THE DESIGN AND CONSTRUCTION OF THE PAULIN'S KILL VIADUCT.

The Paulin's Kill Viaduct is a reinforced concrete structure, 1100 ft. long, composed of five 120-ft. and two 100-ft. arches carrying the new double track cut-off of the Delaware, Lackawanna & Western Railroad across the Paulin's Kill valley, in which runs the Paulin's Kill River, a private crossing, a public highway and a branch line of the New York, Susquehanna & Western Railroad. It is located in Northern New Jersey about 3 miles east of the Delaware River, near Portland, Pa. The completed structure will contain 42,000 cu. yd. of concrete and about 500 tons of reinforcement steel. A general description of it will be found in the Engineering Record of Aug. 15, 1908, and some details of the concrete plant and of the early construction methods, in the Engineering Record of Apr. 24, 1909.

The tracks on the structure will be on a rising grade eastward of 0.50 per cent. and the west end will be on a I-deg. curve, the point of curve being at about the crown of the second arch from the end. Solid rock is found from 0 to 35 ft. below the surface and the piers and abutments are founded on rock.

in which L is the live load stress, D, the dead load stress, and I, the resulting impact stress. The arch when analyzed with these loads according to Professor Cain's theory shows that the resistance line follows very closely the center of gravity of the sections, and nowhere goes outside the middle third, thus eliminating tension in both the intrados and the extrados. The compression in the concrete has been kept below 400 lb. per square inch in both the 100 and 120-ft. arches, and throughout the rest of the structure.

The stress in the steel throughout the structure has been limited to 16,000 lb. per square inch.

The spandrel arches are carried on reinforced concrete walls which vary in height from 5 ft. $9\frac{1}{4}$ in. to 38 ft. $8\frac{3}{4}$ in. The thickness is shown in the accompanying drawing. They are reinforced in each face by $\frac{3}{4}$ -in. square corrugated bars placed vertically on 9-in. centers and by $\frac{1}{2}$ -in. bars horizontally on 2-ft. centers. The horizontal bars are continued around the intrados up to the crown, while the vertical bars are bent toward the curve of the arch at an angle of about 30 deg. and terminate in the reinforcement of the solid concrete floor.

The floor has a thickness of 2 ft. above the soffits of the spandrel arches. The reinforcement of I-in, corrugated bars 6 in, on centers, is For the analysis of the pier various combinations of the thrusts from the adjacent spans, due to above loadings, were made and the resultants were each combined with the weight of the pier to determine the maximum pressure on foundations. This was obtained with the combination of the dead load thrust from one span and the full live plus dead load thrust from the adjoining span. The pier, 20 ft. wide, for this combination has maximum toe pressure of 25 tons per square foot on the rock foundation.

Each abutment consists of three vertical walls parallel to the axis of the viaduct, tied together by a solid floor system across the top and by horizontal struts at lower levels. These walls are 3 ft. thick and are reinforced vertically in both faces by 34-in. square corrugated bars 12 in. apart for the full height. No horizontal reinforcement is provided below the line of the earth slope, for the walls will there be protected against severe temperature changes. Above that line, however, 34-in. square corrugated bars are spaced on 24-in. centers to take the temperature stresses.

The east abutment has a maximum height from foundation to top of parapet wall of 58 ft., and the west abutment, a maximum height of 87 ft., with lengths of 70 and 90 ft., respectively.



General View of Viaduct, with Main Arch Rings Completed, and Spandrel Arches Started.

Both the 120 and the 100-ft. spans are semicircular arches with their springing lines approximately 25 ft. above high water level. The base of rail is about 110 ft. above high water and about 120 ft. above ordinary stages.

The main arches are solid rings of concrete, 34 ft. wide, carrying spandrel arches of $12\frac{1}{2}$ -ft. span, poured integral with the solid floor. The rings of the 120-ft. spans are 6 ft. thick at the crown and about 12 ft. thick at the pier skewbacks. Reinforcement of new style corrugated bars is placed near both the intrados and the extrados, the same size reinforcement being used in both planes. In the 120-ft. arches the longitudinal bars are 1-in. square, placed 9 in. center to center, and the transverse bars are $\frac{1}{2}$ in. square, placed 2 ft. center to center. No bars are placed closer than 3 in. to the surface.

