchester County, showing location of new Croton Lake crossing

the bottom chord of the arch, and anchorages at the ends of the span, where the reactions are taken by the transverse bracing and carried to the bearings. The chords of these cantilever trusses are supported at the ends of the floor beams and pass outside of these members, so that they extend from end to end of the span, interrupted only at the two expansion points. In designing the floor a 20-ton truck was assumed in each lane of traffic with a live load of 100 lb. per sq.ft. on the sidewalk.

The bridge is exposed to the effect of violent storms, and the bracing was designed for a wind pressure of 50 lb. per sq.ft. of exposed surface on both arches, together with an additional allowance for exposed surface of bracing. The bracing is so designed that the wind pressure from the top chord will be carried by frames to the bottom chord, and the bottom chord laterals are proportioned to carry all wind loads to the abutments. The laterals of the top chord are proportioned to provide proper stiffness to the chord as a compression member.

Erection

The erection of the steel superstructure presented several difficulties. The depth of the water and the steep slope of the lake bottom for over 100 ft. out from each

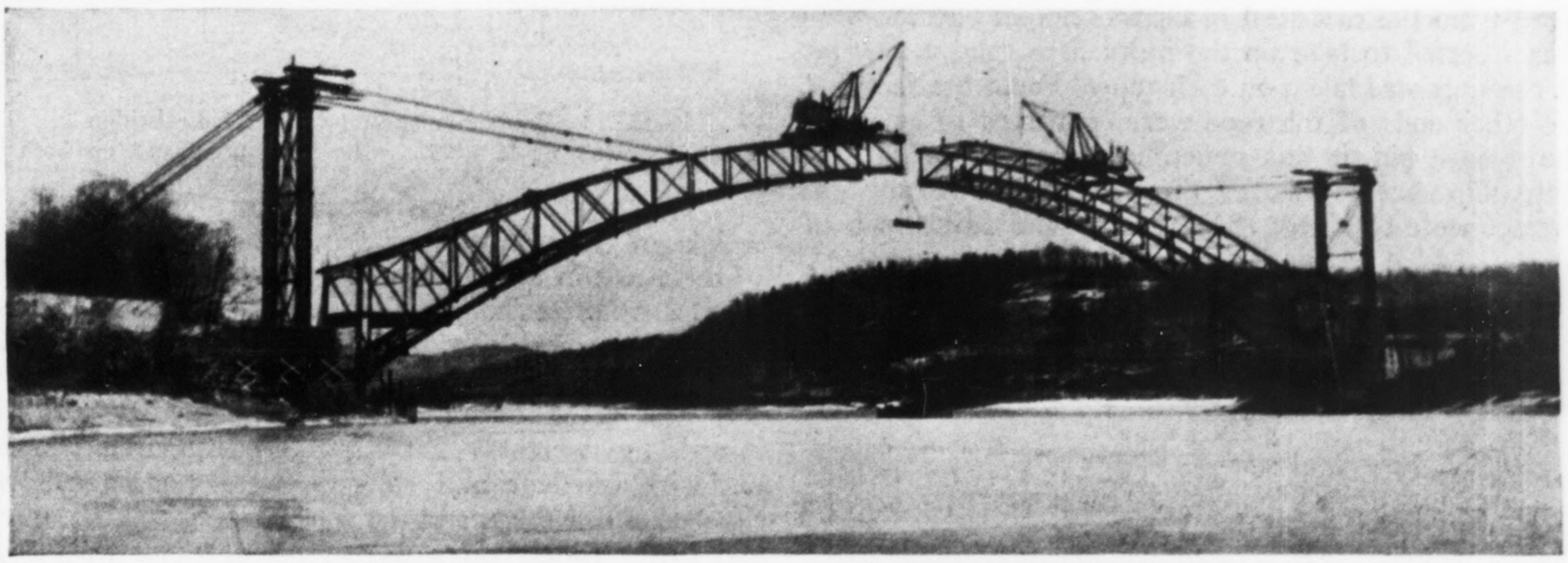

Fig. 3—Deep water and presence of water-supply aqueduct under bed of lake dictated adoption of cantilever erection without falsework

The curve of the bottom chord was made parabolic. Consequently, for a uniformly distributed load over the entire span there would be no stresses in the arch outside of this member, the top chord and web members being stressed only from live loads unevenly distributed and from minor variations in the dead load. The bottom chord being the main stress-carrying member, it was found economical to design it in silicon steel. Other members are of carbon steel rolled to special specifications.

