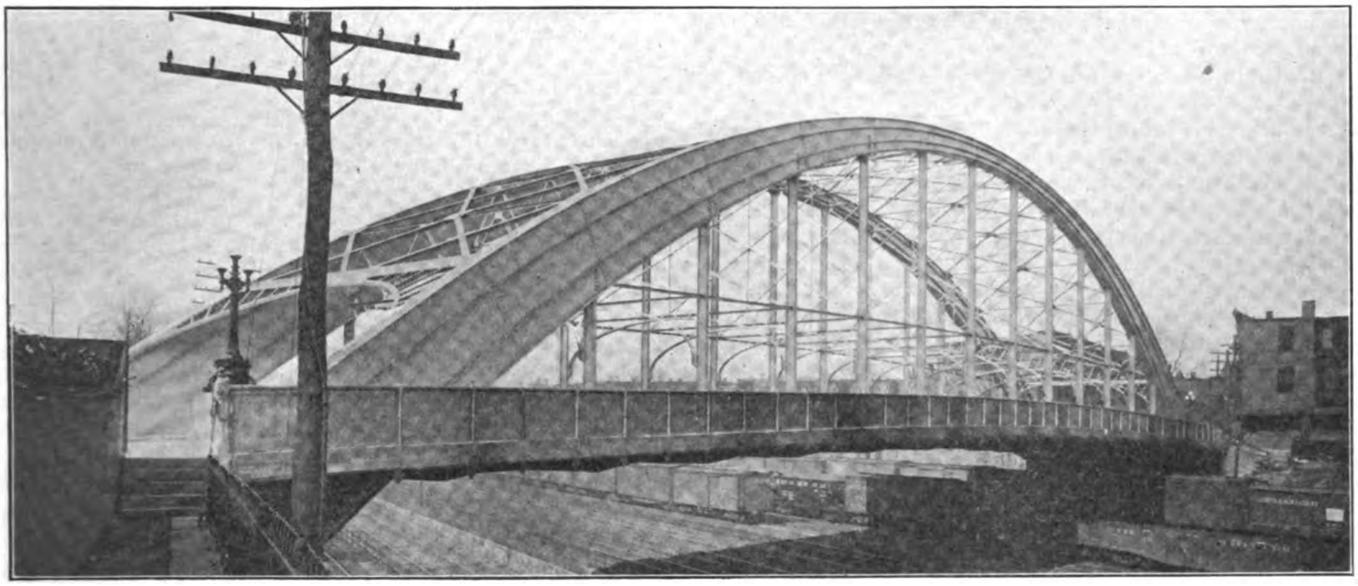
Concrete Filled Steel Arches*

By HENRY H. QUIMBY

The bridge carrying Forty-second street over the main line of the Pennsylvania railroad in Philadelphia is believed to be the first example of a new type of construction that will be found by designers to be economical and applicable in a number of cases.

The bridge is a pure unbraced arch with suspended floor, the arch being in two ribs of steel plate box construction of rectangular section 15¼ ins. inside width and varying depth, filled with concrete. The floor is of structural steel and concrete, built girder cross floor beams with cantilever extensions for outside sidewalks, and under the driveway floor rolled beam stringers with concrete jack arches, the sidewalks being rod reinforced concrete slabs.

The arch ribs are not hinged and yet are not quite hingeless. They are fixed—or rather square ended—at the spring; and at the crown, though 3 ft. deep, are keyed with a steel plate that gives a bearing depth of only 16 ins. The depth of the arch ring at the spring is about 10 ft. and at the crown 3 ft., abruptly reduced to 16 ins. on the key. This "semi-hingeless" construction was adopted for the purpose of obtaining stiffness against variable loads without excessive depth at the quarters and without inducing very high temperature stresses.



CONCRETE FILLED STEEL ARCH BRIDGE CARRYING FORTY-SECOND STREET OVER THE TRACKS OF THE PENNSYLVANIA RAILROAD IN PHILADELPHIA, PA.

If hinges had been used at the spring the arch would have required to be made much deeper at the quarters than at the ends, giving a very ungraceful appearance, and besides, the construction would have cost considerably more. Hinges practically eliminate temperature stresses and enable us to determine more accurately the line of pressure for any given condition of loading, but in arches with good pitch—ratio of rise to span—the temperature stresses are not so severe as in flat arches, and, therefore, the advantages of hinges do not, in such cases, compensate for the increased cost and awkward appearance which they entail.

The economy of the arch type of bridge in this case is found in dispensing with a tension chord and a web shear system, the excess of the arch section at the spring over a compression truss chord being slight in comparison, and the greater cost of the masonry being also considerably less than the saving in steel. In fact, the total cost of the masonry as built in this case was less than that of tension chords would have been for a truss span, and it had to be carried down about 40 ft. to get satisfactory bottom for foundations.