In the 100-ft. arches the crown thickness is 5 ft. The longitudinal bars are $\frac{3}{4}$ in. square, spaced 9 in. on centers, and the transverse bars $\frac{1}{2}$ in. square, spaced 2-ft. on centers.

These main arch rings were designed for a dead load consisting of their own weight, the weight of the spandrel arches, solid concrete floor, 5 ft. of fill and ballast, and the tracks, together with a live load consisting of Cooper's E50 loading. Impact was allowed for in all parts of the structure according to the formula

I = L[L/(L+D)]

laid parallel to the axis of the bridge, and 3 in. above the plane of the spandrel arch crowns.

The main piers are 20 ft. wide and 42 ft. long and vary in height, from springing line to foundation, from 25 to 63 ft. The highest pier is on the east bank of the stream, it being 1521/2 ft. from base of masonry to top of parapet, while the first pier on the west bank, carrying the other end of the same arch, is 55 ft. high from rock to springing line, or 1441/2 ft. in total height. The piers are solid and without structural reinforcement from rock up to a point about 25 ft. above the springing line, where the extradoses of adjacent arches meet. Except for the intrados reinforcement, which is carried down to a point 81/2 ft. below the coping, there is no reinforcement in the lower parts of the piers. Above the coping horizontal and vertical reinforcement of 1/2 in. square corrugated bars is placed in the faces of the pilasters, and above the junction of the extradoses the pier is hollow and consists of four vertical walls, reinforced in both faces, in the same manner as the walls carrying the spandrel arches. The floor over the hollow pier is 3 ft. thick and reinforced in the lower element.

The arch rings were analyzed for three conditions of loading, namely, dead load only, live load on half of the span plus the dead load, and live load on the entire span plus the dead load. In the east abutment struts 2×4 -ft. in cross section, each reinforced with three 1-in. square bars in both the upper and lower surfaces are placed at about mid-height of the walls, 12 ft. apart on centers horizontally. The unsupported length of the struts is $12\frac{1}{2}$ ft., which is the clear distance between these vertical walls.

In the west abutment these struts are required at two different elevations. The upper set is 20 ft. below the concrete track slab, and the second set 24 ft. below the first.

The design of the vertical walls of these abutments was based upon the assumption that the horizontal earth pressures on opposite sides of each would be equal and opposite, which would justify a wall designed for bearing only.

The horizontal struts were introduced to give lateral stability to the walls, which are very high as compared with their widths. They also serve to cut down the unsupported height of wall during construction before the fill is made, thus furnishing a factor against any unbalanced condition that might develop during construction or subsequent settlement of the fill. Owing to the indeterminate nature of these stresses likely to be set up during construction and filling, the struts had to be designed to take both compression and tension considerably in excess of any that might reasonably be expected in the completed structure. In addition_they were made of sufficient depth to give them value as diagonal cross-bracing between the vertical walls. Enough steel was distributed in each member to make it a tie capable of taking approximately 100,000 lb. tension, using a unit stress of 16,000 lb. in steel having a specified elastic limit of 48,000 lb. per square inch. As a strut the design will safely take care of about 500,000 lb. in compression, while as a beam it safely supported the staging and centering for the heavy floor slab and the upper walls.

The track is carried on these abutments by floor slabs 3 ft. thick, reinforced with 1¼-sq. corrugated bars spaced 4-in. on centers spanning between the abutment walls. The abutment floor slab was made very heavy to prevent any defleclaid on the center line of the floor system of the viaduct from end to end, and summits are formed at alternate piers so that the drainage is collected and discharged through 6-in. vertical tile drains embedded in the concrete walls of the piers. Drainage from the extrados is carried to the in spection openings by proper crowning and finds its way down into the hollow abutments, from which it is discharged to the stream through 6-in. pipes. A 6-in. dike at the face of the voussoirs extends above the extrados, so that any water driven in by the rain cannot flow down and mark the face of the arch, but must find its way through the inspection openings.