The floor, for the greater length of the span, is suspended from the arch but crosses the bottom chord at the second panel point from each end. A reinforced-concrete slab, continuous from curb to curb, rests on 18-in. I-beam stringers carried on top of the floor beams, this arrangement providing easy installation of forms for the floor slab and accessibility for inspection. Two main expansion joints are provided in the floor 100 ft. from each end of the span.

The floor has its own lateral system, designed as a horizontal cantilever with hinges at the expansion joints, fulcrums at the two points where the floor intersects

abutment made the use of ordinary falsework impracticable; the use of steel cylinder piers was not advisable because of the difficulty of securing good footings. Another objection to supporting the arch from the bed of the lake was the uncertainty as to the location of the old Croton aqueduct near the south end of the bridge. This aqueduct, which carries part of New York City's water supply, is buried only a few feet beneath the bed of the lake; and since an injury to it would be serious, it would have been necessary to make a subaqueous excavation to locate the aqueduct before placing bents for the support of the arch.

The plan finally chosen involved a system of tie-backs and heavy concrete anchorages buried in the earth some distance back from each end of the bridge. From these anchorages the cable tiebacks were connected to three points on the top chord of the arch (Fig. 5). The first tieback ran from the anchorage direct to point U_6. The other two ran from the anchorage to the top of a 147-ft. cable-bent tower, supported on the arch abutment, from where forestay cables ran to points U_5 and U_8. The tower was designed to rock in the plane of the cables

(by machining the base of the tower to a radius equal to the height of the tower) so as to avoid bending stresses. Each half-arch was erected as a separate operation, with closure at the center. Steel was erected with two steel travelers, each equipped with a stiff-leg derrick and steam hoisting engines.

Erection Towers—The cable-bent towers were built from the floor beams of the bridge. There were two pairs of posts in each tower, and each post was made up of three floor beams on end, one on top of the other. A special structural-steel base and top were fitted to the ends of these lines of floor beams. Each pair of posts was laced together with angles to form a tower leg; and floor-beam hangers, which were made of four angles, battened, were used as bracing between the legs.

Since there was no material in the floor system of the bridge suitable for use as tiebacks, $2\frac{3}{8}$-in. diameter galvanized-steel bridge cables were used. These cables had an ultimate strength of 256 tons each, were pre-stretched at the factory to take out the construction stretch and were socketed to length under the maximum tension that they would receive when in use. Adjustment of cable length was accomplished by the use of a hydraulic pulling jack, which pulled each cable separately. All the cables in a group were pulled to a certain reading of the gage on the pump jack, and the distance that the socket pulled away from the cast-steel block was noted. Shims were then inserted to take up the inequalities, and a new set of readings was taken on each rope. From the fact that the other ends of the rope were connected to equalizer plates on a pin, it was sometimes necessary to go over these adjustments two or three times before uniform stresses were obtained. The erection and adjustment of

Fig. 4—Accentuated form-marks decorate faces of concrete abutments and approach spans

these cables proved to be tedious and very expensive.

The towers were placed symmetrical with respect to the span. This was not possible with the anchorages, and at the north end the anchorage was placed relatively close to the tower in order to avoid interference with a road that ran parallel to the lake shore. At the south end of the bridge it was desired to erect a concrete approach arch before the erection of the main span. The south anchorage, therefore, has to be placed far enough back so that the first-stage cables would clear this work.

