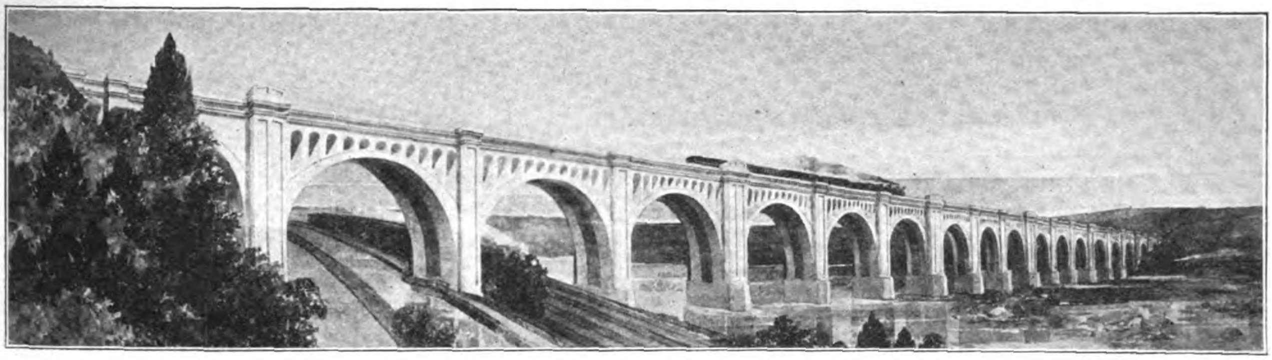

Fig. 1. Perspective Drawing—James River Railroad Viaduct, Richmond, Virginia.

Long Concrete Railroad Viaduct Cheaper Than One of Steel

Reinforced Concrete Arch Viaduct of Open-Spandrel Type Wins Out Against Structural Steel Viaduct

By ALBERT M. WOLF

Assoc. M. Am. Soc. C. E.

In the fall of 1916, plans were made for a new bridge across the James river at Richmond, Virginia, by the Richmond, Fredericksburg & Potomac Railroad and the Atlantic Coast Line Railroad, joint owners of the present single track structure known as the Belt Line crossing. The old bridge, a single track structure built in 1889, had lately proven inadequate for the traffic demands, and for this reason is to be replaced by a double track bridge located parallel to, and 30 feet upstream from, the present structure.

Under ordinary conditions a high-level crossing nearly one-half mile long, such as the one in question, would logically have been built more economically of steel, at least as far as first cost is concerned. In the case at hand, however, the high cost of structural steel, the comparatively low cost of aggregate, and the very favorable foundation conditions—a solid foundation of granite available with very little excavation, in fact, during low water a large part of the river bed being exposed—were responsible for the fact that the bids on a reinforced concrete arch viaduct of the open spandrel type as shown in Fig. 1, were lower than those for a structural steel viaduct with plate girder spans on steel towers resting on concrete piers. Put more concretely, a concrete arch viaduct 2278 feet long is now being built at a cost of nearly $15,000 less than a steel structure. It should be mentioned, however, in all fairness, that undoubtedly the reason for this unusual showing was the fact that the railroad agreed to furnish sand and gravel aggregates for the concrete work at a price of 60 cents per cubic yard, while the then prevailing market prices in Richmond were $1.05 for sand and $1.20 per for gravel.

Concrete Arch Viaduct.		Steel Viaduct.	
Bid to sub-grade	$416,122	Bid to sub-grade	$444,885
Ballast and ties	5,520	Track	7,950
Rails	6,532	Approaches	49,600
Approaches	49,600		
Total	$477,774	Total	$492,435

An actual difference of $14,661 in favor of the concrete bridge.

If, however, the cost had been based on commercial prices of aggregate, a total of $30,900 would have been added to the cost of the concrete structure, and $2530 to the cost of steel design, in which case the total costs would have been $508,674 for the concrete viaduct and $494,965 for the steel bridge. Even at these figures the concrete bridge would in the long run have been the cheaper, owing to the comparatively short life and heavy maintenance cost of a steel viaduct, to say nothing of the advantages of more beautiful appearance, better riding qualities and safety of a ballasted deck as afforded by the former.

General Design.

The original design contemplated a structure composed of 15 twin-rib arches of the three-centered type of 116-foot clear span, two 60-foot solid-barrel, full-centered arches at one end and one at the other, with cellular abutments of reinforced concrete at each end. In the final design, however, the three large arches on the south end (right side in Fig. 1) were increased to 122-foot clear-span with full-centered ribs, so as to clear the Southern Railway's right-of-way along the river bank. The bridge is 32 feet 6 inches wide overall, between piers, with the base of rail 100 feet above the river datum.

Main Arches.—The main span piers are 14 feet

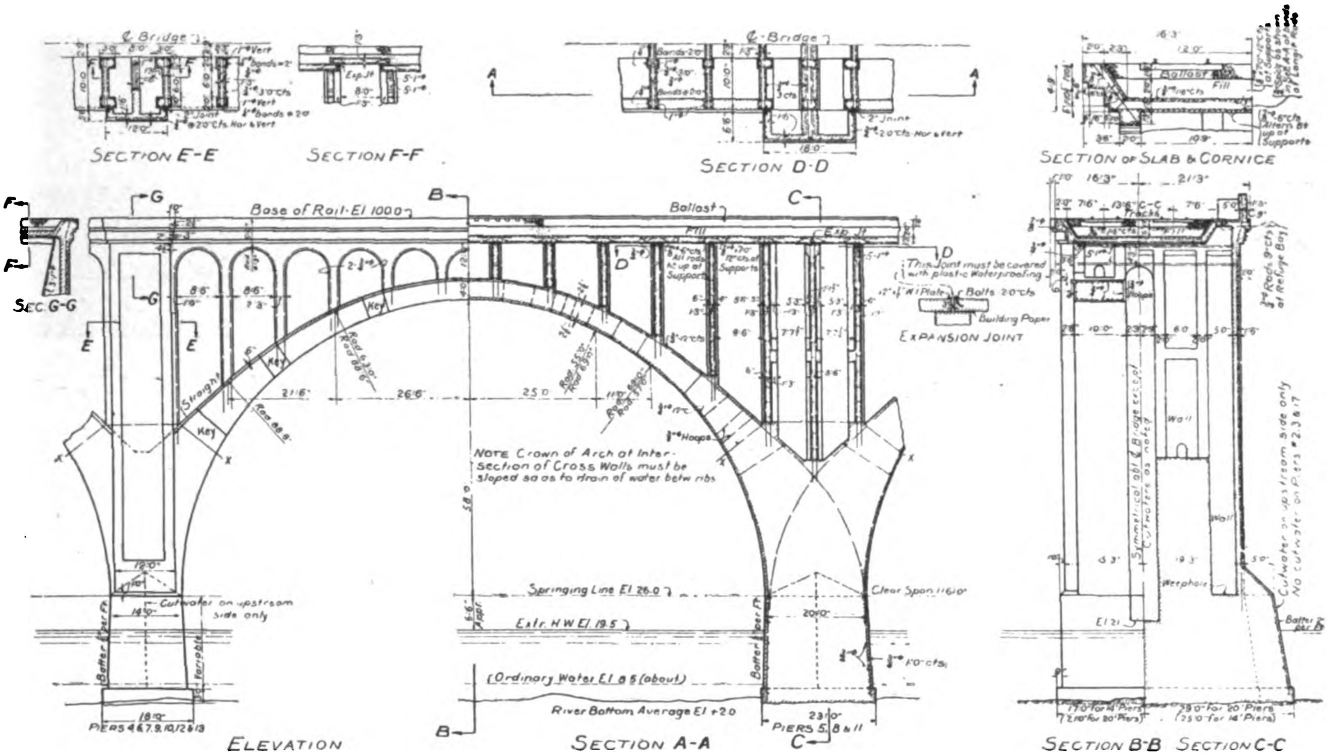

Fig. 2. Details of Main Arch Spans.

thick at the springing line, except that every third pier is made 20 feet wide to act as an abutment pier for each group of three arches, which renders each group stable, without considering the counter thrust of the arches in the groups adjacent. From these piers spring the twin ribs of the arches, 10 feet wide, spaced 15 feet 6 inches centers, with a crown thickness of 4 feet for the 116-foot arches. The main rein-

