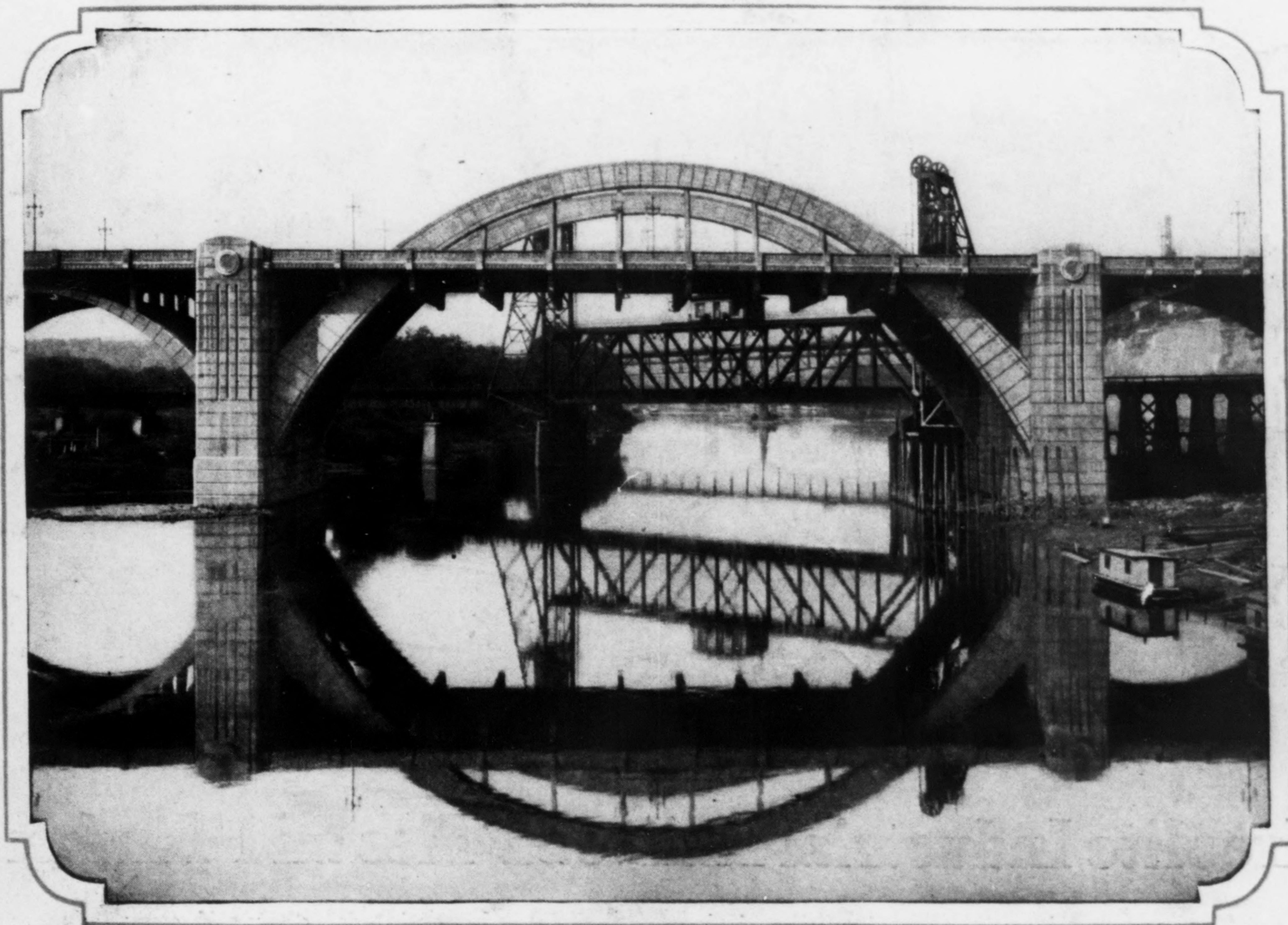


NOV 8 1926

Engineering News-Record

Devoted to Civil Engineering and Contracting. McGraw-Hill Publishing Company, Inc.

November 4, 1926



Robert Street Bridge Across the Mississippi at St. Paul

Engineering and Architectural Design of a Long Concrete Bridge

By W. E. King and Roy Childs Jones

Structures on a Texas Water Service District

By J. L. Lochridge

Straightening the Chicago River Involves Many Problems

Concrete Drydock Completed in Twelve Months

Engineering and Architectural Design of a Long Concrete Bridge

Robert St. Bridge at St. Paul Has 264-Ft. Two-Rib Arch Channel Span Flanked by Five-Rib and Barrel Arch Spans—Structural Steel in Main Spans

By W. E. KING AND ROY CHILDS JONES

Of Toltz, King & Day, Inc., Engineers and Architects,
St. Paul, Minn.

A CONSPICUOUS structure at St. Paul, Minn., is the new Robert St. bridge across the Mississippi River, which was opened for traffic Aug. 6, 1926. It is a reinforced-concrete arch structure replacing a steel bridge built in 1881, the replacement being made to secure a wider roadway. As the old bridge had a minimum width of 32 ft. between curbs, with two sidewalks 8½ ft. wide, congestion resulted largely because vehicles could not pass the street cars. The new bridge has a 56-ft. clear roadway with two 10-ft. sidewalks, the bridge being made the full width of the street. Interest in this bridge centers in the reasons for the adoption of the parts which make up the whole, and in the architectural treatment. The construction methods will be dealt with in a separate article.

* * *

Engineering Features of the Bridge

By W. E. KING

ANY study of the engineering features of this bridge must take into consideration the very congested local conditions, the location of nearly every pier being predetermined by the clearances required by existing structures and railroad property. From the general elevation, Fig. 2, it will be noted that the bridge crosses successively over Second St., the freight shed and tracks of the C., St. P., M. & O. Ry., the tracks of the St. Paul Union Depot, which handles the entire passenger traffic of the city, the main line of the Chicago Great Western R.R., and the river channel of the Mississippi as defined by the War Department, the south end of the bridge then terminating in a busy manufacturing district. The elevation of the roadway was determined by the grade of Robert St. at the two ends of the bridge and by the limitation that the grade on the bridge proper must not exceed 3.1 per cent, which was the grade of the old bridge. These conditions, combined with the clearances required by the railroads and the government clearance of 47 ft. above ordinary high water, practically determined the location of the roadway.