Both north and south anchorages consisted of a block of concrete 15 ft. high, 20 ft. wide and 60 ft. long, reinforced along the bottom and the vertical side farthest from the bridge with $\frac{3}{4}$-in. square bars, $8\frac{1}{2}$ in. on centers. Embedded in this concrete block were 6-in. eyebars, one group on the center line of each truss, the bottom end of these eyebars coming to the lower rear corner of the block of concrete. The upper ends of the eyebars came above the subgrade of the roadway and were connected by a pin to a structural-steel shoe that rested on top of a structural-steel bent. The same pin connected them also to the plate hitches of the backstay cables. The structural-steel bent at this point was necessary to take the vertical reaction of the first-stage cables, which were not in line with the direction of the eyebars.

In designing the concrete anchorages the following assumptions were made: weight of concrete, 140 lb. per cu.ft.; backfill over anchorage, 90 lb. per cu.ft.; weight of undisturbed earth, 100 lb. per cu.ft.; bearing pressure on undisturbed earth, 4,000 lb. per sq.ft.; pressure on vertical side of anchorage against undisturbed earth, 4,000 lb. per sq.ft. at bottom of anchorage and 0 at the surface of ground. The friction of concrete on earth was assumed at three-tenths of the net downward

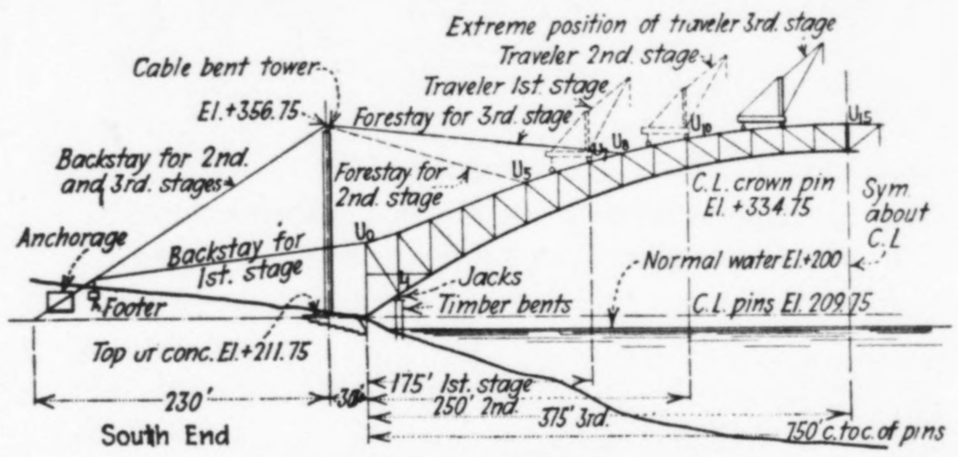

Fig. 5—Erection diagram, Croton Lake bridge
Closure was made at L_{15}. Erection procedure on both arms was similar.

weight of the concrete—that is, the vertical component of the stress in the cables was deducted from the weight of the concrete before figuring the friction. These anchorages were designed for a factor of safety of 2.

Erection Procedure—After the general dimensions and location of towers and anchorages had been determined, the weights of the steel in the arch trusses, exclusive of floor and hangers, were computed from the design drawings, and the concentrations at the upper and lower panel points were figured. The weight of the traveler was estimated to be 70 tons, or 35,000 lb. on each of four wheels, the spacing of the wheels along the truss being approximately one panel length. The stresses in the cables and towers were computed analytically for the three stages of erection. The first stage covered the panels from U_0-L_0 *to* U_7-L_7, with the arch supported by backstays attached at U_0. The second stage continued the erection from U_7-L_7 to U_{10}-L_{10}, with the truss supported by backstays at U_5. The third stage covered the erection of the remainder of the half-truss, with the truss supported by the backstays at U_8. This three-stage erection was necessary because the top chord was not heavy enough to carry the truss and traveler as a cantilever for more than seven panels. It was found that the erection stresses in three of the web diagonals—namely, U_8-L_9, U_9-L_{10} and U_{10}-L_{11}—were excessive for carbon steel, and these three members were made of silicon steel.