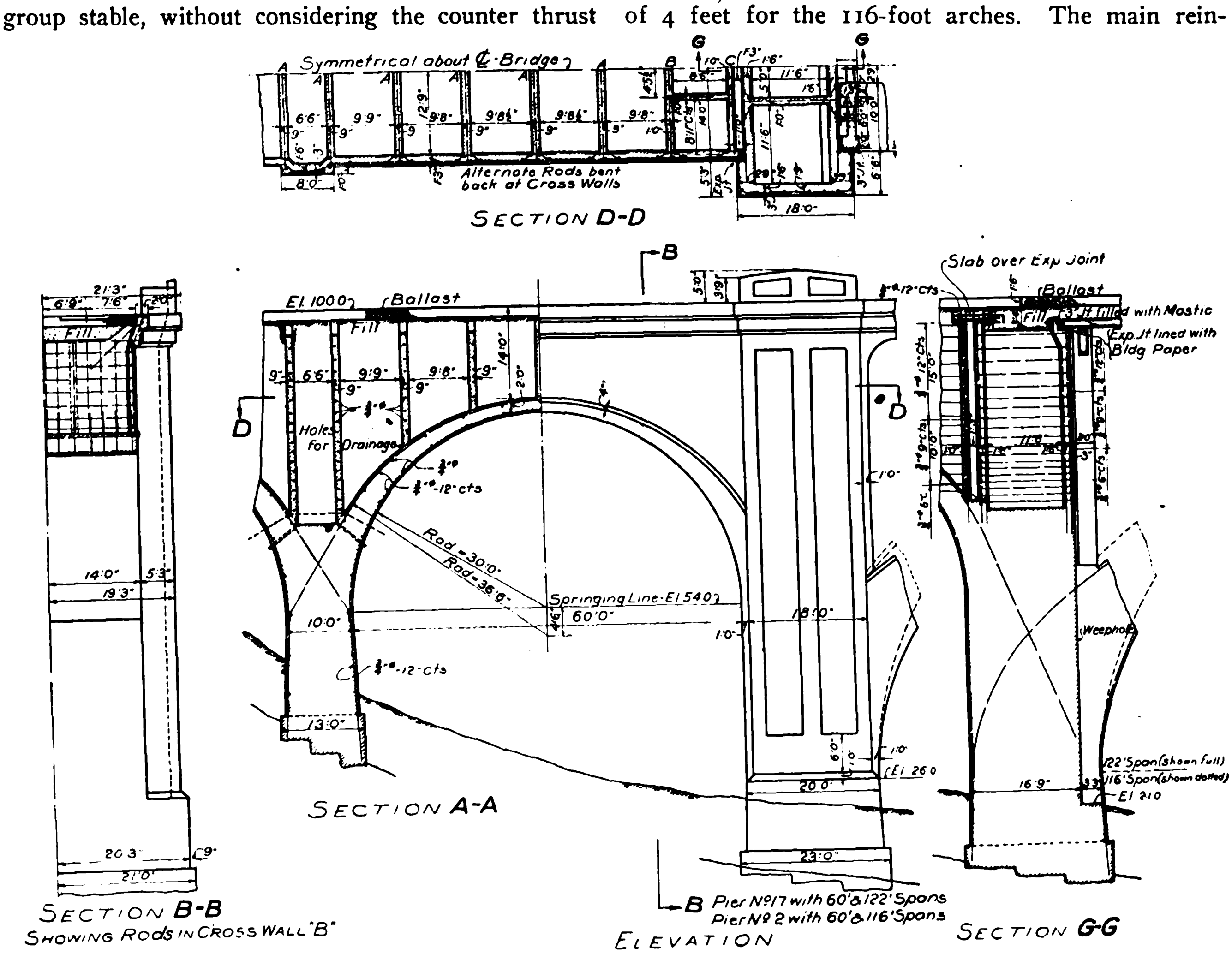

Fig. 3. Details of Earth-Filled Spandrel Arches.

forcement of each arch rib consists of ten ¾-inch diameter cars 12-inch centers, near both extrados and intrados, tied together with ¾-inch hoops at about 5-foot spacing. (See Fig. 2.)

The deck is composed of a reinforced concrete slab, supported by reinforced concrete transverse spandrel walls, resting on the arch ribs and arching over the space between ribs. These spandrel walls are only 1 foot 3 inches thick, but are stiffened at the ends, that is, at the edges of arch ribs, by 6-inch projections, 2 feet wide on each side, reinforced as columns. The outer ends of spandrel walls are connected by a rib 2-foot wide, with curved under side to give the appearance of transverse, open-arch spandrel construction. The deck slab is 1 foot 3 inches thick, reinforced with bent rods so as to provide for the continuous slab action developed over the walls.

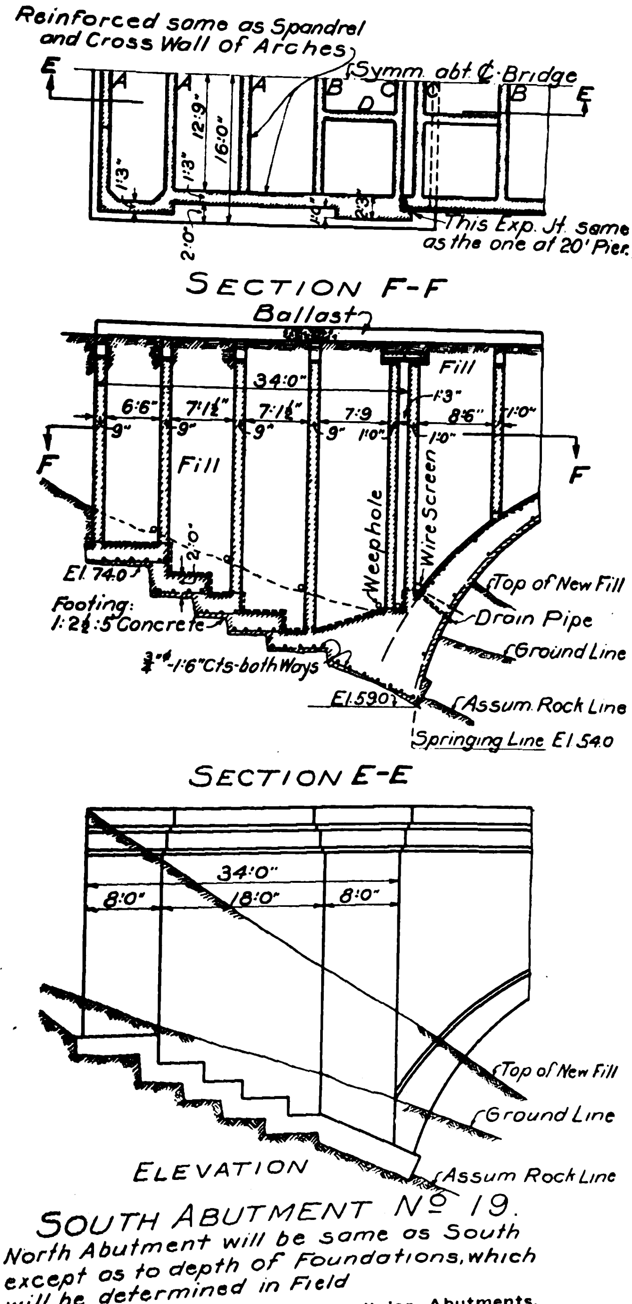

Fig. 4. Details of Filled Cellular Abutments.

To give access to the backs of arch ribs, all spandrel walls are pierced by arched-head openings. The high transverse walls supporting the deck over piers have thicker buttresses, or stiffening columns, than the others, and in addition have horizontal struts at about mid-height to increase their stiffness. (See Fig. 2.) The deck is anchored to the spandrel walls, except at the walls directly over the center of piers, where a 3-inch expansion joint, covered by a wrought iron plate, is provided in the slab. The spaces between the walls over piers are closed by reinforced concrete walls, paneled to simulate massive pilasters; those over the abutment piers terminating in a massive pediment and refuge nook, while the others merge, with slight projections, into the molded coping formed in the parapet wall. The base of rail is located at the level of the top of copings.

End Arches.—The 60-foot arches at the ends of the bridge are of an unusual type for, instead of having the usual gravity or cantilever type of spandrel walls to retain the earth filling over the backs of arches, the longitudinal walls 15-inch thick, are tied together at intervals of about 10 feet 6 inches by transverse walls of reinforced concrete 9 inches thick, the cellular spaces thus formed over the arch being filled for a depth of 2 feet immediately over the arch with coarse gravel to allow ready drainage, and the balance to sub-grade being ordinary earth fill. (See Fig. 3.) The transverse walls are kept down 3 feet 6 inches below base of rail under tracks, and have five large drain holes provided at back of arch to carry seepage to the drain pipes at the piers. The outer spandrel walls are reinforced with bent bars as fully continuous slabs over the transverse walls to which they are anchored.

