Double-Deck Viaduct Built Over Cincinnati Terminal

Concrete two-rib open-spandrel arches and steel spans make up Western Hills viaduct upon which difficult foundation problems were solved

A DOUBLE-DECK VIADUCT, 3,500 ft. long, of reinforced-concrete and concrete-cased structural steel, crossing the Mill Creek valley at Cincinnati, is the solution of a difficult street-traffic and grade-separation problem arising from the construction of the new union passenger terminal and re-arrangement of freight facilities, as described in *Engineering News-Record*, Feb. 26, 1931, p. 348. This railway development necessitated the removal of two highway viaducts and the closing of two streets crossing the site at grade. Better communication between the city and its rapidly developing residential section on the heights across the valley will be provided by the new Western Hills viaduct, which will also connect with McMillan St., an important cross-town thoroughfare. This viaduct was opened to traffic on Jan. 16, 1932.

It is estimated that this viaduct will provide ample capacity for the traffic until 1970, when additional crossings may be necessary. The structure has been designed in accordance with the specifications of the Ohio state highway department, using a live load of 20-ton trucks and 50-ton street cars. The 120-ft. arch span carrying the single-deck part of the structure over Spring Grove Ave. is shown in Fig. 1, while Fig. 2 gives a plan and profile of the entire structure.

The upper level, which will carry the high-speed vehicular traffic, extends west from Central Parkway, a wide and heavily traveled boulevard, to Harrison Ave. near Beekman St. It has a 40-ft. roadway and two 6-ft. sidewalks. The lower level, which will carry street-car and truck traffic, extends from Spring Grove Ave. to Harrison Ave.; it also is 40 ft. in width but has no provision for pedestrian traffic. From bents 25 to 50 galleries have been provided outside the main structure at the elevation of the lower roadway, one on each side, to carry a 36-in. water main and a 30-in. gas main across the terminal area. Two concrete arches are introduced for long spans.

At the west approach a wide plaza, designed to separate and distribute the various classes of traffic, is being provided. Traffic on the lower level will reach this plaza by means of ramps, one on either side of the main viaduct, while street-car traffic from the lower level will pass under the plaza and reach the street grade beyond by means of two approaches between retaining walls. This approach presented many interesting problems in its details, on account of the complexity of the street-railway intersection, the irregular shape of the area and the necessity of maintaining traffic across it during construction.

Architectural Treatment and Lighting—Careful attention has been given to the architectural appearance of the structure, the architects and engineers working in close collaboration for the purpose. The treatment is modernistic in style, with a minimum of applied ornamentation, and with emphasis placed on vertical lines and surfaces. Considerable care has been taken to keep the treatment uniform, so that the finished structure may present the appearance of a complete whole rather than a composite. Pylons carrying lanterns mark the ends of the structure and the abutments of the arch spans. To give a good surface finish, the exposed surfaces of concrete are rubbed with carborundum blocks. An open design of parapet wall (poured in place) is used for the upper deck, while the lower deck has solid parapet walls with paneled faces.

The absence of trolley poles on the upper level gave the incentive to the search for a type of lighting that would eliminate the need for the usual lighting standards. The type adopted makes use of fixtures recessed in the dies of the balustrade and employs a lens designed to concentrate the light on roadway and sidewalk surfaces. Extensive experimentation indicates that it will be quite successful. For the lower deck, bracket lights attached to the columns will be used where clearance permits; elsewhere, pendant overhead inclosed lighting units will be concealed by the floor beams of the upper deck.

Structural Design—With the exception of two arch spans and the west approach, the entire structure consists of a series of two- and three-span frames, with the two columns of each bent connected by a cross-girder at each deck, and with a separate rectangular footing under each column. Longitudinal beams or stringers with lateral struts between them support the deck slab. This design is shown in Figs. 3 and 4. Double bents are used at expansion joints. In crossing the railroads the arrangement of spans and location of piers had to be planned in conjunction with a definite layout of the numerous tracks.