The total length of the bridge including approaches is approximately 1,900 ft. Starting at the north end, there are a reinforced-concrete trestle with three spans of varying length totaling 89 ft.; a skew steel deck-girder span of about 53 ft. across Second St.; three flat barrel arches with a combined length of about 291 ft. followed by a two-rib arch span of 264 ft., c. to c. of piers, and four five-rib arch spans totaling 514 ft.; then a 311-ft. concrete trestle on concrete piles, with eight spans; and finally 260 ft. of earth fill between buildings and concrete retaining walls.

Foundation conditions were determined by borings made during the winter of 1923, some twenty holes being driven about 10 ft. into a fairly level layer of

Shakopee limestone found at El. —81 or about 66 ft. below the river bottom. The material above the limestone consists of indiscriminate layers of gravel, coarse sand and fine sand, with occasional layers of clay and pockets of fine sand (possibly quicksand). On the north shore is encountered a layer of sandstone overlain with "tumble rock" from the cliffs above and cemented together with clay into a hardpan.

Foundations and Piers—Two types of foundations were considered: Piles and a caisson type which would extend the concrete foundations to the limestone ledge. The latter would have provided the unyielding foundation so necessary for an arch bridge, but the expense would have been much greater than for the wood-pile design which was adopted. In order to secure rigidity, the piles were jetted and driven to a practical refusal. In every case they were driven below any possible river scour and were cut off at or below low-water line. At the north end, where piledriving was impossible, the foundations were set upon hardpan. For the trestle and retaining wall at the south end of the bridge, where there is no danger of scour, short concrete piles were cast in place, with cores driven to refusal. These foundations were stopped at El. +6, the only consideration being that they would extend below frost line.

One of the interesting problems lay in the location of piers 1, 2, 3 and 4. It will be noted that the government river channel, 160 ft. wide, passes under the bridge at a skew to the south. The location of this channel is determined by that of the lift span of the Chicago Great Western R.R. This line crosses under the bridge on a skew to the north and it was necessary to locate a pier in the angle between these clearances if an arch span was to be used.

Pier 2 had to be no wider above ground than the pier of the old steel bridge. Pier 1 likewise was limited as to width by the clearance lines of existing railroad tracks. A glance at the design of these piers, Fig. 3, will show that they are much more slender than would ordinarily be used, and are in fact vertical reinforced-concrete cantilever extensions of the wide footings below ground. South of pier 4 there were no limitations as to pier locations, so that span length was determined by economic considerations, taking into consideration also the architectural appearance of the bridge as a whole.

Each pier footing consists of a heavily reinforced concrete mattress resting on piles spaced 30 in. c. to c. in each direction. Above this, the piers are of mass concrete, reinforced for temperature stresses and for eccentric loading. Where piers are extended for architectural treatment, the concrete has been cored out for economy, the exterior walls being approximately 2 ft. thick. Above the haunches of the arches the piers are hollow and are utilized for manholes for the public utilities.

Through-Arch Span—The main point of interest is the 264-ft. through-arch span, 244 ft. in the clear between piers. This design was necessary because of the government requirements of 62-ft. headroom above low-water for a skewed channel width of 160 ft. or 180 ft. along the bridge. With the roadway elevation as fixed, a through span was necessary if an arch span was to be used. This through-arch span is shown in Fig. 4.

Since the station of the north springing line was fixed, as was also the point where the intrados passed the clearance line of the channel, the variations open to the designer in trying to adapt the neutral axis to

The heavy box section of the top and bottom chords of the steel arch permitted the building in of the steel posts and hangers between the two side members of the chords in such a way as to give lateral support to the arch rib from the floor girders. The arch ribs have heavy steel cross bracing below the roadway. These steel arches were erected on timber falsework, the crown closing sections being drilled in the field. Steel floor girders 22 ft. apart were used to give a maximum clearance over the river channel. The use of structural steel hangers provided a simple method of delivering and distributing the floor girder reactions to the arch ribs. A covering of gunite on wire mesh