The topography at the north end of the bridge was such as to make the handling of heavy steel pieces very difficult. At the south end of the bridge, however, there was a roadway along the shore of the lake only a few feet above the level of the water, so that it was decided to haul all material from the railroad station (a distance of $3\frac{1}{2}$ miles) to this end of the bridge. A stiff-leg

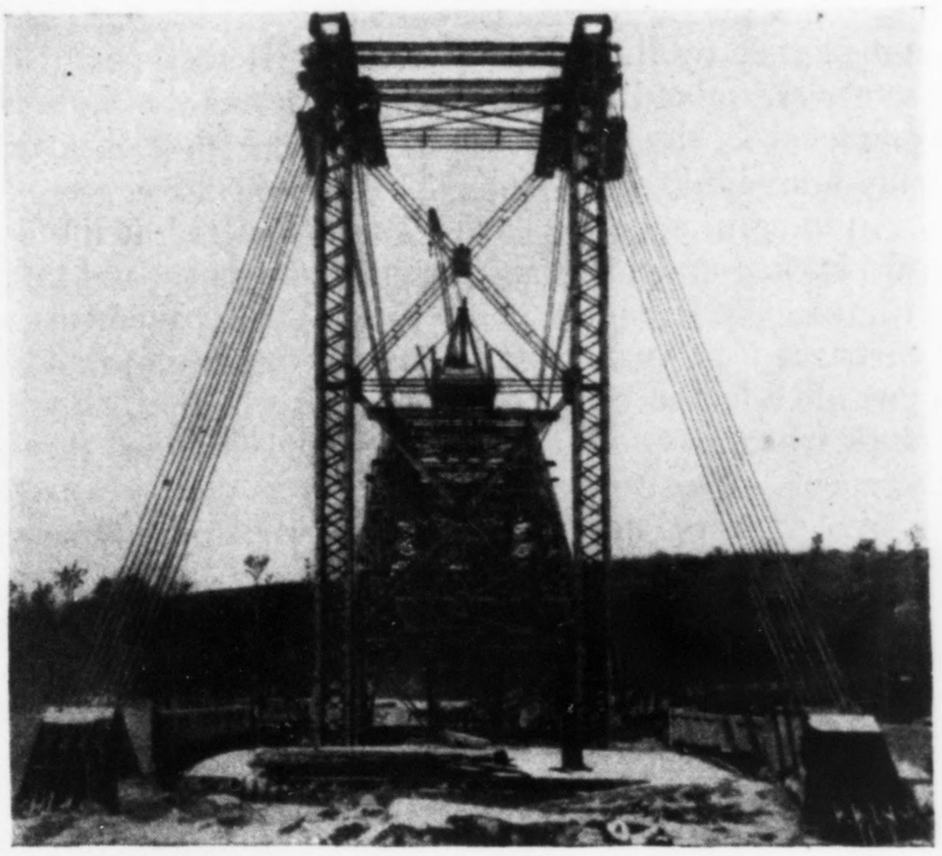

Fig. 6—Backstay cable anchorage and cable-bent tower

derrick was erected in such a position that it could unload the steel from the trucks as they arrived and store it in the small space available at this point. The derrick also was so located that it could place the steel on barges for transportation to the point where it was needed in the bridge, although the severe drought of 1930 caused the water in Croton Lake to fall to such an extent that a second derrick was later required to reach the barges.

Two timber barges 45 ft. long, 22 ft. wide and 4 ft. 3 in. deep were decked over tight so as to prevent possibility of being swamped by waves when loaded. At one end of each barge a two-drum gasoline hoisting engine was installed, the steel cable from one drum being attached to the south shore and that from the other drum to the north shore of the lake. By properly locating the anchorages of these cables the barge could be brought to any desired position. Each barge had sufficient carrying capacity to accommodate all the steelwork of one panel of the arch.