The office of the concrete filling of the arch ribs is threefold. It takes the place of interior steel diaphragms, an extensive system of which would be required to make the wide web plates available throughout as section to carry compressive stress and to prevent buckling and distortion, and which would have cost just about as much as the concrete did. It also protects the interior surface of the box against corrosion more permanently and more conveniently than would painting, for means of future access to the interior would otherwise have to be provided, and even then the work of repainting would be difficult, and because the need of it would not be obtrusively conspicuous, it would be likely to be neglected. The concrete also gives to the arch very considerable strength for carrying compressive stress.

The floor suspenders are rolled steel I-beams (15-in., 60-lb.) with webs transversely, the advantages of this shape being that the suspenders could be used as posts for temporary support of the arch segments in erection, and are competent to transmit to the rigid floor one-half of the wind loads on the arch. They also make very sightly, clean limbed truss members, no lacing or other trimming being needed.

The arch ribs are carried upon independent concrete abutment piers, the railroad bank being sloped between them, and the floor of the bridge extended back to the crest of the bank. It was found to be more economical to span the slope with the floor than to construct a retaining wall and abutment wings and fill the space over the slope. It was also desirable to keep all foundation excavation away from the houses which, at the four corners of the bridge, were standing at the street line, and whose foundations were in two cases on filled ground, and in all cases far less in depth than was required for the pier foundations.

*Paper delivered at the seventh annual convention of the National Association of Cement Users, New York City.

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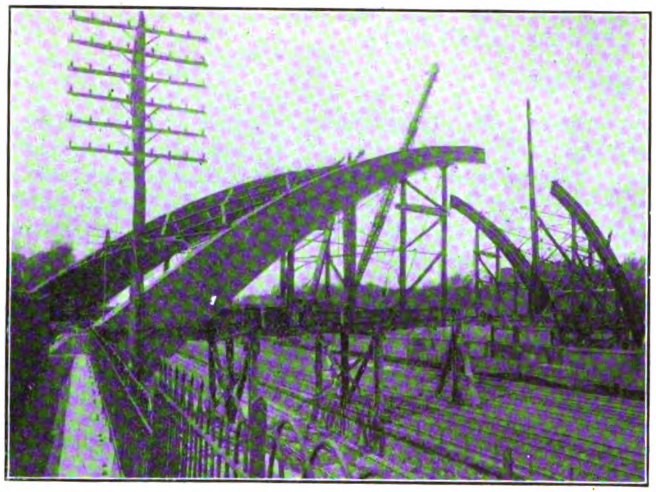


FORTY-SECOND STREET BRIDGE, PHILADELPHIA, PA.—STEEL ARCHES IN PROCESS OF ERECTION.

The floor over the slope is similar to that suspended from the arch ribs—steel floor beams and stringers with concrete jack arches—except that the diagonal end floor beam which was built directly on the ground is a rod reinforced concrete beam.

The abutment piers are of rubble concrete founded on a good grade of micaceous rotten rock, the pressure being about 4 tons per square foot. The piers are 10 ft. wide at the bottom and 8 ft. at the top, with a transverse grillage of twelve steel beams, 20-in., 80-lb., 7 ft. long, in two groups of six each, and two additional beams at the middle to take the bearing of the temporary erection blocking.

The span of the arch is 262 ft., c. to c. of bearings on the grillage in the skewbacks, crossing fifteen railroad tracks on an angle of 28 degrees. The rise to the center of the rib at the crown is 52 ft. The intrados line is a parabola of 252 ft. span and 53 ft rise. The extrados line is a segmental curve of 200 ft. radius between points 11 ft. above the floor, and tangents from there to the skewbacks, which are at an angle of 45 degrees. The ribs are 37 ft. 6 ins. apart c. to c., giving a driveway, which is asphalt paved, 34 ft. wide between curbs. The sidewalks are granolithic, 11 ft. 3 ins., wide from curb to center of railing, the overhang from centre of arch rib being 9 ft. 6 ins.

The floor, with the paving, forms the greater part of the load. The horizontal thrust in each rib from the steel work alone was 117 tons, and the resultant delivered to the abutments 150 tons. With the concrete filling in the arch the thrusts were 165 and 256 respectively. With all dead load they are 614 and 800, and with a distributed live load of 100 lbs. per sq. ft. over driveway and sidewalks 857 and 1,110 tons.