The arch barrels for these secondary arches are 2 feet thick at the crown and reinforced with ¾-inch rods at 12-inch spacing near extrados and intrados, with ¾-inch transverse distributing on each layer of main reinforcement at about 5-foot spacing. The pier common to the two 60-foot arches at the south end is 10-foot thick, and is pilastered in the same manner as the other piers.

Filled Abutments.—The abutments are of the reinforced concrete, cellular type, filled with earth and supported on reinforced concrete stepped footings resting on rock as shown in Fig. 4. The walls spaced as shown in the detail are reinforced in the same general manner as the cellular walls over the end arches just described. The outer walls are pilastered at the ends and over the arch abutment to harmonize with the remainder of the structure. Two transverse walls are erected over arch abutments with a space of 15 inches between them and a vertical expansion joint provided for the longitudinal wall of arch in such a manner as to be hidden by the abutment pilasters.

Design Data.—The bridge was designed for the equivalent of Cooper's E-60 loading. All surfaces of the concrete are reinforced to prevent face cracking, and all reinforcement is proportioned for unit stresses of 16,000 pounds per square inch tension in steel, and 650 pounds per square inch maximum compression in concrete. The concrete in piers, arch abutments and filled abutment footings is of a 1:2½:5 mixture, while all other concrete is to be of a 1:2:4 mixture. Where splices are necessary in reinforcements laps of 48 diameters are specified.

All vertical rods in spandrels are to be spliced to anchor embedded in the arch rings or piers, and all rods are to be accurately spaced and held in position during concreting.

Surface Finish and Waterproofing.—Exposed surfaces of concrete are to be given a spade finish, secured by using dressed lumber forms, spading the concrete while placing, thus securing a dense mixture of mortar at the surface. All surfaces in contact with fill or ballast on bridge proper are to be waterproofed with a bituminous 4-ply membrane waterproofing. The spandrel walls of the abutment are to be coated on inside with two coats of pitch, as are the cross walls for a distance of about 3 feet from inside face of outer walls.

COMMENT.

J. E. Greiner & Company, consulting engineers of Baltimore, executed the design and are supervising the construction, which is now being carried on by the W. W. Boxley & Company, of Roanoke, Va. E. W. Stearns is resident engineer for the consulting engineers, and E. M. Hastings for the Richmond, Fredericksburg & Potomac Railroad, of which road, S. B. Rice is engineer maintenance of way. J. E. Willoughby, chief engineer, has charge of Atlantic Coast Line Railroad's interest in the work.

The writer is indebted to H. G. Perring, member of the firm of J. E. Greiner & Company, for photographs, plans and data used in this article.

Concrete Increases Revenue of Live-Stock Men.

As a result of tests conducted at the Ohio Experiment Station cement floors in live-stock feeding will result in a large saving. Tight stable floors save soluble plant food from seeping away as it does with earth floors.

Manure was increased in value by $4.48 annually for every thousand pounds live weight of steers over that recovered from animals standing on earth floors. In the experiments 58 steers were fed. The cost of concreting was about $4.50 a steer. Two 6-month feeding periods would therefore pay for the expense of the concrete floors.

Much of the fertility value of manure is in the liquid part, which is easily carried away through earth floors. Concrete prevents this seepage, making each ton of manure worth more, and at the same time there is a greater quantity of this material.

Are the Coal Companies Holding Up Power Plants.

In discussing the general need of fuel conservation in the boiler rooms, Van. H. Manning, director of the Bureau of Mines, has issued the following statement:

There is one phase of the present coal situation which may put an entirely different light on the supposed increased production of coal of the present year. In round numbers, there was produced 600,000,000 tons of fuel last year.

Statement has been made that 50,000,0000 more tons will be mined this year. The preparation of this increased quantity of coal has not been as good as in times past. Analyses of samples show in many cases a greatly increased quantity of ash.

Repeated cases are brought to the attention of the Bureau of Mines where coal which would run from 6 to 8% ash in normal times is running from 12 to 18% in these abnormal times. Complaint about the preparation of coal is very general and it is not at all improbable that 5% more ash is included in this year's coal than in previous years. If such a figure is true, it means that 32,500,000 tons of the estimated output of 650,000,000 tons is nothing but increased ash. If we can imagine over 600,000 carloads of ash being added to the present burden of transportation, the evident effect on car supply and transportation troubles would be seen. If this were the end of the matter it would not be so bad, but there is another factor well known to engineers which is apt to be overlooked by the non-technical user.

In the extensiive experiments carried on by the Government it is found that with the coals used there is a decrease of about 1½% in efficiency for each 1% addition to the ash content of the coal—that is to say, the inclusion of more ash with the coal decreases the valueo f the fuel, not only the amount equal to the useless ash, but it makes the remaining good coal less effective to the extent of 1½% for each 1% of ash. The inclusion of 5% more ash in the fuel, therefore, means a reduction in efficiency of the remaining good coal of about 7½%, which, added to the 5% useless ash, makes a total reduction in effectiveness of 12½%.

According to this point of view, although 650,000,000 tons may be produced in 1917, its effectiveness as compared with previous years is probably about seven-eighths of this, and equivalent to a production of normally prepared coal of about 570,000,000 tons. We have, then, instead of an increased production as compared with last year, an actual decrease of effective coal of about 30,000,000 tons. If this is added to the estimated increased needs, due to our accelerated activities, of 100,000,000 tons, we have a deficiency of the equivalent of fully 130,000,000 tons, instead of 50,000,000 tons to make up by good engineering and true fuel conservation in every boiler room.

Cement and Engineering News

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Bridging the James River at Richmond, Va.

Structure Consists of Eighteen Reinforced Concrete Arch Spans

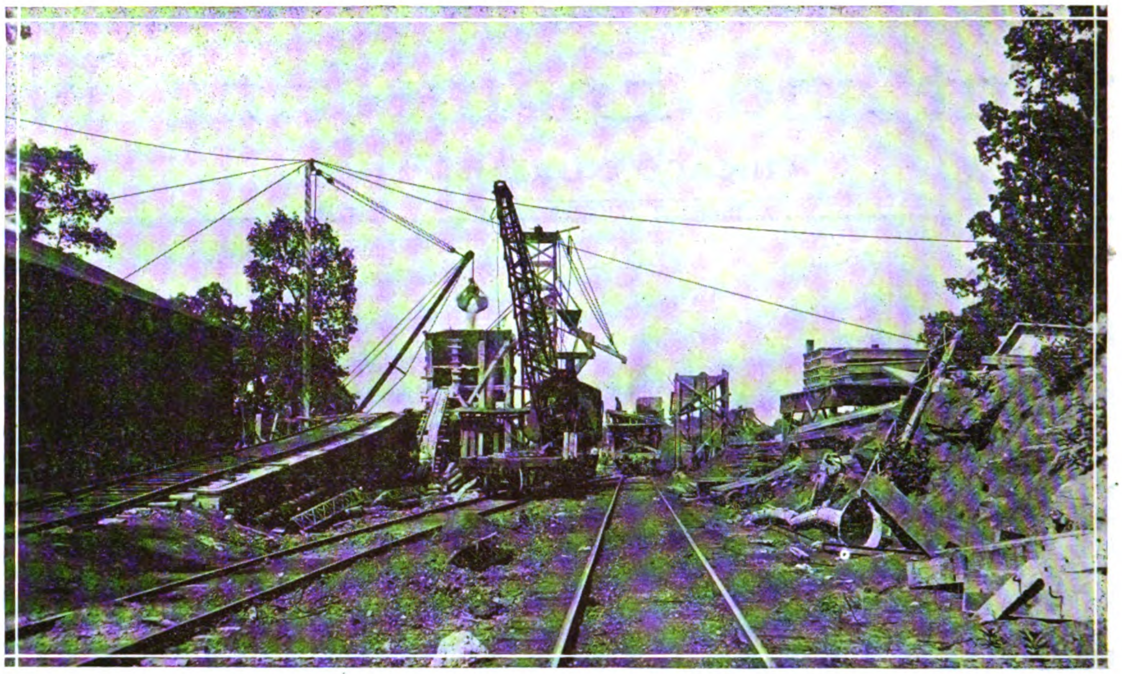
The bridge that the W. W. Boxley Company, of Roanoke, Va., is now building across the James River at Richmond, Va., will require 40,000 yards of concrete and about 1,500,000 pounds of steel rods.

This structure is 2,278 feet long and 32½ feet wide, stands 100 feet above the water surface, and it is to replace an old steel bridge immediately adjoining.

It is made up of 18 arch spans. There are two 60-foot arches at the south abutment, one 60-foot arch at the north abutment, three 122-foot spans and twelve 116-foot spans.