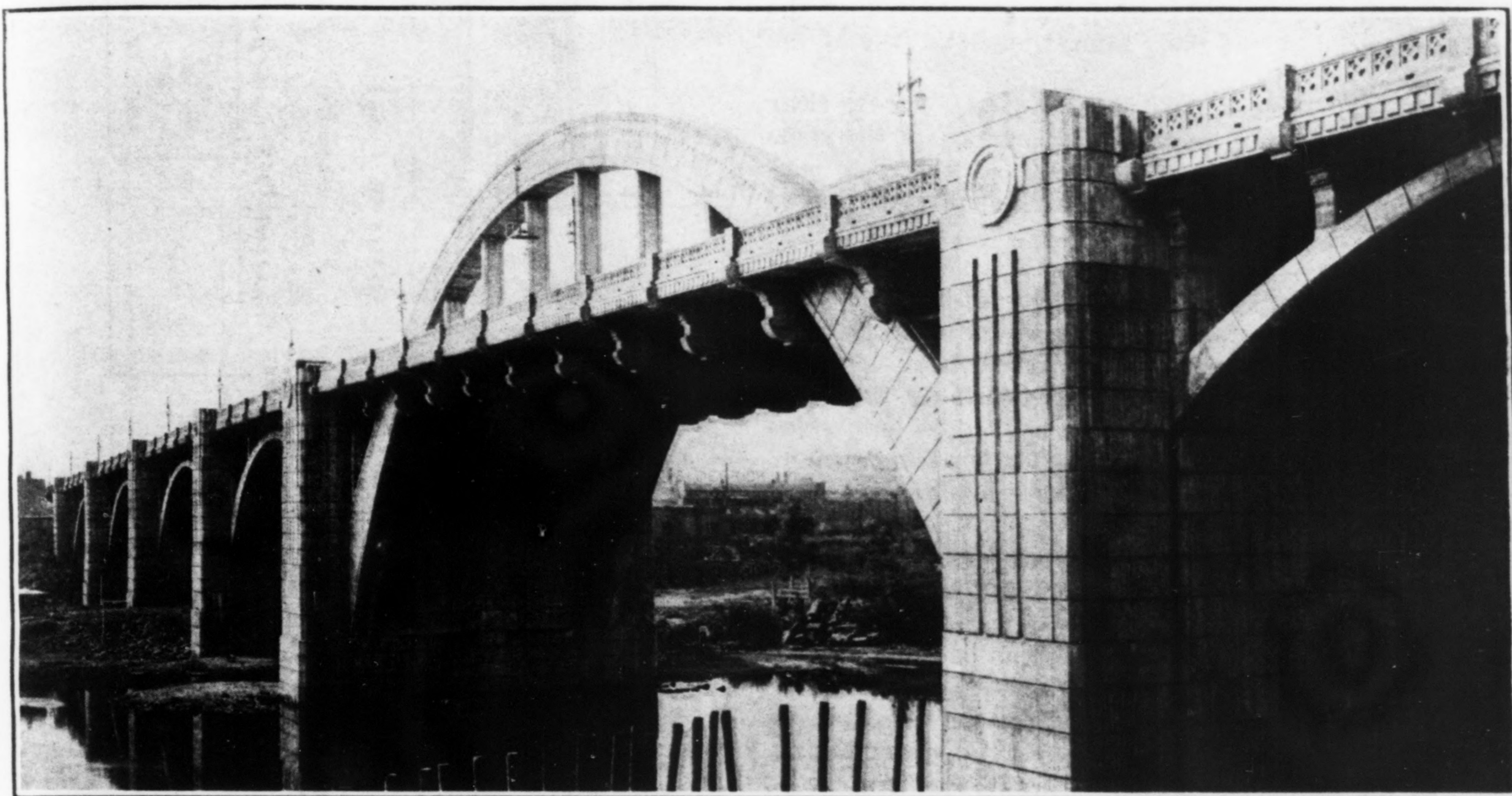


FIG. 1—LOOKING ALONG THE COMPLETED ROBERT ST. BRIDGE, ST. PAUL, MINN.

the dead-load equilibrium polygon were restricted. While for the final design a curve was found to give a line of resistance which remained within the middle third, the deviations of the polygon from the neutral axis were a maximum at the crown and at the quarter points. Instead of the usual compound curves resembling a basket handle, with the long radius at the crown and the shorter radii at the haunches, the radius is 122.16 ft. at the crown and 191.60 ft. at the haunch.

The two main ribs, each 6 ft. wide and 8 ft. deep at the crown, were spaced 64 ft. 8 in. c. to c., so as to clear the roadway 8 in. at each curb. The sidewalks were then detoured outside of the ribs in a way which adds to the architectural interest of the roadway. This is shown in Fig. 5. Considerable thought was given to the lateral support of these arch ribs and also to the expansion and contraction relative to the roadway.

A structural steel frame is used for each arch rib, as shown in Figs. 4 and 7. The steel arches are designed to be erected either as cantilevers supported from temporary towers or on falsework. They are designed to carry the weight of the steel structure, including the steel floor system, and also the dead-load of the concrete arch proper. The dead-load of the concrete roadway and the live-loads are carried by the composite concrete and structural steel arch.

was applied to the girders and bracing in order to protect the steel with a minimum of dead weight.

Special care was used in pouring the sections of the arch ribs so as to transfer the load to the concrete without disrupting the bond between the concrete and the structural steel. The concrete was poured in sections so as to equalize the load on the arch, with provisions for keys between the sections.

Barrel and Ribbed Arches—The design of the three barrel arches has no special interest except in the application of an arch design to very trying conditions. Thus, arch 2, a 70-ft. span, crosses the four main tracks leading west from the union depot, which tracks carry traffic for nine railway systems. With the center of the north track at the minimum allowable distance of 8 ft. from the south face of pier 1, clearances for the intrados of arch 2 were figured as closely as for the portal of a through steel truss span.

Clearances for the intrados of arch 3 were determined from the requirements of the main line of the Chicago Great Western R.R. which runs under the arch at an angle of 55 deg. with the center line of the bridge. This arch is a 98-ft. span with the springing line 50 ft. above low water and 35 ft. above the springing line of arch 4. Arch 1 is a skew arch, 96 ft. long at the center line, with its springing line 6 ft. below that of arch 2 and

1 ft. below that of arch 3. The three arches are designed to make up a unit, with the north abutment and pier 3 acting as its abutments.

In piers 1 and 2 the shafts have been designed to resist the moments resulting from the excess of the thrusts of the longer spans 1 and 3 over arch 2. The thickness of the piers below track clearance lines was increased from 8 ft. to 14 ft. and the footings, 32 ft. wide with piles spaced 30 in. c. to c., were offset 24 in. from the center line of the pier. The moment of the thrust of barrel arch 3, with its springing line high above that of the ribbed through arch, exceeded that of the latter. The footing, 42 ft. in width, was offset 18 in. from the center line of the pier to reduce the maximum load on the piles along the south face of the footing.

The five-rib arches, 5, 6, 7 and 8, are 112-ft. clear spans set at varying heights to accommodate the slope of the roadway. They are designed and located to neutralize the thrust of the through arch at pier 4. One of these spans is shown in Fig. 6.

Girder Spans—The steel span of the north approach crossing Second St. consists of twelve 48-in. plate girders, 46 ft. long, protected with gunite. Steel girders were necessary to give the required headroom for trucks. The 33-ft. concrete girders forming the eight spans of the south approach were flanked on both sides by shops of the American Hoist & Derrick Co. Much of the area under this portion of the bridge has been bricked in to be used for shop purposes, the girder and beam type of span being well adapted for this use.

Expansion Joints—The provision for expansion and contraction, together with the waterproofing of such joints, is regarded by the designers as one of the very important things to be provided for. An inspection of a large number of concrete bridges showed that in nearly every case failure or deterioration was taking place at the expansion joints. Wherever concrete was arranged to slide on concrete the joints usually failed by the failure of the concrete to slide and thus cracking elsewhere. Many joints failed because of water being trapped and freezing. Some joints filled with dirt which, caked with bitumen, appeared to be nearly as hard and inelastic as the concrete itself. In general, no satisfactory joint was found and the joint used on the Robert St. bridge, Fig. 3, while having some advantages, is regarded only as a step in the right direction.

The location of expansion joints is shown in Fig. 2. In general there are no sliding surfaces. The joints are placed at frequent intervals and any movement is taken up by bending in the supporting columns. This results, as a rule, in a double set of supporting columns. These columns (or one column and the adjacent pier) are separated by a 1-in. layer of elastite. The expansion joints extend completely through the roadway, sidewalks and railings in every case.