From the east end to bent 22 (Fig. 2) the frames are single-deck, while the rest of the structure is double-deck. The length of span averages 42 ft. for the single-deck portion and 56 ft. for the double-deck portion, with a maximum span of 78½ ft. (exclusive of the arch spans). The height from top of footing to top of roadway varies from 22 to 90 ft.

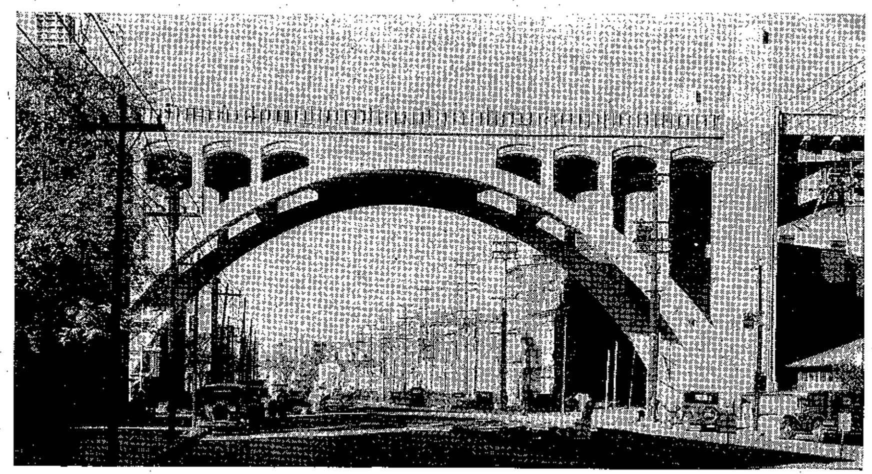

Fig. 1—Arch over Spring Grove Ave., Cincinnati, in single-deck portion of Western Hills viaduct.

Except between bents 27 and 47, all of the frames, both single- and double-deck, are of reinforced concrete, with beam and girder decks and floor slabs supported on spirally reinforced columns. Between bents 27 and 47 the frames are of structural steel, incased in concrete, with reinforced-concrete floor slabs. Structural steel was adopted for this part of the structure because the span lengths are too great for economical construction in reinforced concrete and because the ability to support forms from the steel without falsework is an aid to construction over the tracks in this area.

In designing the double-deck concrete frames from bents 47 to 58, it was found necessary to introduce a hinge in each column at the top of the lower deck to relieve the moments induced in the columns by the frame action. This hinge consists of a steel lower casting with its top surface machined to a convex spherical segment, and a steel upper casting with the lower surface machined to a concave spherical segment of a slightly larger diameter. A steel pin connects the two castings on the vertical axis to aid in transmitting the horizontal shear. These hinges are entirely concealed in the column concrete.

In the steel portion of the structure the framing consists of I-beam stringers supported by trussed floor beams framing into main longitudinal trusses. These trusses are framed into the columns with connections designed to transmit the moments induced by frame action into and across the columns. The lower-deck main trusses are of the half-through type, with the upper portion of the truss incased to serve as a parapet; the upper-deck main trusses are entirely below the deck. On account of the long spans the two levels of roadway and the limitation of two columns to a bent, the steel column sections are extremely heavy. Each column is of built-up H-section, with plate and angle web and I-beam flanges, the complete steel column having a maximum weight of 1,285 lb. per foot, including details.

Concrete Arches—There are two reinforced-concrete arch spans, one of 120-ft. clear span and 41-ft. rise over Spring Grove Ave. and the other of 109-ft. clear span and 62-ft. rise over Mill Creek. While foundation conditions were not ideal for arches at these locations, careful study indicated that arches were the most economical type for providing the long spans required at these two points.

The Spring Grove Ave. arch (Fig. 1) is a single-deck open-spandrel arch with two ribs having a maximum section 6 ft. square. The Mill Creek arch (Figs. 5 and 6) has two decks, is of open-spandrel construction and has two ribs with a maximum section 7 ft. deep and 6 ft. wide. It has the central portion of the lower deck hung from the arch rib, while the rest of this deck and the entire length of upper deck are supported on spandrel columns. Every effort has been made in the design of both arches to minimize the restraining effect of the deck on the ribs.