Construction.—The construction plant was described in the Engineering Record of April 24, centers a second time in constructing corresponding spans on opposite sides of the middle span. The center was left under this middle span while the others were being moved forward to complete the structure. In moving the centers they were taken apart, the sections lowered by derricks, transferred to cars, hauled to the new location and re-erected.

An accompanying diagram shows the order in which the concrete was placed in the main arch rings. The semi-arch, from springing line to crown, was divided into five main blocks and three keys, and an extra key was placed at the crown to close the work. The blocks and keys were cast in pairs extending the full width of the arch, and each pair was finished at a continuous operation. The maximum yardage in one of the main blocks is 250 cu. yd. The largest pair were cast in 30 hr., when the work was originally undertaken, but on account of the efficiency developed this time was cut down to 24 hr. on the last arch.

The side forms around these blocks were made of 2-in. tongued and grooved faced lagging, held by 3×6 and 3×8 -in. studs, and securely braced against the lagging of the top of the arch by means of diagonal struts. An extra rib was placed on each side in the main centering, beyond the face of the concrete ring, in order to form a working platform and allow the voussoir



Noil Lagging to Outside < + Segments Only Segments Etilets 50 Section ArA Section B B 510 Etils 50 "Splices Medge Ox 34 "Bolts States"

Collapsible Centre for Spandrel Arches.



Two Views of Main Arch Ring, Showing the Key Spaces between Voussoir Blocks.

tion in the slab which might cause flexure in the supporting walls, which are connected to the slab as a monolithic unit.

In order that inspections may readily be made a 30-in. manhole is placed in the solid floor and spandrel arch above the crown of each of the main arches. Arched openings $2\frac{1}{2}$ ft. wide and $4\frac{1}{2}$ ft. high are placed in the walls carrying the spandrel arches so that the inspector can examine the entire structure. Openings are also provided into both chambers of the abutments. Where the extrados is steep, ladders made of pieces of bent reinforcing rods are built into the concrete.

Provision has been made for carrying off rain water, not only from the solid floor, but also from the extradoses of the main arches. Water may find its way onto the latter by being driven in by wind during storms. An 8-in. tile drain is 1909. The mixing plant is located close by, and the concrete is brought to the viaduct in 1½-yd. Shannon bottom-dump buckets, hauled on flat cars by Baldwin 12-ton locomotives.

In building the piers up to the springing lines, derricks were seated on the ground and transferred the concrete from the cars to place. A steel tower was then erected on each pier, and upon it was placed a guyed derrick with a 75-ft. mast and a 65 or 80-ft. boom, together with a 7¼ x 10-in. Mundy double-drum hoisting engine. Each derrick could place concrete up to the crowns of the arches on both sides of it.

Timber centering was employed for all arches, and did not differ materially from the design shown in the Engineering Record of Aug. 15, 1908. As only three 120-ft. centers and one 100-ft. center were provided, it was necessary to use the 100-ft. center and two of the 120-ft. forms to be readily braced. In addition, long rods and two 10 x 10-in. struts were run across the tops of the forms from face to face of ring for each block. The main blocks numbered 2and 4 did not require any special precautions to prevent them sliding, but between blocks 3 and 5 it was necessary to introduce struts in order to hold number 5 in place until key 6 could be cast. These struts consisted of four concrete blocks, 2 ft. wide and 3 ft. deep, which were cast on block 3 when it was poured.

All reinforcement was securely wired at intersections. As soon as the lagging had been placed on the centers for a main arch the reinforcement was placed, that for the intrados being held the proper height above the lagging by $4 \times 4 \times$ 18-in. concrete blocks. The extrados reinforcement was held in place by tying it to the IO \times 10-in. braces across the top of each block form.

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The specifications required that at least 7 days should elapse between placing the blocks and the keys, and that 28 days should elapse after the placing of the last key before striking centers.

Three classes of concrete were used. Class A, for the floor system and spandrel arches, was mixed in proportions of 1:2:4; Class B, used in the main arch rings, spandrel piers and abutment walls, was mixed in proportions of 1:3:5; Class C, used in the main piers and footings, was a 1:3:5 mixture, having two-man quarry stone embedded in it. The stone used was limestone, crushed to pass a 2-in. ring. Nazereth Portland cement was used.