The piers are 38 feet long and vary in thickness from 14 feet to 20 feet, and up to a height of about 25 feet above the surface of the water are solid concrete. These piers rest upon solid granite which was encountered a short distance below the river bed.

All construction operations were carried on from the before-mentioned adjoining steel bridge. There are two mixing plants, one at each end of the bridge.

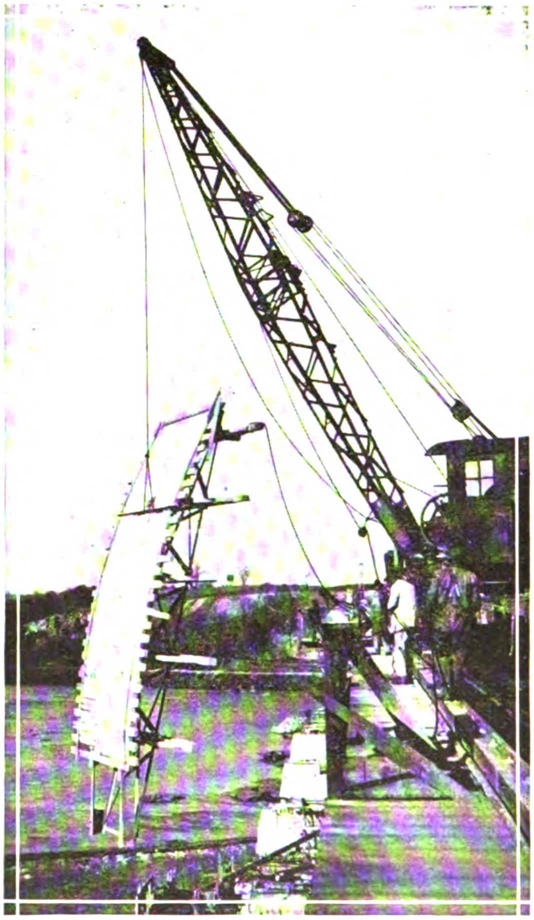


Here is shown one of the mixing plants, the derrick that supplies it with material, and a flat car and crane that transport the concrete to the old steel bridge, from where it is distributed.

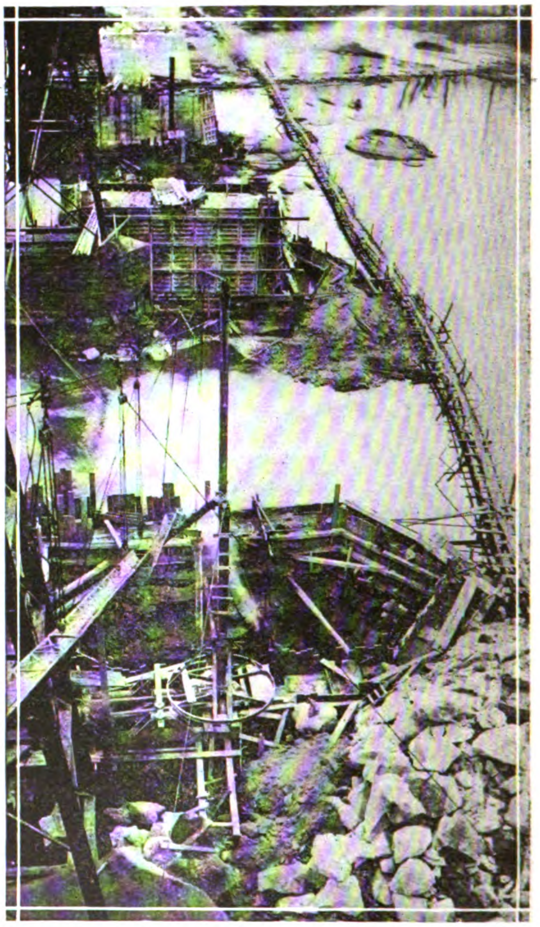
A small locomotive hauls the concrete out on the steel bridge, from various points of which chutes carry it to different parts of the work that are at least 16 feet below the top of the bridge.

For distributing concrete to points above 16 feet below the top of the bridge, a wooden tower 12½ feet high was built upon a flat car.

Two locomotive cranes are used for handling concrete, steel, forms and other materials, and there is a stiff-leg derrick for supplying aggregate to the main mixer. On all of these machines, as well as on the spouting systems, considerable Leschen Wire Rope is to be found.

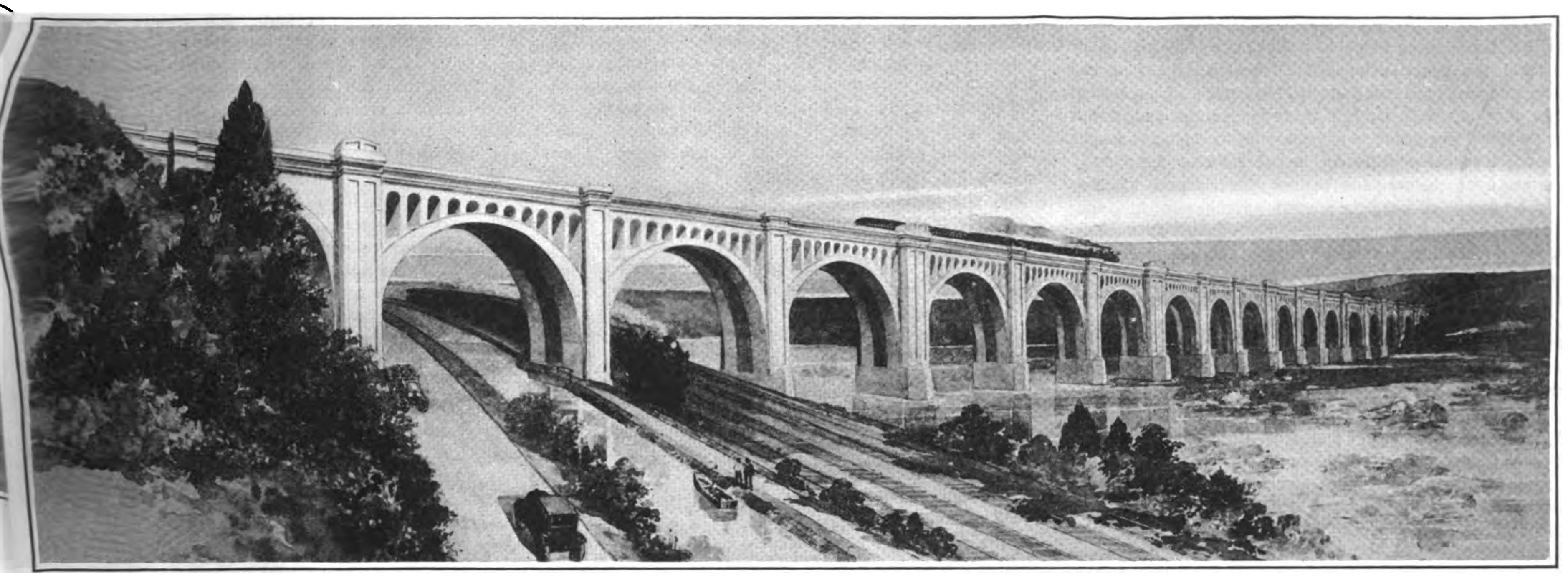


Locomotive crane lowering a form section.



This gives some idea of the foundation work.

This structure is being built jointly by the Richmond, Fredericksburg and Potomac Railroad and the Atlantic Coast Line Railroad.



A new concrete bridge across the James River, at Richmond, Va.

The James River Bridge

The accompanying illustration shows the design of the James River concrete bridge at Richmond, which indicates the advantage of concrete over steel railroad viaducts.

On account of the low cost of the concrete aggregates, furnished by the railroad, the bid for a concrete arch viaduct 2,278 ft. long was nearly $15,000 less than for an alternate steel design of plate girders and steel towers on concrete piers. This bridge replaces the single-track steel structure at the Belt Line crossing of the James River in Richmond by the Richmond, Friedericksburg & Potomac R.R. and the Atlantic Coast Line R.R.

The new double-track structure is being built parallel to and 30 ft. upstream from the old bridge and the new concrete structure is designed for the equivalent of Cooper's E-60 loading. The river bed is of granite, and a solid foundation is secured with comparatively little excavation. The maximum river stage is 11 ft. above mean water, while at times a large part of the river bed is exposed!

This location seemed well suited to concrete arch construction, but alternate designs were made by the consulting engineers for a concrete arch bridge and also for a steel viaduct with plate-girder spans, supported on steel towers resting on concrete piers.

A comparison of the bids for concrete and steel structures is of interest.