For waterproofing the roadway joints a crimped lead plate of special composition was placed across the joint, the ends being brazed together to make a tight joint across the roadway. This plate is held in place by the bolts which extend through the anchors in the concrete below and also the 3x3-in. angle above. It extends back into the fabric waterproofing so as to make a tight job. The steel angle is used as a stop for the brick paving, which rests on a 3-in. sand cushion, the joint in the paving being closed with asphalt. The concrete deck slab was waterproofed with three layers

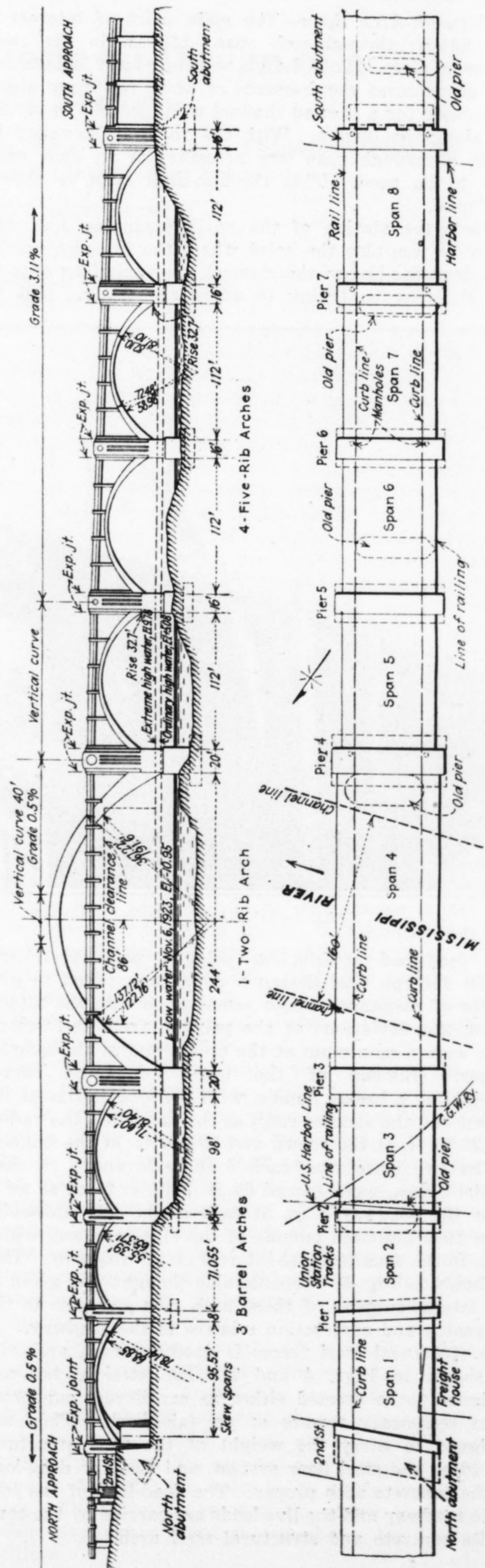


FIG. 2—ELEVATION AND PLAN OF ROBERT ST. BRIDGE OVER MISSISSIPPI RIVER

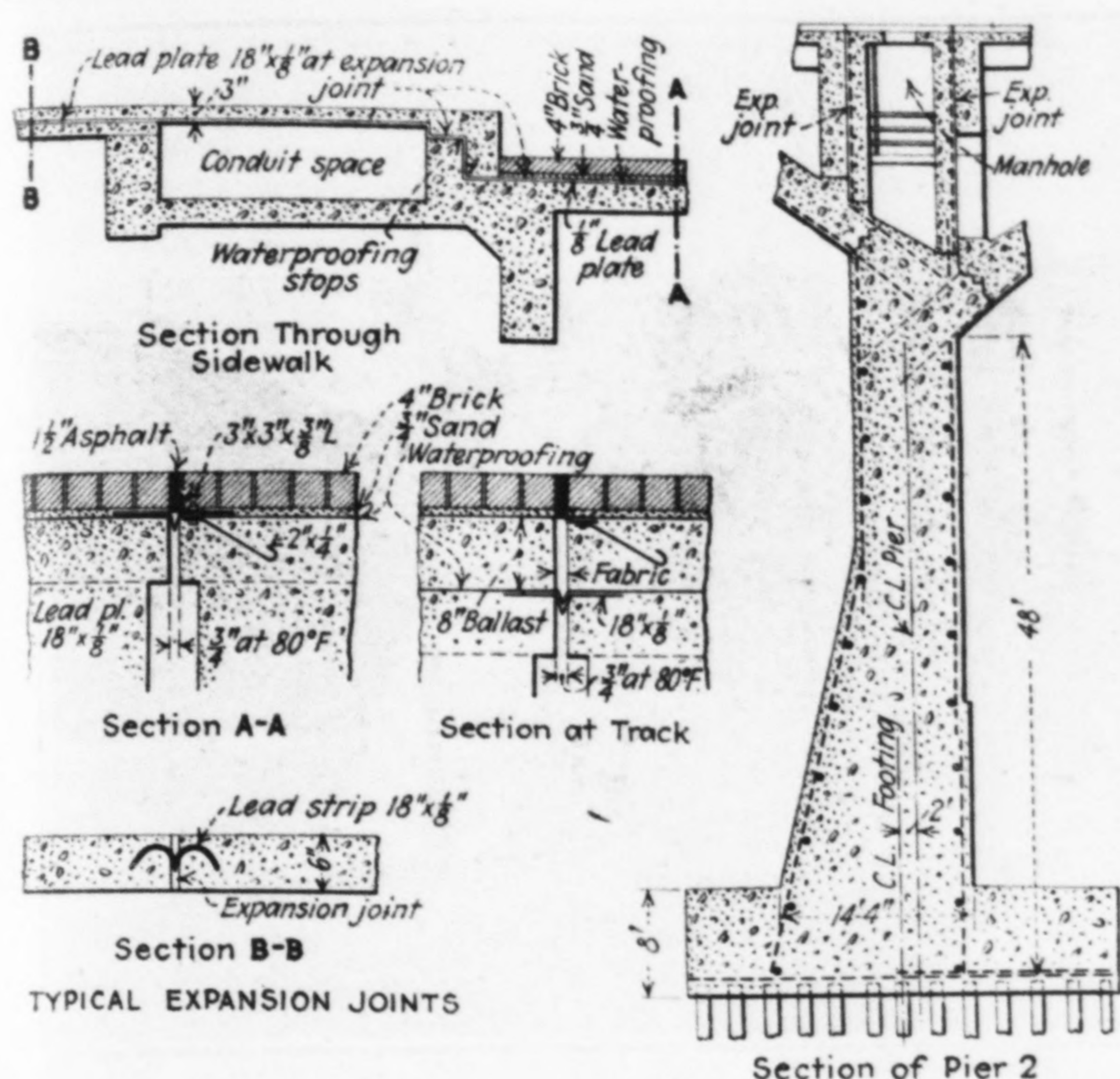


FIG. 3—EXPANSION JOINTS AND PIER SECTION

of cotton fabric impregnated with asphalt and laid with four coats of asphalt.