In order to take care of the horizontal thrust of the arches, which in the original design had been provided for by batter piles in the case of the Spring Grove arch and batter piers for the Mill Creek arch, it was decided to construct a tension tie under each rib in order to connect the footings, and the proposed batter supports were eliminated, as noted later. These ties (Fig. 5) consist of groups of 2¾-in. steel rods varying in length from 16 to 47 ft., which have upset ends and are spliced by means of turnbuckles. The rods are incased in concrete, which is carefully treated with membrane waterproofing. They extend into the footings far enough to develop their stress in bond, and in addition they are in bearing against steel channels buried in the foot-

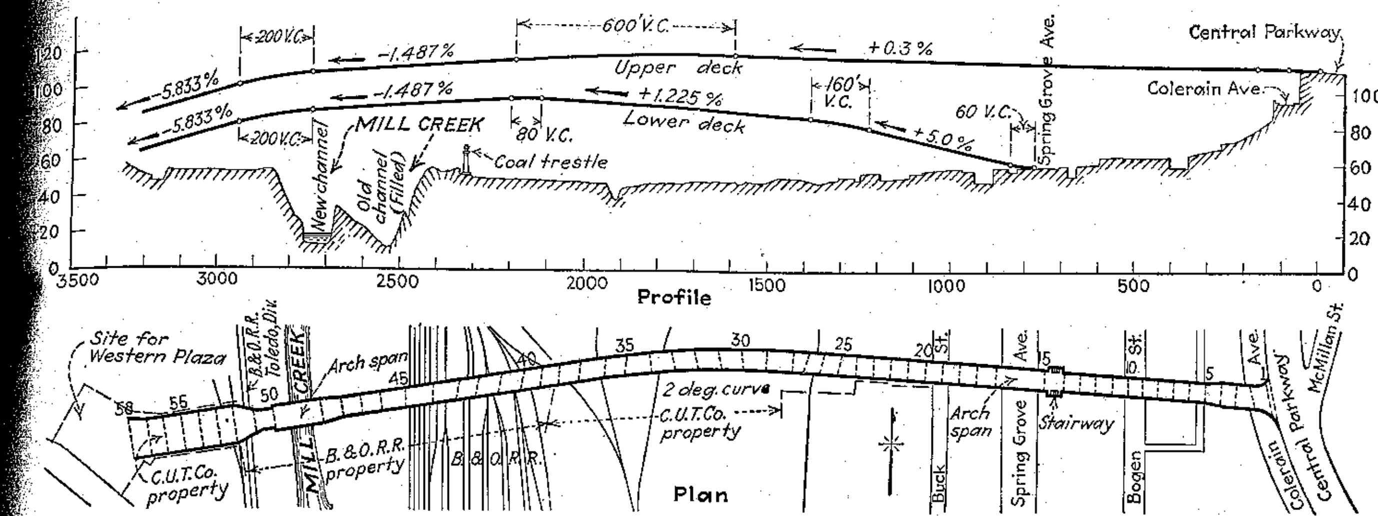

Fig. 2—Western Hills viaduct, Cincinnati, a 3,500-ft. double-deck structure built to carry traffic over the new railroad terminal tracks.

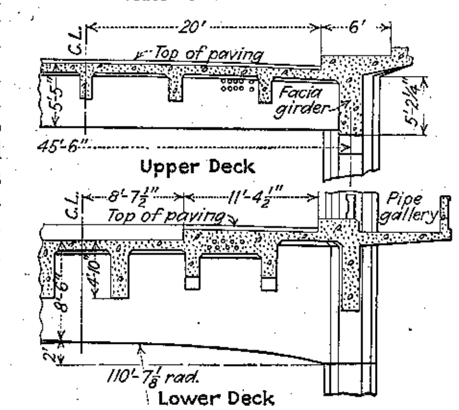

Fig. 4—Cross-sections of viaduct. Depressed roadway slab of lower deck provides for street-car tracks.