Measurements showed a maximum crown deflection after the centers were struck of 3/16 in.

It will be noted from the accompanying photograph that when all of the main arch rings had been completed the centering was removed before the spandrel arches were placed.

After the completion of the main arches work was begun upon the two spandrel arches above the crown of each main arch. The centering and concrete was swung to place for these two spandrel arches by the derricks on the piers.

The derricks were then moved from the towers on the piers to the two completed spandrel arches, the centering of the latter being left in place. In this position each derrick could place the remaining spandrel arches on either side as far as the piers.

The forms for the spandrel arches are of the collapsible type, so that they may readily be removed from span to span. They are shown in detail in an accompanying cross section. It will be noted that they are hinged at the top and that the tie across the bottom at the springing line can be extended by means of a wedge.

All exposed surfaces of the concrete were carefully spaded during construction. No subsequent finishing has been necessary.

The viaduct is being built under the general direction of Mr. G. J. Ray, chief engineer of the

RAISING A HIGH-PRESSURE WATER PIPE.

In regrading one of the streets in the business section of Seattle, it was necessary to raise an 1800-ft. length of 20-in. cast-iron water main operating under a pressure of 130 lb. to the square inch. The location of the main was such that it was impracticable to cut it out of service while the raising was in progress. The decision therefore was made to undertake the work without interfering with the operation of the pipe.

The street in which the pipe was laid had a dip in grade about midway on the 1800-ft. length that it was necessary to raise. The street improvement was made to remove this dip and to secure a uniform grade of 4.9 per cent. The pipe was laid at a depth of 4 ft. below the original street surface and the maximum raise required timbers built up in cob-house fashion. Side struts were used at intervals to maintain the alignment. Extra cribs were placed under valves and specials.

Enough men were employed to turn the jacks so that 60 ft. of the pipe could be raised simultaneously. The work was started at one end, by raising about 60 ft. of the pipe I in. Then the next 60 ft. was raised that amount and so on continuously to the opposite end of the work. As soon as that end was reached, the men worked right back again, and so on until the pipe was up to the proper height.

One man was stationed at each jack and all of the men worked to a signal from the foreman so the jacks under the 60-ft. lengths in which the raising was handled were turned at a uniform rate. As soon as the jacks were extended a 6 x 6-in. timber was slipped under the pipe at each crib to take the load until the jacks could

Method of Raising High-Pressure Water Pipe.



Centering and Steel Tower for Derrick, Paulin's Kill Viaduct.

Delaware, Lackawanna & Western Railroad, and under the immediate direction of Mr. F. L. Wheaton, engineer of construction. Mr. O. H. Kellogg is resident engineer and Mr. Galvin, inspector.

The viaduct was designed under the direction of Mr. Lincoln Bush, formerly chief engineer. The detailed design was made by Mr. B. H. Davis, formerly assistant engineer in charge of masonry design.

John Goll & Company, contractors, Philadelphia, are building the viaduct, under a sub-contract from Reiter, Curtis & Hill, of Philadelphia. Mr. John Feite is superintendent of construction. was to be about 13 ft. above that surface, making a total of 17 ft. From this maximum the amount of change tapered off gradually toward both ends of the length of the main affected.

The scheme of raising adopted was to carry up the whole length of the pipe by means of jack-screws and cribbing. The trench was first opened and the pipe brought to the surface in this manner. Then shoring was placed across the trench and the raising continued until the final position was reached. A cross-timber was placed near the bell end of each section of the pipe, to provide a bearing for a pair of jackscrews that were seated on a crib of 6×6 -in. be removed and another story added to the crib. The jacks and timbers thus were manipulated so the pipe was never unsupported at any point.

After the pipe had been raised to the final grade a framed timber bent was built under each section to carry it until the fill was completed. While the work was in progress practically no leakage occurred at the joints although some of the latter had to be caulked occasionally. After the pipe was out of the trench the balance of the raising was accomplished in 14 days.

The work was done under the immediate direction of Mr. T. H. Carver, assistant city engineer of Seattle, by Paul Steenstrup, contractor.