Concrete arch.		Steel viaduct.	
Bids to subgrade..	$416,122	Bid to subgrade..	$444,885
Ballast and ties...	5,520	Track	7,950
Rails	6,532	Approaches	49,600
Approaches	49,600		
			$492,435
	$477,774		

It may be stated that these prices were based upon a very low cost for aggregates, as the railroad company agreed to furnish sand and gravel for concrete at 60c. per cubic yard. The commercial prices per cubic yard of these aggregates at Richmond were $1.05 for sand and $1.20 for gravel. The concrete arch bridge contains 41,400 cubic yards of concrete and the steel structure 3,350 cubic yards.

In order to make a comparison of figures that could have been expected had the contractors furnished sand and gravel at market prices, there should be added to the above totals $30,900 for the concrete arch design and $2,530 for the steel design, thus making the cost of concrete arch $508,674 and of the steel viaduct $494,965, and this may be taken as a fair comparison of the relative costs of the highest types of design. The concrete bridge has beautiful lines and the advantages of a ballasted track, low maintenance and long life, as against a plain and less satisfactory design in steel with open floor, higher maintenance and shorter life. The contract was awarded for the concrete arch bridge and it is now being built.

This concrete structure consists of a bridge 32 ft. 6 in. wide and 2,278 ft. long, including abutments, and the base of rail is at elevation 100 ft. above the river level, which is taken as datum. There are twelve arches of 116 ft. clear span and 58 ft. rise, three arches of 122 ft. clear span and 58 ft. rise, three arches of 60 ft. clear span and 30 ft. rise, and 70 ft. of abutment approaches.

The main span piers are 14 ft. thick springings, with an abutment pier 20 ft. thick for each group of three arches. The abutment and the 60 ft. arches have solid earth-filled spandrels, while the main arches are of open spandrel design with slab floor system. The main arches spring from elevation 21 and are full centered and concealed expansion joints are provided for the structure above the arches at each pier throughout the bridge. No hand rail is used, but refuge bays 5 ft. wide are provided over each abutment pier on both sides of the bridge.

The upper part of each pier has a pediment which, together with the refuge bay treatment, breaks the straight line of the coping, giving a pleasing, artistic effect. All surfaces of the concrete are reinforced to prevent face cracking, and the reinforcement of the whole structure is in accordance with the standard specifications of the engineers, allowing 16,000 lbs. per sq. in. tension in steel and 650 lbs. per sq. in. maximum compression in the concrete. The exposed surfaces are given a spade finish, secured by using dressed-lumber forms and spading the concrete during placing to secure a dense mixture of mortar near the form surface and all arches and walls are provided with drainage and are waterproofed on the inside. The photograph and data relative to the bridge were furnished by Engineer H. G. Perring of Baltimore.

Model of Largest Copper Mine in the World

In Bingham Canyon, Utah, near Salt Lake City, is the largest and most remarkable mining operation in the world. Here where infrequent rains once washed furrows into the sage-covered slopes of the Wahsatch Mountains, a half hundred hungry steam shovels are now eating their way into the heart of a mountain of copper ore—not copper ore as ordinarily seen, rich and heavy, in conspicuous seams and veins; but a new sort of copper ore, rock with such a scant scattering of copper minerals that to the ordinary eye it looks no more like ore than common granite, rock so lean in copper values that to old-line mining methods it remains as unprofitable to mine as common granite. Yet this new type of copper ore, developed not only at Bingham, but recently also as a result of its leadership at several localities in the Southwest as well as in Mexico and Chile is now producing more copper than the whole United States provided a decade past.

Here is an object lesson of the present; a vision of the future that all should see. It is now available for all to see, for a model reproduction, larger than an ordinary room, true in detail as well as in general effect has been completed and installed in the Division of Mineral Technology of the United States National Museum. This model has been prepared with faithful elaboration because it represents not only a unique application of the relatively new open-cut, steam-shovel type of mining operation, but also a specific and important source of the essential metal copper.

This achievement of adding millions of tons of copper to the world's output is due to the vision and constructive imagination of a single mind. Twenty years ago the mining of rock in which the copper minerals could scarcely be seen was undreamed of, But one man dreamed—and acted; and the dream came true. He is Daniel C. Jackling, first vice-president and managing director of the Utah Copper Company.

In 1898 Bingham Canyon was a district of small and none-too-flourishing gold mines. Low-grade copper ores had long been known to be present, ever since, in fact, the Third California Infantry, stationed at Salt Lake City in 1863, varied their activities by prospecting in the neighboring mountains and drove a tunnel into the copper-bearing rock. But rock carrying in each ton only thirty pounds of copper, and that in the form of complex minerals, had to await large-scale engineering ideas to materialize. Jackling made an examination of this ungainly copper occurrence in 1898. He saw its possibilities. He reported that millions of pounds of copper were scattered through a mountain of rock and that the copper could be secured at a profit if operations were planned on a large enough scale; in other words, if the whole mountain were demolished in the process. But the idea was staggering, and not until five years later did capital venture into this tremendous undertaking. Success has now crowned the venture, not merely material or financial successes; but success of deeper significance. We have here the turning point between the mining of the past and the mining of the future. The bonanza type of mine, in which rich values are gotten from the earth with little effort, is fast becoming obsolete, even in the undeveloped regions of the globe. The world must turn more and more to low-grade ores for its essential metals, and the achievement at Bingham has blazed the trail.

Bingham Canyon is easily reached from Salt Lake City. After skirting the spurs of the Wahsatch Range and passing the enormous mills and smelter at Garfield, placed at the mouth of the Canyon twenty miles from the mine to handle the thousands of tons of ore that come down daily, the visitor's train turns into a narrow valley. Near its head, he dismounts in a mining town, pressed between precipitous slopes, smoky and noisy from passing ore trains. If he climbs the steep slope surmounting the place, he can gain a panoramic view of the mining activities. He sees a whole mountain, resting against the crest line of a snow-clad range, stripped bare of its mantle of soil, raw and naked in its demolishment. Terrace after terrace of gray rock, twenty-five in all, rise step-like from the valley bottom, and extend like giant stairs to the very summit, supporting nearly fifty miles of railroad. As the eye wanders up to the top it catches here and there puffs of white vapor, accompanied by raucous noises, where ponderous steam shovels, looking tiny in the distance, are scooping out tons of copper rock and loading their charges into long trains of cars gaping for their burden. It is ugly, yet fascinating, this unwilling tribute yielded up to the masterful effort of modern industry.

A City of Gardens

Every city of homes—and that means every city in at least part of its area—should be a city of gardens. People should be taught how to make it so, how little it costs to make it so, and how certain are the garden crops when properly irrigated. They should be led to realize that vegetables and berries plucked fresh are infinitely more palatable than the inevitably stale stuff that the markets provide.—*Engineering and Contracting.*

Alternate Designs for New James River Bridge, Richmond, Va.

In March, 1913, the Administrative Board of Richmond, Va., advertised a competition for the design of a concrete bridge across the James River on the site of the old Free Bridge, which on the Richmond side of the river is at about Ninth St. After considerable delay, and a variety of conflicting circumstances, all of which have been stated in these columns, the award of prizes was made August, 1913.

Some thirty engineers submitted designs for the structure. A collation of all of these designs would be very instructive as showing different solutions of the same problem, but it is beyond the space which we can allow. We have, however, secured the drawings submitted by the three prize winners, together with brief explanations of their respective reasons for the designs which they submitted. It is interesting to note that these three designs are of different types of bridges, that is, as far different as the restrictions of the competition would allow. The first prize of $1500 awarded to B. H. Davis, of New York City, is for a series of long-span, rather flat, elliptical reinforced-concrete arches. The second prize of $500, awarded to R. A. Cummings, of Pittsburgh, is for a series of short-span, semicircular concrete arches; while the honorable mention awarded to Messrs. Scarborough and Roelker, of Richmond, Va., is for a reinforced-concrete beam-and-column viaduct.

The requirements of the competition were very simple, so simple in fact that the competitors were seriously handicapped in their effort to meet the views of the Board as to the type and cost of the bridge. The requirements were that the bridge was to be erected on present Free Bridge site; that the bridge and the approaches were to be designed of reinforced concrete, of such construction as to provide and care for the heavier traffic loads for municipal service and for street cars of an estimated weight of 60 tons each; that the bridge and approaches were to be not less than 60 ft. wide and the roadway not less than 44 ft. wide, exclusive of sidewalks and including railing. The termini of the bridge and of the approaches were definitely shown on a map. Further requirements were stated for the type of sidewalks, trolley and light poles and conduit and sewer provisions. It was stated that the bridge must be of such design as to vent readily the river flow at the highest record, which was shown on a submitted plan. This plan also gave the grades of the old bridge and streets, and the general statement that the new bridge must clear the Chesapeake & Ohio R.R. tracks on the Richmond side of the river by at least 22 ft. No prescriptions as to cost or architectural treatment were made. One very important error in the requirements is the stipulation that the bridge approaches on the Richmond side reach grade at Byrd St., which is some distance toward the river from a grade crossing with 16 railway tracks, over which all traffic to the bridge would go. Nearly every competitor called attention to this error in layout, but as a rule the restrictions of the advertisement were adhered to. It will be noted, however, that the last design herewith shown avoids the grade. The accompanying figures give the general and detail elevations, sections and plans of the three premiated designs.