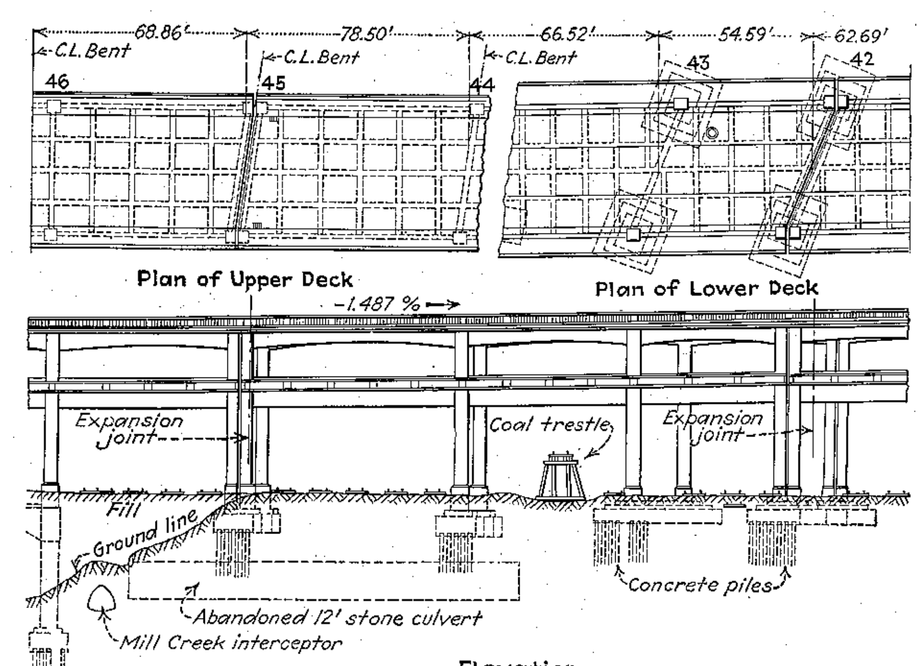

Fig. 3—Portion of Western Hills viaduct in which concrete-incased steel frames are used because of long span lengths and as an aid in erection over the railroad tracks.

ings. No attempt was made to place initial tension in the rods other than to insure that they were in perfect alignment and that all slack was taken out of the connections. The arch ribs were designed for the stresses induced in them by elongation of the tierods.

Subsoil and Foundations—Geological or subsurface conditions at the site were such as to require careful study to determine the proper types of foundations. The structure crosses a wide valley originally occupied by the Ohio River, which was subjected to glacial action during the later geologic periods, causing the Ohio River to be diverted to its present channel. At the present time Mill Creek, a small local waterway, occupies the west side. The valley has walls of hard yellow clay and shale in horizontal beds, while its floor is of yellow and blue clay and various deposits of sand ranging from coarse gravel to quicksand. These deposits are irregular in extent and overlay hard shale and limestone at depths varying from 55 to 115 ft. below the surface.