Paving and Conduits—A 4-in. brick pavement on 4-in. sand cushion provided the wearing surface of the roadway, except that granite blocks were used between the car tracks. This paving was laid to a 5-in. crown, with 10-in. curbs protected by a steel angle. The tracks, with steel ties, were placed by the street car company and concreted in place in the trough provided in the deck. Electric conduits of two power companies

and the telephone and telegraph companies were provided for in two troughs under the sidewalks, suitable manholes being provided at the piers. Space for two gas mains was also provided.

Lighting—With a series system arranged in two circuits, lighting intensities on the roadway will vary from 1 to 2 foot-candles with the minimum of glare. An attempt has been made to harmonize the appearance of the combination light and trolley poles with the remainder of the bridge, as shown in Fig. 8. Standard tubular steel trolley poles spaced approximately 125 ft. apart have double pendant lantern units suspended from special cast-iron brackets at 17 ft. above the roadway. Simple base castings and brackets are the only decorations applied to these poles.

Each lighting unit consists of a 400-cp. lamp enclosed in a lantern with rippled glass sides and top equipped with prismatic dome refractor designed to throw the light on the roadway. Lamps are operated upon a 6.6-ampere primary circuit with transformers at the base of each pole.

Architectural Features

BY ROY CHILDS JONES

THE Robert St. bridge is unique in that its designers included in their own permanent organization both architects and engineers. This fact made it possible to take full account of the mingled utilitarian and esthetic problems present in a structure destined to serve as a civic monument. Instead of architects being called in to beautify with applied ornament a predetermined structure, architects and engineers combined during the initial stages of the design in an effort to select and