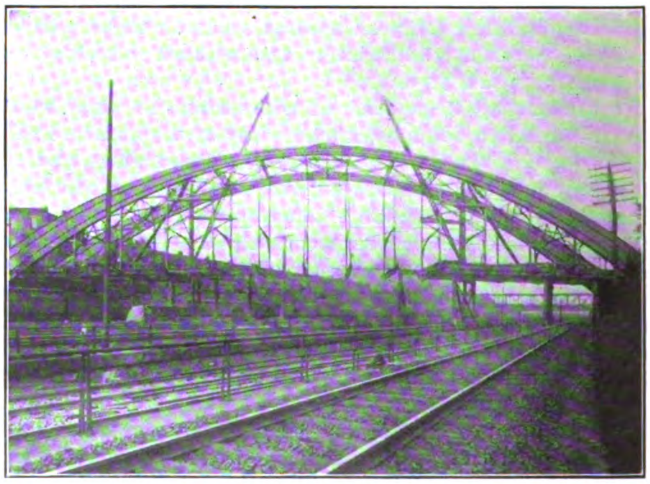
The stresses produced by the steel work and arch filling together constitute the initial stresses on the steel ribs. All subsequent loading must be borne by the steel and concrete jointly, because time was given the filling to set hard before any additional load was placed. As the crown keys were well fitted to an even bearing and the bearing at the spring was evenly keyed up with the steel weight alone, the line of pressure passed very close to the middle at both points, and the initial stress on the steel was therefore fairly uniform at about 3,000 lbs. per sq. in. The distribution of subsequent loading between the steel shell and the concrete core must be in direct proportion to the moduli of elasticity of the two materials, whatever they may actually be, multiplied by the area of available cross section, for neither material can shorten under stress without, or any more than, the other. If the ratio between the moduli be 15 then at maximum load the total stress on the steel, including 3,000 initial, will be 11,000 lbs. per sq. in., and on the concrete 560 lbs. The concrete core itself produces a thrust that causes 1,085 lbs. of the 3,000 initial on the steel, or would, if it carried itself, cause a unit stress of 240 lbs. on the concrete alone, showing that the core has a carrying capacity far beyond its own dead load.

The web plates are tied together at intervals of about 2 ft. with ⅞-in. stud bolts that resisted the hydrostatic pressure of the soft concrete during casting, and serve to prevent the plates from buckling away from the concrete in compression. These bolts also afforded needed and convenient roosting places for the men who spaded the concrete as the filling proceeded and for the inspector who supervised the operation. The clear space between webs was 15¼ ins. to permit free insertion of the 15-in. beam hangers, and it afforded just about enough room for working.

The filling was accomplished by means of sheet iron spouts through 3-in. round holes in the top cover plate at intervals of about 8 ft. As the filling proceeded these holes were closed with hexagonal plates tap bolted to the cover. Near the crown the top cover plate was sprung up and propped open enough to admit the men to the interior until the filling reached the opening, when it was permanently closed and riveted. The spading to the crown was then done through the holes with rods, and the filling was finished with grout using sink-head hoppers on tap bolt holes at the highest point. The filling of the opposite halves of a rib was carried forward simultaneously to avoid unbalanced and distorting stresses.

The erection of the steel work was by means of partial false work below the floor and two long beam stiffleg derricks on it. Each rib was shipped in eight sections, and each section—except the two middle ones—when placed in position was propped on the 15-in. beam hangers as posts. The ribs were started on narrow bearings on the skewbacks that acted as temporary hinges to facilitate control of the camber until the connection was made at the crown, which was accomplished by keeping the false work wedging high and lowering it as needed. This temporary bearing, which was at the mid-line of the arch ring, was composed of two 7-in. by 1¼-in. cast zinc blocks side by side on the two middle beams of the grillage. Zinc was adopted as the material of the temporary blocks because it will squash out under about 3,000 lbs. pressure and thus prevent excessive stress coming on the middle of the arch ring due to the initial load being carried there.

After the steel work was all placed a time of mean at-



FORTY-SECOND STREET BRIDGE, PHILADELPHIA, PA.—STEEL ARCHES COMPLETED AND SUSPENDERS AND FLOOR BEAMS IN PLACE.

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mospheric temperature was awaited for the final keying at the skewback in order to divide the temperature stresses evenly between winter and summer and thus minimize the extreme. It was found by trial stress diagrams of the arch with various distributions of dead loading that with all the steel work in place, but no concrete either in arches or floor, the line of pressure passed through the middle of the arch ring at the spring. This was then the proper stage of the work for fixing the bearing on the skewback.

A temperature of from 55 to 58 degrees F. was found very early one morning and the bearing wedges were then driven up firmly with steel mauls. These wedges were 7 ins. by 30 ins. tapering in thickness from ⅜ to ⅝ in.; one pair on each of the twelve grillage beams in each skewback. The aim in driving was to make them all equally tight, not necessarily to take up all the load at that time, but it was found that such wedging as was done released the pressure on some of the blocks—150 tons. Then holes were drilled through the wedges and tapped into the grillage beams, and tap bolts were screwed in within ⅛-in. of the heads and so left, the purpose being to avoid any possible lift or anchorage effect on the grillage if temperature or other force should open the skewback joint at either intrados or extrados.