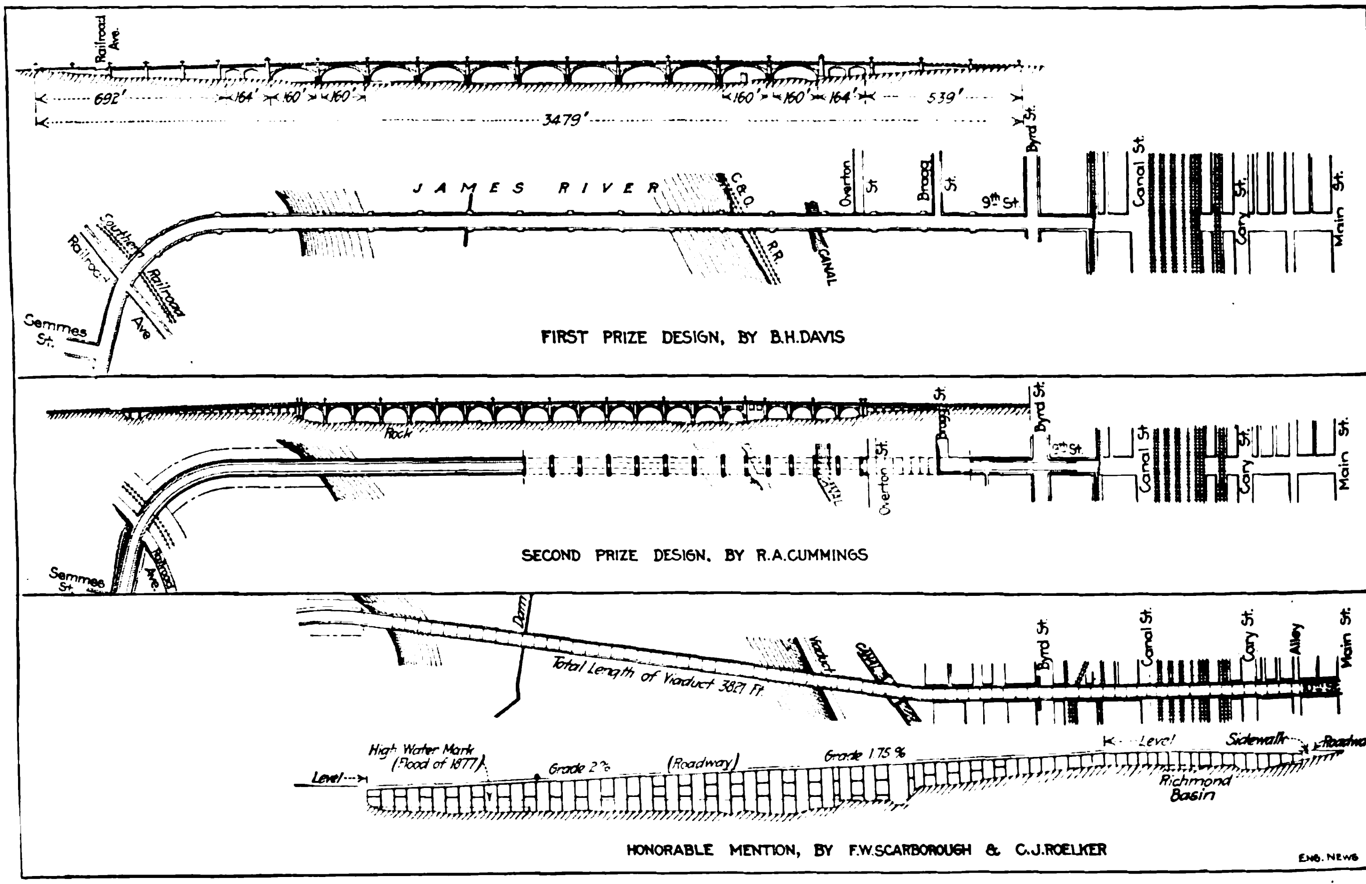


Fig. 1. Plans and Elevations of Three Premiated Designs for James River Bridge, Richmond, Va.

First-Prize Design

The first prize was awarded to B. H. Davis, of New

York City, for the design shown at the top of Fig. 1. Mr. Davis had associated with him as advisory architect, Vance W. Torbert. It consists of a 1940-ft. river crossing of long-span arches, flanked by combination arch, slab and retained fill approaches, 690 ft. long on the Richmond side and 850 ft. long on the Manchester side. The intention of the designer was to produce a monumental structure that would have the dignity and beauty required of a municipal structure and would at the same time comport with the requirements of location laid down by the city authorities.

For the sake of economy of construction, the proposed new bridge was designed to straddle the old structure, which, with its cantilever sidewalk removed, will form an ideal construction trestle with standard-gage tracks already in position for construction operation. The piers, however, do not coincide with any of the piers of the old bridge. This, then, controls the alignment. The grade was fixed by the requirements of clearance over the various railway and canal properties. The long spans of the main bridge were decided upon to clear the railway properties at the shore parts of the bridge and were continued across the river at the same span length, partly for aesthetic considerations, but mainly for economic reasons, the saving in forms and centers for a series of equal-span arches being quite large.

For a short distance at each end of the structure, the approaches consist simply of retained fills, but these give way to floor-slab and curtain-wall construction where the depth of fill becomes excessive and the retaining-wall section correspondingly extensive. Each approach contains, next to the river section, two 56-ft. spans of the arch-girder type, the approach spans being made up of deep narrow girders of segmental form, each having sufficient rise to act as an arch. The bridge itself will consist of a series of eleven semi-elliptical arch spans each 160 ft. long and 40 ft. high, surmounted by segmental spandrel arches. Each of the long-span arches is composed of two parallel arch ribs 4½ ft. thick at the crown by 14 ft. in width and reinforced, mainly against temperature and construction stresses; they are 20 ft. apart, for the whole length, and the floor, a reinforced-concrete slab, is carried on reinforced-concrete girders spanning this 20-ft. opening. Sidewalks are to be carried on projecting cantilevers.

The piers for the approach span are connected in pairs by curtain walls forming hollow rectangles. The piers for the arch spans are solid. All piers are to be carried down to rock, which outcrops very near the surface.

The tracks are carried in the middle of the roadway, spaced as shown in Fig. 2. It is stated by the designer that the very heavy load imposed by the cars to be carried is mainly responsible for the massive nature of the construction.

Second-Prize Design

The design by Robert A. Cummings, of Pittsburgh, Penn., shown in the middle of Fig. 1, was awarded second prize. Messrs. Rutan and Russell were consulting architects. This design consists of a series of short-span concrete arches flanked by retained fill approaches. The general features of the design and an explanation of its fundamentals are set forth in the following extracts of a brief presented by Mr. Cummings to the Administrative Board.

It is essentially an engineering task to secure economical construction for the structural solution of the problem. The first consideration in any design for this bridge is the fixing of the grade line for the roadway. According to the "Requirements" the elevation of each terminus is fixed and there must be a 22-ft. clearance over the right-of-way of the C. & O. R.R., which is located along the north shore of the James River.

My design fixes the grade of the roadway over the C. & O. R.R. at elev. 90. Consequently, the Richmond approach will have a grade of 0.75%. Inasmuch as there is an insignificant saving in the quantities of work in the use of a regular roadway grade over a broken grade from the C. & O. R.R. to the southern terminus, and as a regular grade line would not harmonize with the adjacent structures (railroad bridges, etc.) nor conform to the two last mentioned principles of design, a level grade at elev. 90 for the river crossing was adopted.

Further reasons for a level river crossing are found in the advantage of securing uniformity in construction; and in harmonizing the grade line of a prominent and elevated structure with the horizon and the water level of the river. Besides, the obvious purpose of the bridge is the crossing of the river and railroad and this is emphasized by the grades used.

In the final design there should be a certain "crowning" of the longitudinal level grade so as to avoid the optical illusion of depression at the center, but which is not shown in the drawings.