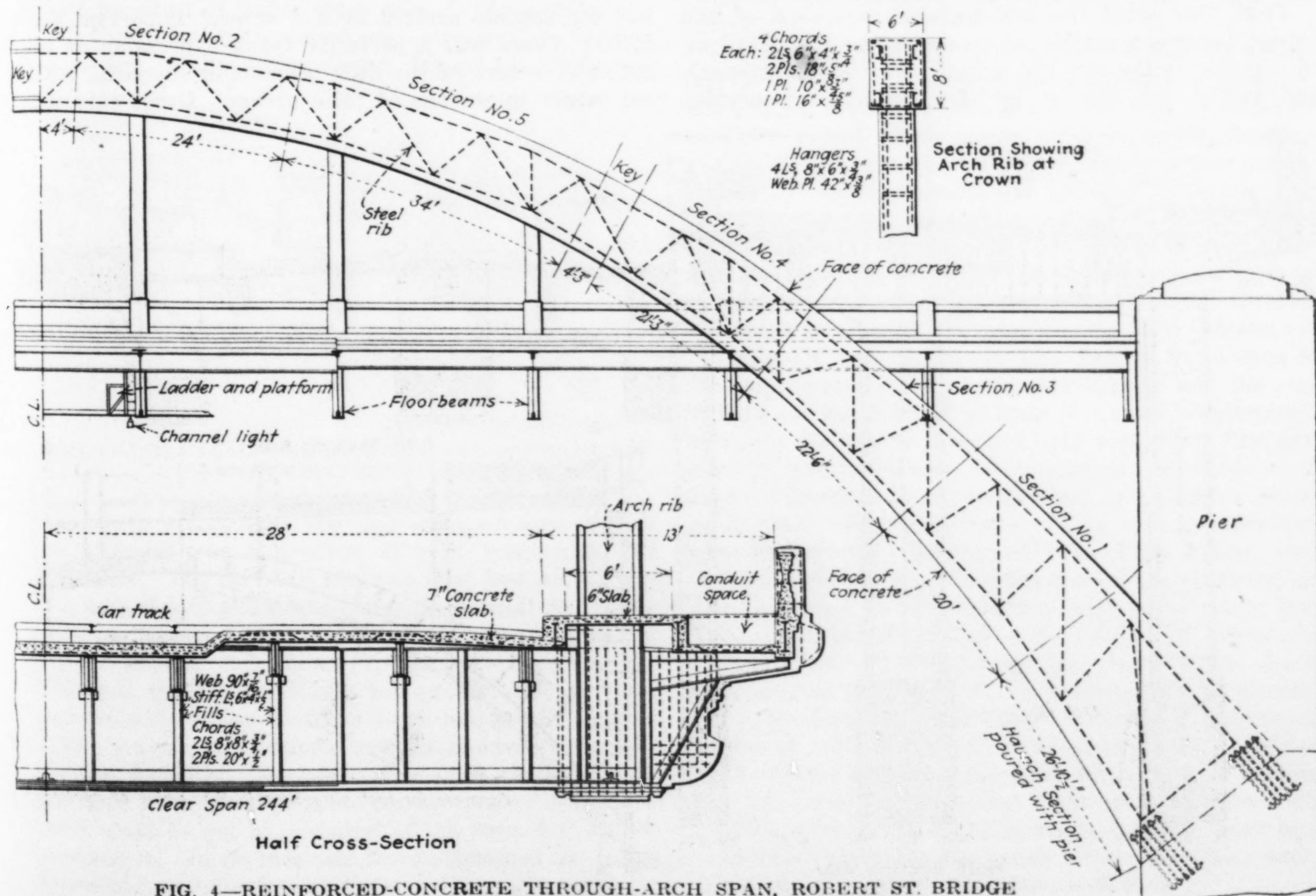


FIG. 4—REINFORCED-CONCRETE THROUGH-ARCH SPAN, ROBERT ST. BRIDGE

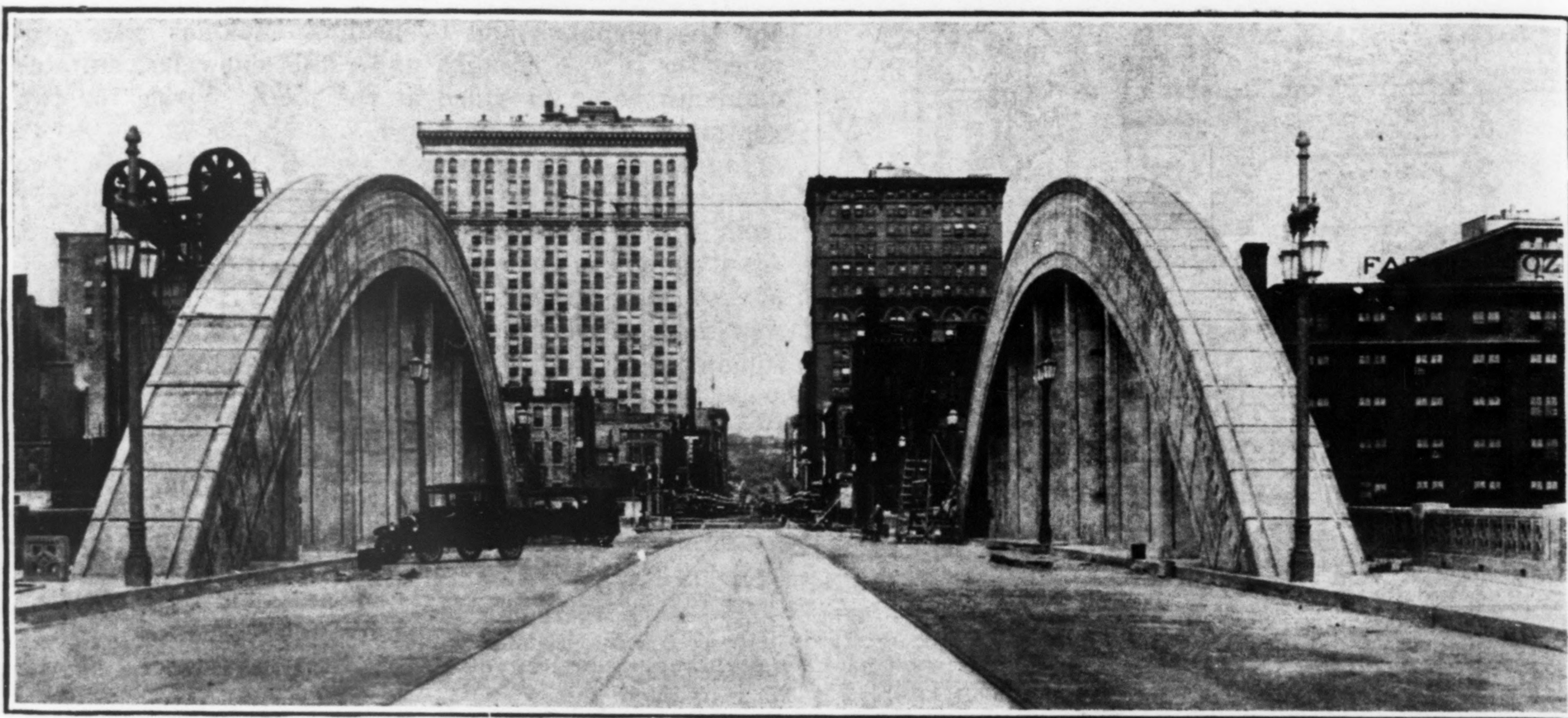


FIG. 5—DECK OF THROUGH-ARCH SPAN OF ROBERT ST. BRIDGE

control the structural features so as to secure for the bridge an inherent beauty of form and proportion.

With the complicated requirements of street grades and of railroad and channel clearances, any simple and regular composition of arches and piers was out of the question. The first effort was to minimize this difficulty by throwing all possible emphasis on the center span, and subordinating the approach spans with their discordantly varying shapes. To carry out this intention, the approach spans were made as short as possible, and their piers were kept comparatively simple.

From this point the architectural treatment of the bridge became a matter of so managing the detail as to express to the eye the actual qualities of strength and utility put into it by the engineer. Generally

speaking, this was accomplished, not by adding ornament, but by controlling the shapes and proportions and relations of the structural members. Fortunately there is an inherent beauty in the mathematically determined curve of an arch that only needs letting alone to be apparent. In this case nothing was done to the arches except to emphasize their size and spring by certain lines of shadow, and by seeing to it that the curves swept unobstructedly and dominatingly from haunch to crown.

Treatment of the piers and deck was more difficult, but the scheme arrived at had several important features. There was a perfectly frank expression of the actual structure of the deck beams and supports, without resort to screens of false arches. Great care was