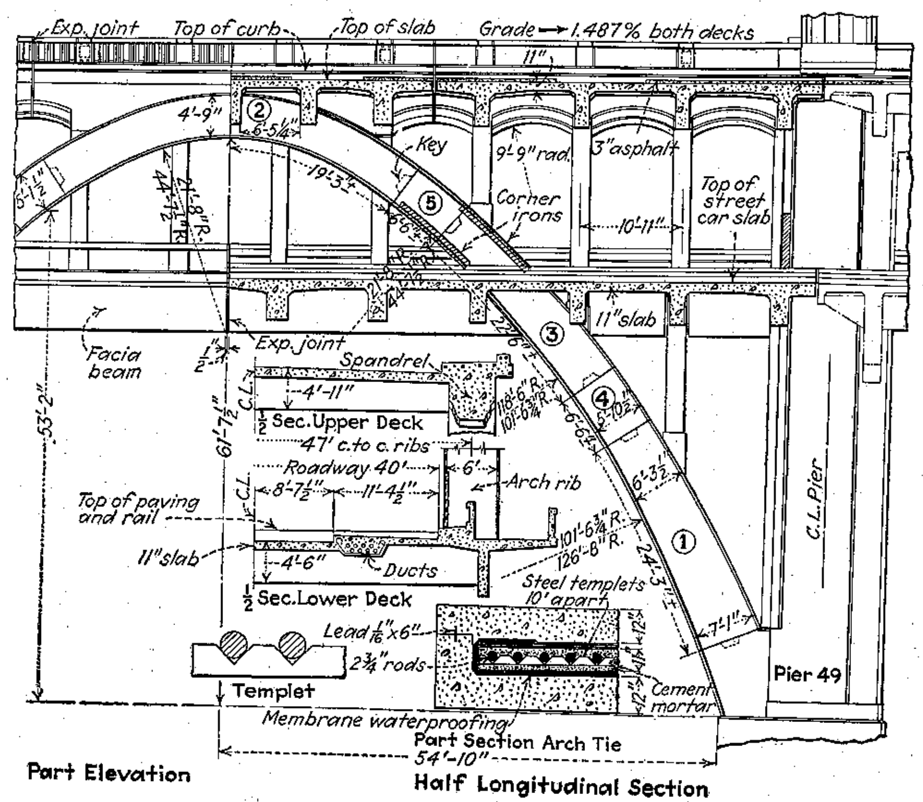

Fig. 5—Arch span over Mill Creek. Note double-deck construction.

The original plans contemplated soil-bearing foundations for bents 1 to 14, inclusive, and from bent 57 to and including the west approach. All other foundations were to be on cast-in-place concrete piles, except that pairs of cylindrical piers sunk to rock were originally designed for bents 44 to 51, inclusive.

Additional test borings, completed about the time work was started, raised a doubt as to the practicability of putting down caissons for these piers by the open-well method, and a few weeks' work by the contractor indicated that their construction by any open method was impractical on account of quicksand. After careful consideration of several alternative plans it was decided to use steel-pipe piles, driven to rock and filled with concrete, as a substitute for the foundation piers. It was also decided to use similar vertical steel-pipe piles as a substitute for the proposed concrete batter piles at bents 15 and 16 for the Spring Grove Ave. arch.

Steel-Pipe Piles — Pipes 20 in. in diameter with ½-in. shell were used, in sections averaging 22 ft. in length, spliced by means of a cast-steel outer ring so as to leave the inner surface smooth. Their allowable load of 170 tons was that specified by the tentative New York building code. These piles were driven with steam hammers in swinging leads suspended from the boom of a crawler crane. They are 50 to 95 ft. in length.

The material inside the piles was blown out with compressed air, water also being used when necessary; after inspection the pipes were filled with concrete. At bent 15, the eastern foundation for the Spring Grove Ave. arch, considerable difficulty was experienced in removing from the interior some of the material encountered, consisting of thin strata of shale and limestone above the elevation at which the piles were to have their bearing. It was first attempted to break this material by dropping a length of T-rail, the lower end of which had been fashioned into a bit, but progress by this method was so slow that the use of well-drilling methods to penetrate the troublesome strata was substituted with success.

Cast-in-Place Concrete Piles — The type of concrete pile used is formed by driving a steel casing, inside of which is a steel mandrel. When the casing has been driven to the proper depth (which does not extend to rock) the mandrel is withdrawn and a corrugated iron shell is placed inside the casing and filled with concrete, after which the steel casing is withdrawn. In most cases the concrete pile has a wooden lower section, which is driven inside the steel casing after the mandrel is withdrawn, but before the corrugated shell is placed. These piles average 24 ft. of wood and 33 ft. of concrete. The joint between the wooden and concrete sections of the composite piles is kept below the water line. For this type of pile the maximum load used in the design is 30 tons.