THE EXTRACTION OF OIL FROM DEEP WELLS by the Leinweber method is accomplished by means of an endless cable carrying absorbent material. As described by Mr. F. A. Talbot in the "Engineering and Mining Journal," a belt faced on one side with carpet shag, is lowered into the bore hole and absorbs oil as the band trails through the pit; the band is subsequently passed through mangling rollers above ground and the oil which it contains is squeezed out, the dry portion of the band descending continuously into the pit. The equipment was put into actual operation at a bore hole 3838 ft. deep in the Galician oil fields. The cable used was built up of a series of steel wires each 0.098 in. in diameter. The band was 2.2 in. wide and covered with shag. It was found that the band possessed an absorbing and hauling capacity of 9.16 oz. of crude oil per foot of cable, and the net yield at the rollers was 7 oz. per foot of band. The cable speed is given as 21/2 ft. per second. A plunger system previously used at this hole raised 44,000 lb. of oil per day, according to Mr. Talbot. With the Leinweber band the yield was about 50 per cent greater, the aggregate being 66,000 lb.

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THE HOPATCONG-SLATEFORD CUT-OFF.

Second Article, Describing Very Heavy Bridge Work, Including Largest Concrete Railway Bridges Ever Built in this Country.

BY C. W. SIMPSON,

Resident Engineer, Delaware, Lackawanna & Western.

One of the distinctive features of the Hopatcong-Slateford cut-off of the Lackawanna, the general description of which was published in the *Railway Age Gazette* of December 6, is the almost exclusive use of concrete for structures. Out of a total of 67 structures at stream, highway and railway crossings only one is of steel. With a few exceptions these structures are of the arch type, with spans varying from three to 150 ft.



Fig. 1-Slab Type Highway Bridge Over Tracks

In some instances where there was not sufficient clearance to permit the use of the arch type, a reinforced flat slab type was used.

The structures may be classified roughly under four heads: reinforced slab or beam type, semi-circular arches carrying the railroad embankment and tracks, elliptical spans carrying the highways over the railroad, and long concrete bridges composed of several arch spans.

SLAB TYPE STRUCTURE.

The slab type is very well illustrated by two structures at Slateford, Pa., one designed to carry a highway over six tracks,



Fig. 2—Typical Slab Type Culvert for Waterway.

four of which have been laid, and one carrying four tracks inforced longitudinally with $\frac{3}{4}$ in. square bars spaced 2 f across Slateford Creek. The highway structure is composed of three 37 ft. spans; the center line of the roadway being at an angle of 55 deg. 8 min. with the tracks. Each span consists of a 12 in. slab resting on eight longitudinal beams 20 versely with $\frac{3}{4}$ in. square bars spaced 2 ft. center to center near both the inside and outside surface roadway being carried on a 1 ft. 4 in. slab, reinforced trans sists of a 12 in. slab resting on eight longitudinal beams 20 versely with $\frac{3}{4}$ in. square bars spaced 6 in. center to center to center spaced 5 ft. center to center. The slab and beam concrete was The slab was built as an integral part of the abutment and is

placed at the same time so that they form "T" beams. Each beam is reinforced with six 1 in. square bars and the floor slab with $\frac{1}{2}$ in. square bars spaced 4 in. center to center. The bottom of the face beams was curved to give the appearance of a very flat elliptical arch. The connection between the floor system and the piers and abutments is stiffened by 22 in., 45 deg. corbels. The piers are 2 ft. $\frac{1}{2}$ in. thick at bottom, 1 ft. 10 in. thick under the corbel, and 25 ft. high above the footings.

As the narrowness of the piers made it inadvisable to have a transverse construction joint in the floor system, the concrete was placed continuously from end to end, and two longitudinal construction joints, midway between beams, divided the floor into three construction sections. A railing composed of concrete posts and two lines of 2 in. pipe protect the roadway, which was paved with a 3 in. coating of Amiesite placed directly on the floor slab.