A study for the design was made with a view of securing the most economical type. That is, the type of bridge in which is combined all engineering requirements for strength, economy of materials, facility in construction, and the requirements of the Administrative Board.

The open-spandrel arch-rib type of span is best adapted to meet this problem. The present piers being in good condition, but too small, were utilized by being inclosed in the new bridge piers. Hence the present piers largely fixed the location of the new ones. It was further contemplated to utilize the present piers and bridge during construction by placing the arch ribs on either side of them.

A gravity retaining wall will be built at the shore end on the Richmond side of the bridge and behind this wall will be an earth filling compacted to grade and suitably drained. The remainder of the Richmond roadway approach will be carried upon an ordinary type of reinforced-concrete slab, beam, girder and column floor system. In each bent there will be six columns 24 in. square connected by a girder at the top having arched bracket braces. The bents are 30 ft. c. to c. and located so that there remains an unobstructed entrance to the warehouses and factories on this section. The floor slab is 6 in. thick and the beams are 20 in. wide by 40 in. deep under the slab.

The intermediate section between Overton St. and the C. & O. R.R. crossing is composed of uniform span ribbed arches, similar to those described later for the river crossing, except that the spandrel walls are solid. The floor system of the roadway is similar to that of the river section.

One of the controlling requirements of the design is the securing of the lowest practical elevation of the roadway over the right-of-way of the C. & O. R.R. with a minimum clearance of 22 ft. above the top of present rails. This has been effected by adopting a slab and girder floor system having eight girders spanning the entire right-of-way and resting upon suitable supports. The obliquity of the right-of-way with the center line of the bridge in 60°, which complicated the problem and necessitated special treatment by a tunnel-like opening through the Richmond abutment.

The James River crossing consists of 13 spans of 90 ft. in the clear and two spans of 72 ft. in the clear, with appropriate terminal abutments. Each arch span consists of four semi-circular ribs 2 ft. 6 in. thick at the crown and 5 ft. thick at the springing line. At the crown the two outside ribs are 5 ft. in width, and the inside ribs 6 ft. 6 in. wide. Each rib is increased in width at the rate of 1 in 45 measused vertically from the crown to the springing line. Each outside and inside rib is connected on the soffit by a 6-in. slab and two streets located at points equidistant from the crown. Uniformly located on the arch ribs, is an open spandrel colonnade consisting of 8-ft. semicircular arches and columns which support the floor system carrying the roadway, street railway, sidewalk and handrail.

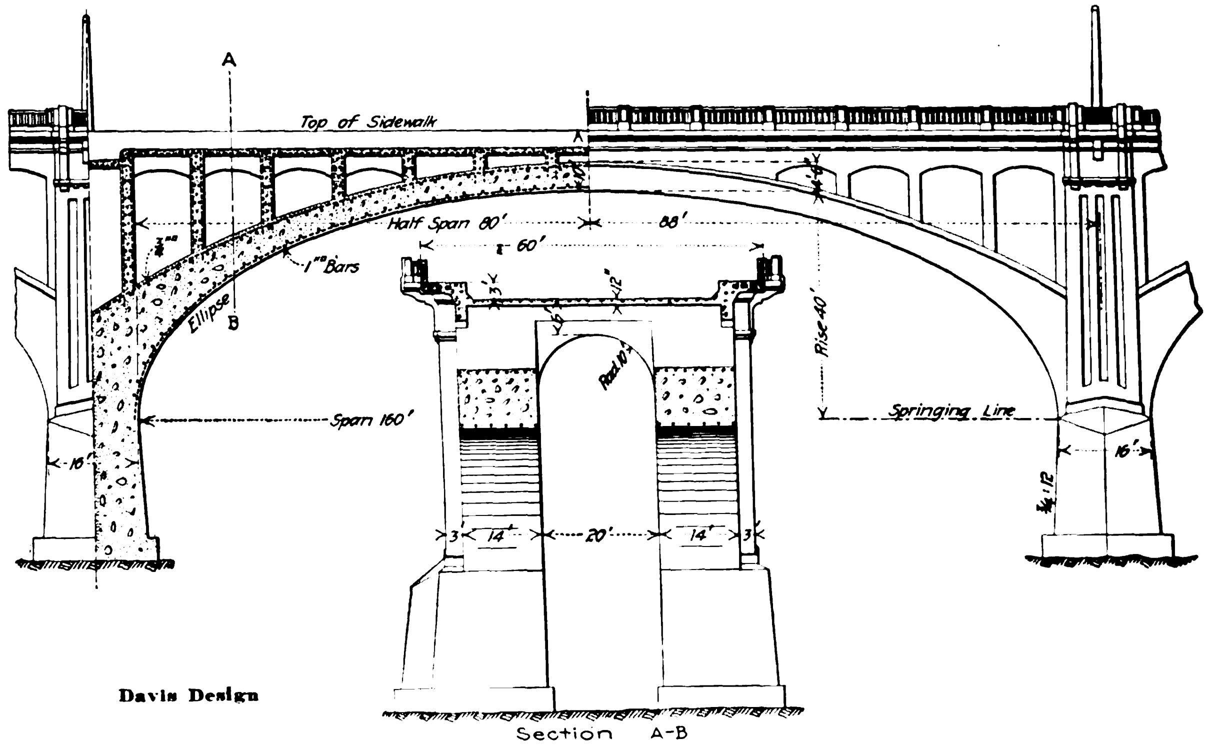
The slab is 6 in. thick and transverse girders are 20 in. by 40 in. spaced 10 ft. c. to c. The street railway is located directly over the interior ribs, (Fig. 2) and alongside the sidewalk for the greater convenience of pedestrian traffic on such a long structure. This also avoids danger from traffic that is always present when boarding cars located in the middle of the street.

The south approach is similar in design to the floor system and supports of the Richmond approach and comprises the section between the James River crossing and the North line of Railroad Ave. The section between Railroad Ave. and Semmes St. will consist of an earth embankment properly graded and paved.

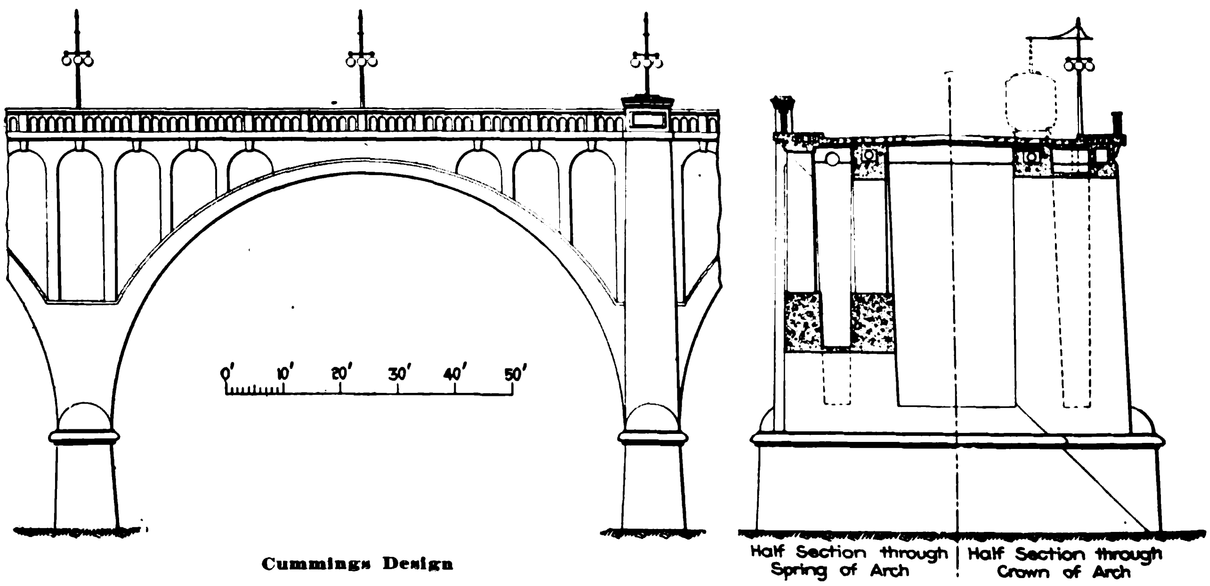
The estimated cost is approximately $475,000. This is based upon similar work in the vicinity. It is believed that in the structural solution of the problem the first object of engineering skill has been secured in an economical construction.

The æsthetic treatment is necessarily subordinate to structural efficiency. However, the nearer an harmonious combination of the two principles can be secured the more ideal will be the result.