Heaving of Concrete Piles—From the start of operations a close watch was kept for possible heaving of piles. This trouble soon developed, and a careful study was made to determine what could be done to offset its effect. It was impossible to redrive the piles on account of their nature, but it was found that by a suitable arrangement of tackle a static load of about 40 tons, including a large part of the weight of the driving rig and a load of pig iron, could be applied to each pile. Where heaving occurred, each pile was subjected to this load, which was almost double the average final constant design load. Careful records of the behavior of the piles indicated that the settlement under load was almost invariably smaller than the original heave. In some cases the piles heaved again after being pushed down, but this was usually a very small fraction of the original heave. However, where this second heaving amounted to more than ¼ in., the piles were again loaded and pushed down.

In two of the foundations where heaving occurred, excavations were made for practically the full depth of the piling to determine the cause of heaving and the conditions of the piles. These explorations disclosed that the soil between the piles had been compacted to a very dense state, that in some cases the pile had separated at the joint between the wooden tip and the concrete section, and that in other cases the concrete section had pulled apart for its entire area. The heaving was undoubtedly due to the fact that the earth was compacted to the limit of compressibility, and further driving caused the soil to heave, moving the piles with it.

Construction Work — The contract for the entire structure, excepting the west approach, was awarded early in November, 1930. The contractor concentrated on excavation, piledriving and concreting of foundations during the winter. He used a crawler crane equipped with a clamshell bucket and

had as many as five piledrivers at work simultaneously. The concrete for both piles and footings was ready-mixed, bought from a commercial concrete mixing company and mixed either at a central plant or in transit on trucks equipped with mixers.

The principal difficulty encountered in winter concreting of the footings was in placing and holding the anchor bolts for the structural-steel portion of the structure. There were either four or six heavy anchor bolts in each foundation. As each footing was poured monolithic, the anchor bolts had to be suspended from a timber frame resting on the sides of the excavation. When heat was applied to thaw out the foundation pits preparatory to concreting, there was a tendency for the frame supporting the anchor bolts to shift out of line.

Early in the spring of 1931 work was started on the erection of structural steel and on the construction of the reinforced-concrete frames. Most of the steel was erected by two heavy locomotive cranes with 80-ft. booms, which were extended for certain operations to lengths of 90 and 110 ft. These cranes operated on a temporary track along the center line of the structure. Erection by this method began at bent 27 and proceeded westward to bent 44. On account of main-line railroad tracks and a sharp break in the ground line, the steel thence to bent 47 could not be erected from the ground. Therefore, a traveler placed on the upper deck was used for this portion of the structure, the steel floor system being reinforced where necessary to take care of the erection loads. The maximum load on this traveler was a lift of 50 tons at a radius of 75 ft. A total of approximately 5,300 tons of steel was erected complete between March 11 and June 19, incasement of the steel structure following closely upon its erection. All incasement was of poured concrete.

Forms for concrete work are fabricated in a centrally located shop, transported to the job by truck and lifted to place by a crawler crane. After the forms are stripped they are returned to a yard near the shop, where they are either cleaned and oiled or dismantled and the lumber salvaged.

For supporting the deck of the concrete frames, use is made of timber towers built of units 6 ft. square and 8 ft. high, each unit consisting of four 8x8-in. posts with 2x8-in. top and bottom sills, diagonally braced on four sides. A tower is made by erecting these units one above the other to the proper height, the units being spliced and adjacent towers being braced together for stability. Variations in height are cared for by the use above the towers of adjustable shores of the type ordinarily used in building construction. The advantage of this type of construction is in the facility with which it can be erected, dismantled and re-used.

All concrete is delivered ready-mixed, is raised to the site of the work by two steel towers and two mast hoists and is usually chuted direct to the forms, although in some cases a part of it is delivered in buggies. Construction joints are provided in the columns at the bottom of the cross-girders, and all concrete in each frame above this joint is poured as a continuous operation, the maximum volume involved in a single pour being 1,050 cu.yd.

The deck slabs, where the grade is not prohibitive, are cured by ponding, while sidewalks and other exposed surfaces that cannot be cured in this way are covered with burlap and kept continuously wet, the forms being left in place a minimum of seven days to prevent surface drying. After curing, all exposed surfaces of columns, beams and handrail are finished by rubbing with carborundum blocks by hand.