The structure over Slateford Creek is composed of two 14 ft. slab spans carried on two plain abutments and one plain pier, on gravel foundation. The pier is 2 ft. 6 in. thick above the ground surface and 4 ft. 6 in. thick at the bottom of foundation. The slab is 2 ft. thick and is stiffened at the pier and abutments by 24 in., 45 deg. corbels. The slab reinforcement consists of 1 in. square bars spaced 4 in. center to center,



Fig. 3—Typical Arch Culvert for a Highway.

with every third bar bent up at the quarter point. The top of coping is level with the top of the rail.

THE SEMI-CIRCULAR ARCH.

The semi-circular arch type is best illustrated by the arch over the Morris and Sussex turnpike near Andover, N. J. This is a combined highway arch and culvert, under an embankment 90 ft. high. Originally the stream and highway were 300 ft. apart, but the stream channel was changed so that both could pass through the same structure. The arch barrel is 221 ft. long, has an inside diameter of 33 ft. and varies in thickness according to the depth of the embankment over it. Thus the crown thickness at the center is 2 ft. 9 in., while at the ends it is 2 ft. 6 in., and the abutments are 22 ft. 2 in. broad at the center and 17 ft. 10 in. at the ends. The arch ring is reinforced longitudinally with 3/4 in. square bars spaced 2 ft. center to center near both the inside and outside surfaces. The culvert occupies the entire width between abutments, the roadway being carried on a 1 ft. 4 in. slab, reinforced transversely with 34 in. square bars spaced 6 in. center to center and longitudinally with 1/2 in. bars spaced 2 ft. center to center.

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divided into two spans by a center pier 2 ft. wide, making the culvert a double box with 15 ft. 6 in. span. Beyond the arch barrel the culvert is carried along the wing walls until it clears the roadway.

ELLIPTICAL ARCHES.

A good example of the overhead highway arches is shown in

intrados is a semi-ellipse having a rise of 9 ft. 6 in. The barrel is 18 in. thick at the crown and is reinforced longitudinally by 1 in. square bars spaced 12 in. center to center, near the upper and lower faces, and transversely by 1-in. square bars spaced 24 in. center to center. Spandrel walls, with a 2 ft. 6 in. coping, retain the spandrel filling and the roadway is pro-



Fig. 4—Elliptical Arch Carrying Highway Over Tracks.

one of the accompanying photographs. All arches of this type provide clearance for four tracks, requiring a minimum span of 56 ft. The highway at this point makes an angle of 74 deg. 15 min., with the tracks, requiring a span of 58 ft. 2 in. The tected by a concrete railing surmounting the coping. The concrete for the arch ring was placed continuously from springing line to springing line, and the spandrel walls, up to the bottom of coping, were placed at the same time.



Fig. 5-Early Stages in Construction of Paulins Kill Viaduct.

THE PAULINS KILL VIADUCT.

There are two structures of the fourth type; one at the crossing of the Paulins Kill river, the New York, Susquehanna & Western, and a highway at Hainesburg, N. J.; and one across the Delaware river, the old line of the Delaware, Lackawanna & Western, and two highways near Slateford, Pa. These bridges have been said to be the largest concrete structures yet erected for railroad purposes in America.

The Paulins Kill bridge is composed of five 120 ft. and two 100 ft. semi-circular arch spans, carrying a floor system composed of 13 ft. semi-circular spandrel arches. The abutments are a modification of the "U" type, being composed of three longitudinal walls carrying a reinforced floor slab. The embankment is allowed to take its natural slope between these two 6 in. centrifugal pumps, but the other excavation was so wet that the concrete was deposited by means of a tremie.

The construction work was carried on by a system of derricks, having 75 ft. masts and 65 to 80 ft. booms, operated by Mundy double drum hoisting engines. The derricks were first erected on the ground surface at each pier and from this position constructed the piers to a point about 10 ft. above the springing line. A steel tower 30 ft. high, composed of six 9 in. I beams braced with 5 in. channels was then erected on the pier and the derricks transferred to a platform at the top of the tower. From this position the derricks completed the main arches and two spandrel arches over the crown of each main arch. They were then moved to the top of these spandrel arches and from this location completed the remainder of the work.