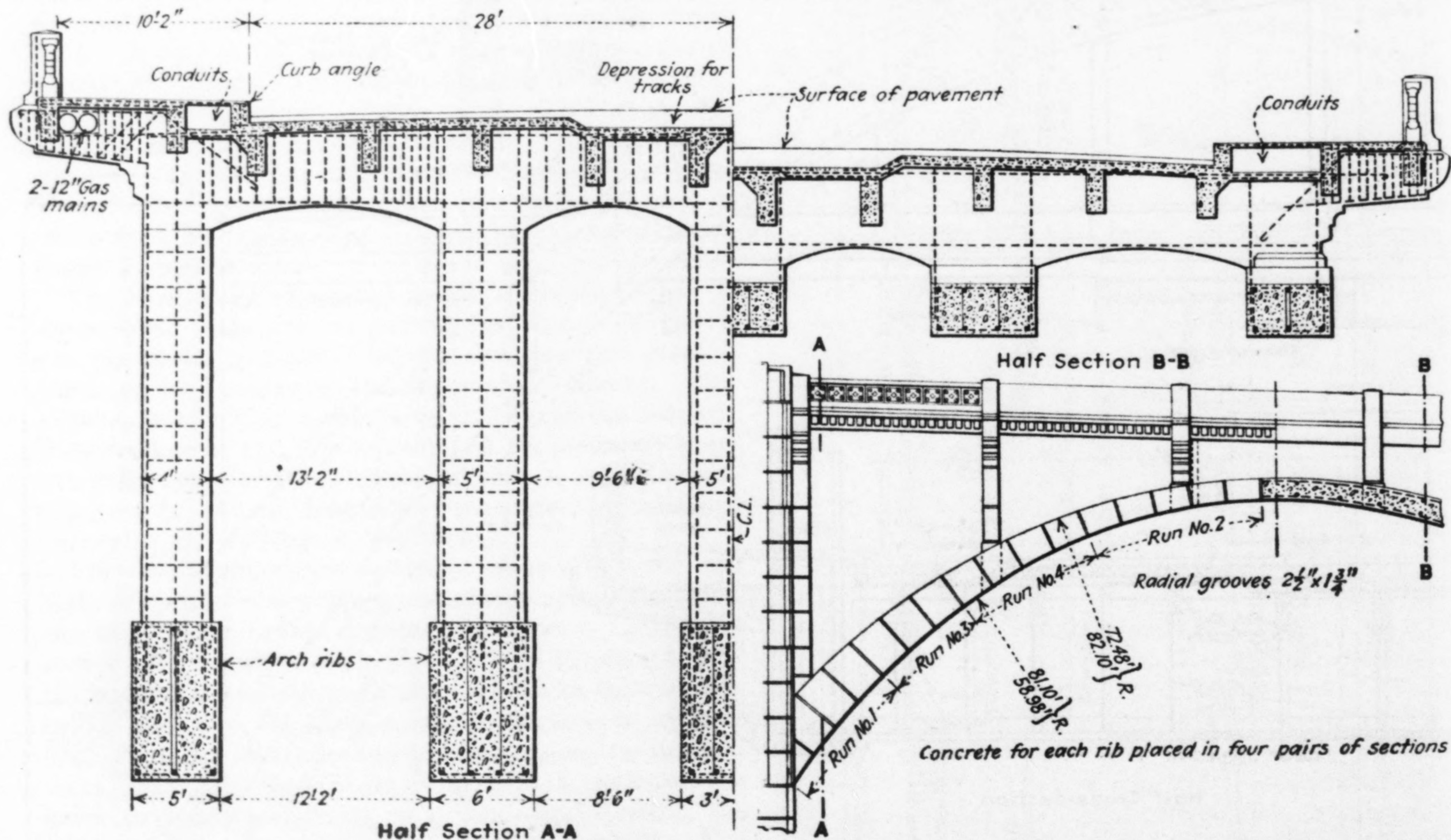


FIG. 6—FIVE-RIB ARCH OF 112-FT. SPAN

taken to preserve the continuity of the actual line of the deck and to emphasize and enrich it by appropriate sectioning.

Hand-Railing—As a part of the deck treatment, the rail naturally came in for a large share of attention, since the appearance of a bridge from the point of view of the people who use it is almost entirely a matter of the rail. Furthermore, it is seen from close up, and must have a refinement of scale and a degree of finish not easy to obtain in concrete. In addition, it must not only have great rigidity to resist the possible impact of heavy modern trucks, but sufficient flexibility to expand and contract without unsightly cracks.

The problem was met here by a scheme of precast perforated panels anchored between poured, heavily reinforced members at top and bottom, and between posts from side to side. This design is shown in Fig. 8. Concealed expansion joints were provided by slots in the posts which received the ends of the rail sections. This satisfied the engineer's requirements as to strength, while to the architect the interesting feature of the treatment lay in the fact that it promises a decorative quality growing unmistakably out of the material, and of being susceptible to such a degree of finish as to avoid the crudeness so often seen.

Decorative Treatment—As a contrast to the sweeping horizontality of the deck, the piers have had their vertical quality emphasized. Strong vertical lines of shadow were created by a control of the pier section. Grooves were run up and down the faces of the piers, their depth decreasing toward the bottom so as to create an effect of diminishing shadow to enhance their interest. The pier corners were beveled, with successively increasing set-backs from bottom to top to create an effect of batter when seen in perspective.

All this detailed treatment was necessarily a matter not merely of the bridge design, but of the bridge as

the designers that the tendencies of forms to spring, and of concrete to vary, inevitably doomed such attempts to failure in realization. Continuity of surface and line was considered as the sum of a series of

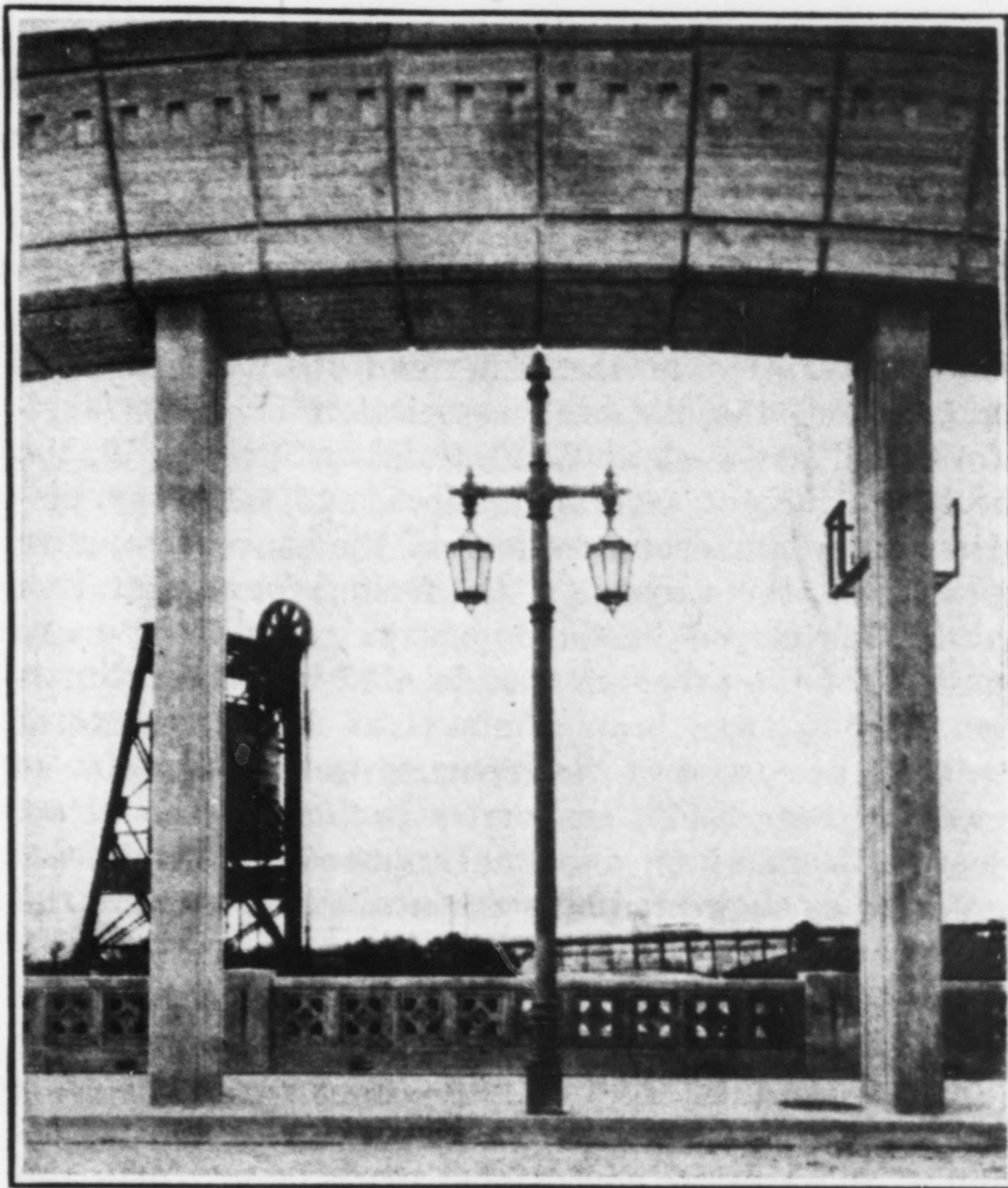


FIG. 8—DECORATIVE TREATMENT OF ROBERT ST. BRIDGE

definitely bounded segments rather than as literal continuity.