Careful examination since, in both extremes of heat and cold, has failed to discover loosening of any of the wedges, though a difference in pressure on them was perceptible by sounding with a hammer. This indicates that the line of pressure has not yet wandered to either edge of the middle third of the bearing.

The live load for which the bridge was designed is a general load of 100 lbs. per sq. ft. over the whole floor, or a concentration of 110 lbs. per sq. ft. on sidewalk members, and of 40 tons on two truck axles 20 ft. apart, or two lines of street railway cars, and various combinations of these loads to find maximum possible stresses. Each arch rib is composed of two web plates 15¼ ins. apart in the clear, varying in thickness from 7/16 in. at the lower section to ⅝ in. at the crown section, four flange angles and four intermediate angles 5 ins. by 3½ ins. by 11/16 in., and one top and one bottom cover plate 27 ins. by 11/16 in. The intermediate angles are counted in as section, and they both stiffen the web plates and relieve the blank plainness of the exterior surface, breaking it up with graceful shadow lines.

The lateral bracing along the extrados is designed for a wind pressure of 50 lbs. per sq. ft. on the arch ribs, and the flange is reinforced against bending at the portal by carrying the end strut angles down to the skewback. In addition to this the transverse sway bracing at every hanger is designed to be competent to carry to the floor one half panel of the wind load on the arch. The floor, being a monolith 57 ft. wide, constitutes a very rigid lateral beam to resist wind pressure. It has two expansion joints with steel aprons, one at each intersection of the floor with the intrados of the arch. The floor beam at this point is fixed to the arch and the floor stringers rest upon and slide on seat brackets to which they are bolted through slotted holes. As this joint is exposed to locomotive gases it was desirable to encase it as completely as possible in concrete, and this was accomplished by the use of a coating of clay 1 in. thick over the floor beam casing when the stringer casing was cast, which was in hot weather, and the clay was in large part picked out afterwards. A board form would have been very difficult to remove from the narrow space.

The light longitudinal struts connecting the floor hangers to reduce vibration are bolted to the arch through slotted holes.

The railing or parapet is a composite construction of zinc plate and concrete filling. The panels are solid webs of stamped sheet zinc ⅛ in. thick. The hand rail and the base rail are formed of ⅛-in. sheet zinc and filled with concrete. The hand rail is circular, 4 ins. in diameter, and the base is triangular in shape, 3 ins. wide. The concrete core was intended to give stiffness and prevent denting by accidental or other blows. Both objects have been attained.

The ornamental finials of the posts are zinc castings, and the posts themselves are heavily galvanized steel angles. The railing is rigid and ornamental and protects the bridge deck from the clouds of railroad smoke and steam, and is no more costly than the closed cast iron railings heretofore used in such circumstances, and it is believed to be durable without requiring painting.

The total cost of the bridge was $78,500, which included considerable street and sidewalk paving on the approaches. The cost of the bridge proper per square foot of floor was $4.30.

With the floor exposing only concrete to the action of the locomotive gases, and the railing presenting a surface that is only slightly corrodible, and all exposed steel work easy of access for painting, the structure should entail very slight expense for permanent maintenance.

Road Construction in Baltimore County, Maryland

The report of Henry G. Shirley, roads engineer of Baltimore county, Md., for the year ending Dec. 31, 1910, contains detailed statements of the expenditures on the work done on the roads of each of the 15 road districts in the county. The totals for the county are as follows:

By Districts, Labor	$40,115.81
" " Material	251,432.23
" " Miscellaneous	17,095.92
From general fund not charged to districts	12,902.34
Total	$321,546.30

Work was done on 1,204.8 miles of road. This work ranged from oiling to new construction.

In District No. 8, of which Harry D. Davis is road supervisor, a special form of construction is described as follows:

"The section of the Falls road, from Broadway to Beaver Dam run, has been built under the state aid law by the county's own forces. The road is constructed of local flint stone, except the binding, which is blue limestone.

"The first course is of Telford construction, the field stones being set on end close together, then sledged over and thoroughly rolled. The thickness of this course was about 10 ins. Upon the first course was placed 3 ins. of broken flint stone from 1 in. to 2 ins. in size and rolled, then another 3-in. layer was spread and rolled until firm and hard. Over this course was spread limestone screenings, and watered and rolled until firm and well bound together.

"All the stone was purchased from farmers living along the road or near by, and the work was done with neighborhood labor. Of the total cost of $10,976.02 for the work, only $1,595.72 was paid outside of the neighborhood of the section of the road. The farmers not only procured a good piece of road, but sold stones from their fields. The engineer believes that with the hearty cooperation of the farmers, many miles of good roads can be built at small cost, along the lines above described."

The city council of Harrisburg,, Pa., has authorized the construction of a viaduct over the Philapelphia and Reading railroad at Thirteenth street. The cost is estimated at $35,000, of which the railroad company and the city each pay one-half.

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