The procedure for erecting the steel was as follows: one of the travelers with a 145-ft. boom was assembled on the south shore and erected the cable-bent tower, which was held in place by temporary guys. Working through the tower, the traveler then set the first two panels of the truss, using the arch shoe and a temporary timber bent at L_1 as supports. The first-stage cables were then stretched between the anchorage and the hitch at U_0, using a heavy hydraulic jack on top of the timber bent at L_1 under each truss to raise the truss sufficiently to connect the backstay cables. The second traveler was then erected on top of the top chord. The jacks then let the truss down so that the load was taken by the backstay cables, and the timber bents at L_1 were released.

The erection of the trusses was then continued, using the cantilever method, to U_7-L_7, at which time the traveler was moved just far enough beyond U_5 to allow the auxiliary boom that was placed on the rear of the traveler to erect the hitch material at U_5. One group of four cables was then attached between U_5 and one of the links at the top of the tower. There were two of these links for each truss spaced 5 ft. on centers, symmetrical about the center line of the truss. After these cables were attached and adjusted the 400-ton jack in the link picked up the load of the truss so as to release the cables from the hitch at U_0.

The second stage of the erection then proceded to U_{10}-L_{10}. At this point the traveler was moved forward just enough to allow the erection of the hitch material at U_8. Four cables were now attached from the hitch at U_8 to the other link at the top of the tower. After being adjusted the jack in this link picked up the load so as to slack off the cables at U_5. These cables were lengthened by attaching additional cables of the same size. This second group of four cables was then adjusted and the load divided between the two groups of cables, the stresses being determined by the reading of the dials on the hydraulic pumps.

By the time this point was reached the north abutment was ready to receive steel. It was deemed advisable to stop work on the south side until the erection of the north side was brought up to a similar stage. Then with steel in place out to L_{10} on each side, both arms were erected simultaneously until they met at L_{15}. They were then carefully lowered by the jacks in the forestays until the two half-arches came to a bearing on the center pin at L_{15}.

The travelers were then removed from the top of the trusses, the towers dismantled by the use of the 145-ft. boom, and the hangers and floor system were erected by using runner lines from hoisting engines placed at each end of the bridge, these lines passing over sheaves attached at the panel point of the truss where the steel was being erected. The eyebars of the anchorages were burned off below the subgrade of the roadway; the concrete anchorages were left buried.

All the steelwork of this bridge was assembled in the shop and reamed and match-marked. The trusses were cambered for dead load, the camber being figured along the center line of the chords. However, the depth of the bottom chord was so great that, when the trusses were assembled in the shop with this camber, it was found that the bottom of the joints were slightly open. It was decided to ream and match-mark all members of the trusses in this position except the bottom chord. The trusses were then taken down and the bottom chord reassembled so as to get a full bearing for the entire depth of the joints. These joints were then reamed and match-marked. When the work was erected in the field the same opening at the top of the bottom-chord joints existed until the arch was closed, and the dead load was carried by the bottom chord. For this reason the joints of the bottom chord were bolted until after the arch was swung. Riveting of all other connections was carried forward as the work was erected.

The method of erection and the falsework materials were designed by the Mount Vernon Bridge Co., of Mount Vernon, Ohio, under the direction of J. K. Lyman, assisted by the late Russel Vaughan and approved by Howard C. Baird, consulting engineer, New York City, who designed the bridge. The steelwork was fabricated and erected by the Mount Vernon Bridge Co. The concrete anchorages were constructed by the general contractor, the P. T. Cox Contracting Co., New York, P. T. Cox, president, W. T. Fitzpatrick, chief engineer, and A. J. Foote, superintendent.

The Bronx Parkway Extension is under the administration of the Westchester County Park Commission, Jay Downer, chief engineer, L. G. Holleran, deputy chief engineer, Gilmore D. Clarke, architect. The writer was in charge of field engineering and construction, and Samuel Rosenberg was resident engineer.