The method of placing concrete on the steel portion of the structure is substantially the same as for the reinforced-concrete portion, except that in a majority of cases the formwork is suspended from the steel frame.

Timber centering for the arches is conventional in design. At Spring Grove Ave. it is carried on mud sills, and at Mill Creek (Fig. 6) on timber piles. Openings are provided at Spring Grove Ave. for traffic and at Mill Creek for floodwater. The arch ribs are poured in alternate blocks, the key blocks (Fig. 5) being poured a minimum of three days after the main blocks are poured.

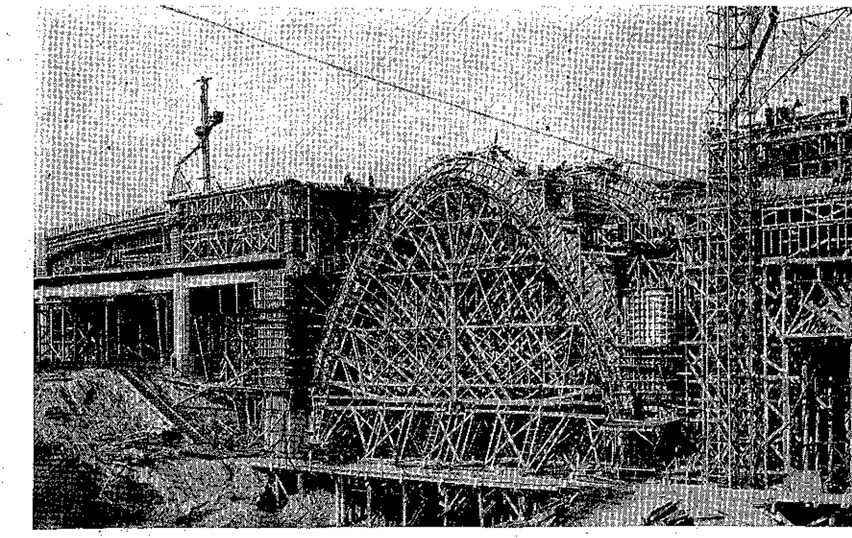

Fig. 6—Mill Creek arch of 109-ft. span was poured in wood forms supported by an elaborate system of timber falsework.

West Plaza Development—Early in September, 1931, a contract was awarded for the construction of the west plaza. This work involves a change in street grade, amounting to a maximum of 6 ft., the relocation of all utility structures, temporary detouring of street traffic, construction of numerous approach walls, and construction of about 40,000 sq.ft. of flat-slab deck. The contractor worked three shifts in an attempt to complete this contract before extreme cold weather.

Engineers and Contractors — The Western Hills viaduct was designed by and is being constructed under the direction of the Cincinnati Union Terminal Co.; H. M. Waite is chief engineer, George P. Stowitts engineer of construction, Pusey Jones engineer of design, E. D. Tyler architect, and A. H. Sullivan electrical engineer. S. A. McGovren, assistant engineer, had direct charge of the design, and George H. Wells, district engineer, had charge of the construction in the field. The city has been represented by H. F. Shipley, engineer of highways.

The MacDougald Construction Co. is the general contractor for the viaduct proper, with the McClintic-Marshall Corp. as subcontractor for furnishing and erecting the structural steel, and the MacArthur Concrete Pile Corp. and the Pierce Steel Pile Corp. as subcontractors for the piling. The Folwell Engineering Co. has the contract for the west approach.

It is expected that the structure will be open for traffic early in 1932. Its cost, about $3,500,000, will be shared by the city, the Cincinnati Union Terminal Co. and the Baltimore & Ohio Railroad.

British Railways Extending Door-to-Door System of Transport

The door-to-door system of transport is being extended rapidly by British railways, not only for internal use but for cross-Channel traffic as well. The most ambitious undertaking so far attempted, which involves the transport of extremely heavy freight loads, is that of the London & North Eastern Railway, which plans to dispatch a number of its loaded trucks from Manchester to Budapest, a distance of 1,200 miles. Freight cars will be of a special variety, with capacities varying from 20 to 110 tons.