In considering the æsthetic side of my design there has

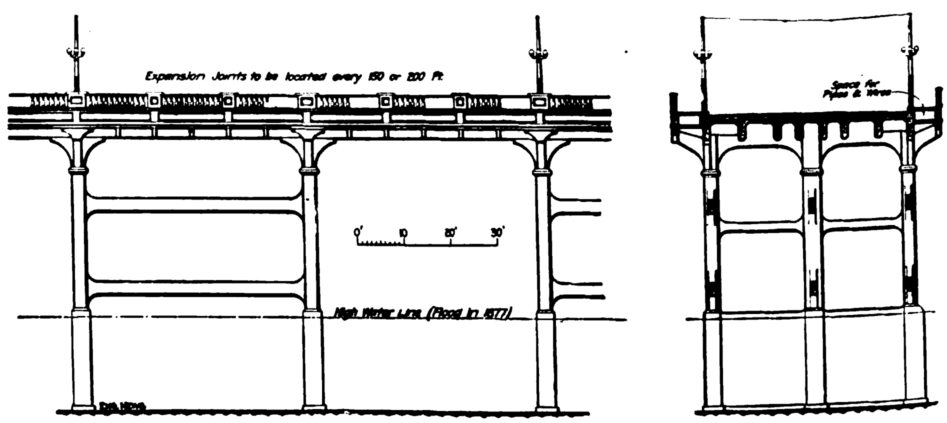


Davis Design



Cummings Design

Fig. 2. Detail Elevations and Sections through Roadway, James River Bridge



Scarborough & Roelker Design

been an effort to express the purpose of the bridge. This is partly emphasized in the grades of the roadway, which are carried level at a high elevation and above high water over the river crossing. The site of the bridge is across the rocky rapids of the James River just above the limit of tide and navigation. The river not being navigable here, it is obvious that long spans are useless and serve no economical or structural purpose. Hence, the present piers were utilized. Further, short spans were naturally suggested by the shallow and frequently bare river bed of rocky boulders and crags

It is equally important to regard the bridge as a whole in which there shall be self-evident a symmetry of composition or of æsthetic "motifs" accentuating their uniformity of purpose. In this design there are three "motifs," the approaches, the river crossing and the intermediate section. The last "motif" was necessitated by the peculiar physical conditions and overhead crossing of the C. &. O. R.R. which broke up the continuous uniform treatment between the two shore approaches

The first "motif" is composed of the two land approaches consisting of the slab and girder floor system supported by columns on footings and concrete piles.

The second "motif" is composed of the river crossing and consists of semicircular arches supporting an open spandrel colonnade which carries the roadway and utilizes the old piers in the new masonry.

The third "motif" is composed of the intermediate section consisting of smaller span arches connecting the Richmond Approach with the center or second "motif."

Honorable Mention

There were only two money prizes awarded, but the Board of Engineers, who finally made the award, decided that the design submitted by J. C. Roelker and F. W. Scarborough, both of Richmond, Va., was deserving of honorable mention. This design, as noted at the bottom of Fig. 1, is radically different from either of the two premiated designs. In the first place, it does not follow the instructions of the requirements as to location, being moved one block away to the line of Tenth St. instead of Ninth St. In the second place, it is not an arch structure but of beam-and-girder type. It may be noted that the city of Richmond has already one of the heaviest reinforced-concrete beam-and-girder bridges, or viaducts, in the country, the one used by the Richmond & Chesapeake Bay Ry.

We give below extracts from the brief submitted by Messrs. Scarborough and Roelker in description and defense of their design:

After most careful consideration we arrived at the conclusion that it would be a serious error to have the approach to the bridge so situated that it would be necessary to cross the Chesapeake & Ohio R.R. yards at grade, also that Tenth St. is most favorably situated, all things considered, as the approach to the proposed bridge.

The following reasons have led up to this conclusion: Tenth St., at present, is a street of small traffic; it is blocked at Cary St. by the Chesapeake & Ohio R.R.; it is resumed at Byrd St., and stops again at the Race Canal.

Ninth St., even without the Free Bridge, is a thoroughfare connecting, the main body of the town with the railroad yards of the Chesapeake & Ohio, the Richmond, Fredericksburg & Potomac R.R., and the Atlantic Coast Line, with all the industries on Tenth St., south of the Chesapeake & Ohio yards, the large industries on Ninth St. proper, and the valuable property on the island south of Race Canal.

Any construction that would interfere with the traffic on this street in any way, would cause serious damage. If this traffic over the Free Bridge was removed from Ninth St., it would still be a busy thoroughfare. Ninth St. is the only through street from Main St. to the river between Seventh and Twelfth Sts. The grades on Ninth St. are fairly easy. The grades on Seventh St. and Twelfth St. are very steep, and Twelfth St. is narrow and crooked.

The above reasons convince us that the best interests of the city are served if we let Ninth St. remain as it is, and build the approach to the Bridge between Richmond and South Richmond in Tenth St. The city would then not only lose nothing in traffic facilities, but if our plan be adopted, would be actually gaining a new street.

The practice in all thickly settled communities is to separate the traffic on the street from the traffic on the steam railroads. The danger and delays of a grade crossing are too well known to bear repetition. The bulk yards of the Chesapeake & Ohio east of Ninth St. are of mutual benefit to the merchants and manufacturers of the city, and to the Chesapeake & Ohio R.R. Very nearly every city in the United States is now suffering from cramped railroad facilities, and, in a number of cities manufacturers are removing their plants to beyond the city limits in order to get adequate railroad facilities. These cities, of course, lose the benefit of the taxes on the plant so moved and the revenue derived from the operatives. The design that we submit is made with a view to avoid such condition growing in Richmond on account of the delayed switching service in these yards.

The wear and tear of the equipment and tracks of a street railway, crossing from 12 to 14 tracks, is a considerable item. Steps are to be provided at Tenth and Byrd Sts. so that pedestrians having business south of the Chesapeake & Ohio yards will not be delayed by the switching.

Our design shows a simple reinforced-concrete viaduct, with spans of about 50 ft. in length over the river, and 35 to 55 ft. over the streets. This construction is continuous from end to end, there being no reason in our opinion to change the construction in the river bed. Our design gives sufficient vent area for the water, being more than given by the Atlantic Coast Line's viaduct and the Virginia Railway & Power Company's dam above.

With regard to accumulation of drift during freshets, we will say that our river spans of 50 ft. preclude the possibility of this accruing to a danger point, and that in the construction of this bridge, the Atlantic Coast Line thought it of so little consequence that they did not deem it of enough importance to remove the old piers which formerly carried their bridge, consequently we have not thought it advisable to change the construction over the river from that which of necessity must be used on land.

The adoption of handsome arches or trusses with curved chords would be very expensive, and, in our opinion, a waste of money. From no point in the city could such an ornamental bridge be seen to advantage. A bridge with a substantial roadway, pleasing to the eye, supported by a structure economically designed for strength and utility, is the one that would best serve the needs of the public. This bridge is hidden from sight from Gamble's Hill Park by the Atlantic Coast Line viaduct, and there is no other point from which it can be seen to advantage; the Atlantic Coast Line contemplates the disuse of Byrd St. as a passenger terminal.

There is no difficult construction on Tenth St., such as will have to be encountered on the lower end of Ninth St., where the grades separate one-half of the street leading to the island above mentioned, and one-half leading to the factories, Arch St., and to the present Free Bridge. The lower division of this street is so narrow that no obstruction should be placed therein.

The south terminus of our design at the end of the present Free Bridge was chosen for the following reasons:

(1) South Richmond is growing very fast to the westward, and this west end should have bridge facilities.

(2) The east end of South Richmond will be well served upon the completion of the Mayo Bridge.

(3) If an attempt should be made to turn this bridge further down the stream the property damage incurred to the Southern Ry. yards and shops would be enormous.

(4) The bridge shown on our plan can be constructed so as not to interfere with the traffic on the present Free Bridge until about two months before its completion, while if Ninth St. route is chosen, no traffic could cross the river at that point for at least one and probably two years.

The piers in the river are designed for economy in cost and in erection. Each pier consist of three pedestals, connected by a reinforced web 1 ft. 6 in. in thickness, thereby saving the expense of a solid pier. Inasmuch as these piers are shown above the highest water of 1877, the work of the superstructure will never be delayed by a rise in the river. The piers to be built ahead of the superstructure, the viaduct bents to be erected by an overhead traveler on the roadway level, and the forms and supports for the roadway to be carried by portable wooden trusses, resting on the piers. The spans in the river being uniform, they allow the use of the same trusses and forms for the entire river section. These trusses and forms can be moved ahead and placed for the spans in advance by the traveler aforesaid.

The estimated cost of structure, complete as per plans, but not including street railway track, is in round numbers $500,000.

No definite move has been made by the city authorities toward the construction of the bridge.