Fig. 6—Completing Arch Rings and Starting Spandrel Walls on Paulins Kill Viaduct.

walls so that they do not act as retaining walls and carry only the load transferred to them by the floor slab. The walls are stiffened by reinforced struts, extending from wall to wall. The viaduct is 1,100 ft. long end to end of masonry, and is 34 ft. wide face to face of arches, with the pier pilasters projecting 4 ft. The top of the coping, which is level with the top of rail is 120 ft. above the stream bed.

The floor is waterproofed with five layers of Neponset Water Dike felt and one layer of burlap, protected from injury by the stone filling with one course of brick. The joints in the brick protection coat were filled with a waterproofing compound. The foundations were carried to bed rock, which is near the ground surface except at the two piers near the stream, where the excavation was 35 ft. deep. These excavations were sheeted with 3 in. x 12 in. yellow pine driven the entire depth by a Vulcan steam hammer. The water was kept out of one excavation by For constructing the main arches the contractor used one set of 100 ft. and three sets of 120 ft. timber centers. These centers were framed and assembled into units that could be handled by the derricks and narrow gage rolling stock, in a timber yard equipped with circular and band saws, a planer, and other wood working machinery. A large part of the forms were built in sections at the timber yard and were erected, taken down and re-erected by the derricks.

The concrete mixing plant was located about 300 ft. north of the bridge on the west side of the stream. Stone was quarried from a hill just back of the mixing plant and conveyed in dump cars to two Farrel jaw crushers from which it was taken by bucket conveyors to two 200 cu. yd. stone bins located over the mixers. Sand was dug from a pit about one-half mile from the mixing plant by a clam shell bucket and was conveyed to the sand bins, located alongside the stone bins, in 4 yd. 3 ft. gage side





Fig. 7-The Completed Paulins Kill Viaduct.

dump cars. Measuring hoppers located below the storage bins discharged into two 1 yd. McKelvey mixers. Each mixer discharged into a hopper from which the concrete passed into $1\frac{1}{2}$ yd. bottom dump buckets on 3 ft. gage flat cars. Twelve ton Baldwin locomotives hauled the cars to all parts of the work, crossing the This structure required 43,212 cu. yds. of concrete and 735.5 tons of reinforcing steel.

DELAWARE RIVER BRIDGE.

The Delaware river bridge, which is 1,476.8 ft. long end to end of masonry consists of five 150 ft. x 40 ft., two 120 ft. x 40



Fig. 8—The Delaware River Bridge in all Stages of Construction.

stream on a temporary wooden bridge. A standard gage track connected the mixing plant with the N. Y. S. & W., and cement was unloaded from the original cars and placed in a cement house, on a level with the storage bins, by a derrick. This standard gage track extended under the storage bins and crushed stone for several smaller structures was shipped from this plant. ft., and two 54 ft. x $16\frac{1}{2}$ ft. elliptical arches, and is 34 ft. wide face to face of arches. The 150 ft. and the 120 ft. arches support a floor system composed of 13 ft. spandrel arches and the two smaller arches carry longitudinal spandrel walls, which retain the stone filling placed directly on the backs of the arches. The west abutment is of the ordinary "U" type, but the east

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Fig. 9-The Completed Structure Across the Delaware River.

abutment is modified in that the walls are not a gravity section, but are tied together at about one-third their height by reinforced transverse ties, and are heavily reinforced to act as cantilever beams above these ties.

The east two-thirds of the bridge is straight and the longitudinal axis of this portion makes an angle of 65 deg. with the centerline of the piers and with the elements of the main and of solid concrete up to the extrados of the main arches, above which the pilasters and adjoining spandrel walls form a hollow pier. In constructing the main arches the work proceeded from the east end and five arches were turned during one season. As the piers were not entirely stable under the unbalanced thrust of one arch, and as it was unsafe to leave any centers in the river during the winter, on account of large amount of ice carried



spandrel arches. The west one-third is partly on a 3 deg. 36 min. curve and partly on a spiral connecting the curve with the straight portion.