The working out of this principle involved the breaking up of all surfaces with lines of light and shade. The natural divisions between periodic runs of concrete were recognized by horizontal grooves, whose location was carefully controlled. Further modeling was accomplished by vertical breaks and grooves, by bevels, and by wedge-shaped indentations. The idea was to make, out of the natural patches of lighter and darker toned material, patterns definitely bounded by strong lines of shadow; and to effect an emphasized interest in light and shade in place of the unattainable color interest.

Engineers and Builders—The Robert St. bridge is the joint undertaking of Ramsey County and the city of St. Paul, represented by Paul N. Coates, county engineer, and George M. Shepard, city engineer. The contractor was the Fegles Construction Co., Ltd., with James Patterson as superintendent and Charles Moore as assistant superintendent. Plans and specifications were prepared by the firm of Toltz, King & Day, Inc., St. Paul, Minn., which also supervised the construction. The personnel of this company was as follows: Max Toltz, mechanical engineer; W. E. King, structural engineer; B. W. Day, architect; Roy Childs Jones, architectural designer; P. E. Stevens, office engineer; W. A. Thomas, electrical engineer; John F. Greene, in charge of arch design and resident engineer. The cost of the bridge and approaches complete is about \$1,750,000, including paving, street lighting and engineering.

[This article will be followed in an early issue by another describing the construction operations and the lessons learned therefrom.—EDITOR.]

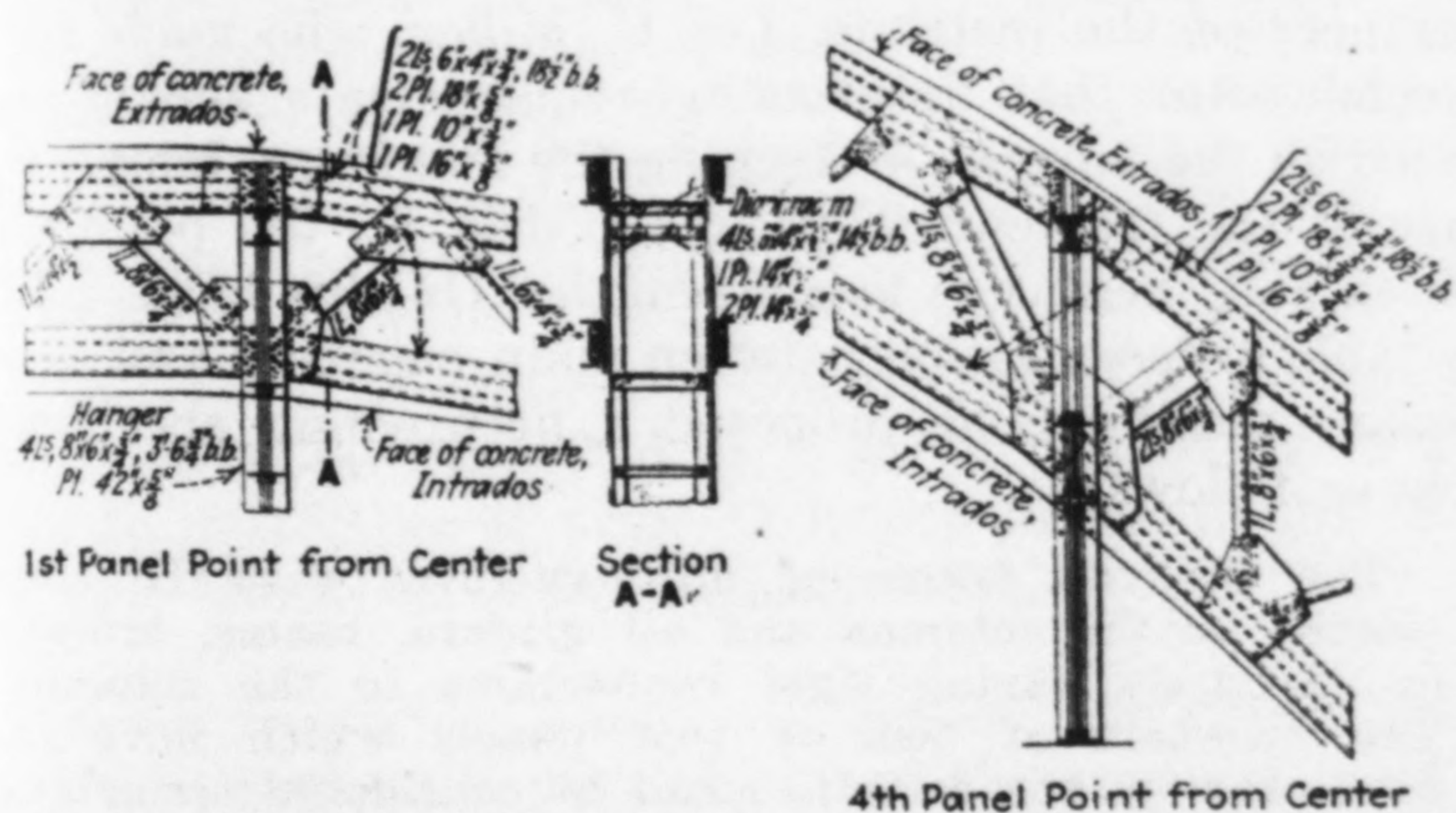


FIG. 7—DETAILS OF STRUCTURAL STEEL FRAMING OF ARCH REINFORCEMENT

a concrete structure. The appropriate expression of the material was a problem of vital concern to the architects. The fact that concrete is at best an intractable material to work with; that its natural decorative value as to color and texture is practically nil; that the cost of any of the known surface treatments to get color and texture artificially was prohibitive; all these were considerations that had to be taken into account.

The scheme of treatment arrived at involved several definite features. No color other than what could be got with the natural concrete and no texture other than what could be got by a control of the form boards was resorted to. In no case was there attempted any effect depending on unbroken surfaces or lines. It seemed to