The west abutment and the pier between the two smaller arches rest on a gravel foundation, but all other foundations are carried to bed rock. The depth of the rock varied from 25 ft. in the center of the river to 60 ft. at the banks and no particular difficulty was encountered in making the excavations. The piers are during that season, the last pier was considerably enlarged be-

Delaware River Viaduct.

low the ground line and acted as an abutment pier. The floor system above the springing line of the spandrel arches was constructed in sections about 90 ft. long, but the reinforcing

was constructed in sections about 90 ft. long, but the reinforcing bars were continuous past the construction joints, so that there are no expansion joints of any nature from end to end of the structure. The floor was waterproofed with a $\frac{1}{8}$ in. layer of a patented compound prepared and applied by the Masonry



Fig. 11-Delaware River Vladuct at Slateford, Pa.

Waterproofing Company, and protected against injury from the stone filling by a 3 in. layer of concrete.

The contractors used timber centering for the 54 ft. and 120 ft. spans and two sets of steel centering, for the 150 ft. spans. The steel centers for one arch consisted of ten three-hinged arch ribs, supported at the piers by short steel columns resting on I-beam grillages which were supported on the footings of the adjacent piers. These ribs were joined together into a rigid structure by lateral and cross-frame bracing. The interesting feature of these centers was the device for lowering them. This consisted of an extension member and toggle on each side of the crown pin. The extension member is built up of two channels battened and latticed together and divided at the center to allow the insertion of an iron block pierced by a threaded hole in the end of each half. A heavy screw is worked in these blocks by means of a ratchet and lever, so as to lengthen or shorten the member. By lengthening this member the horizontal axis of the toggle is shortened and the centers are lowered. The centers were designed, built and erected by the McClintic Marshall Construction Company.

The construction work was handled by a combination of derricks and cableways. The cableway was composed of two 21/4 in. cables spaced 17 ft. center to center, supported at each end by a timber tower 125 ft. high and near the center by a timber "A" frame with the legs resting on two concrete piers 30 ft. high. The "A" frame legs were spread so as to clear the bridge structure, and the concrete piers were removed after the completion of the work. The end towers were 1,950 ft. apart and rested on concrete pedestals. The "A" frame divided the cableway into four independent units operated by four 40 h. p., double drum, Florey engines with a carrying speed of 800 ft. per minute. The contractors maintained an independent organization and plant layout on each side of the river, material being received on the New Jersey side from a switch connection with the N. Y. S. & W., and on the Pennsylvania side from the old line of the D. L. & W. Sand cars were dumped from a trestle into storage piles and the sand placed in elevated bins near the mixers by derricks operating clam shell buckets. Stone was hauled from the railroad excavations or waste banks by wagons to crushers located near the mixers and the crushed stone elevated to bins by bucket conveyors. Sand and stone were conveyed to the mixers by 24 in. gage cars. Each mixing plant consisted of two one yard Smith mixers located directly below the cableway.

A large part of the work was carried out on double shifts and an electric generating plant was installed to furnish light for night work. While concreting certain portions of the main arch rings concrete was placed continuously for three days and two nights and each section of the floor system required a continuous 24 hour run. This structure required 51,376 cu. yds. of concrete and 627 tons of reinforcing steel.

The concrete used on the cut-off was of three classes, known as "A," "B" and "C." "A" concrete was a 1:2:4 mixture, used only for thin walls and reinforced slabs; "B" concrete was a 1:3:5 mixture, used for arch rings and all work where other classes were not specified; and "C" concrete was the same mixture as "B" with two man stone bedded in it, used in massive piers, abutments and walls.

The structures were designed and built under the direction of Lincoln Bush, formerly chief engineer, and G. J. Ray, now chief engineer of the D. L. & W. F. L. Wheaton was engineer in charge of construction.

RAILROAD ACCIDENTS, THEIR CAUSES AND REMEDY.*

By D. F. JURGENSON,

Engineer Minnesota Railroad and Warehouse Commission.

Having found the fundamental causes of preventable accidents, the problem in hand is to accomplish their removal. It may be said in this connection that there is probably no industry in existence which depends so largely upon the human element for its safe operation as does a railway system; also in none of the ordinary walks of life are employees so well compensated for services rendered as are, generally speaking, those of American railways. Their hours of labor and rest have also been regulated by legislation to their advantage. The human equation is manifestly the most important element for consideration, and probably the most intricate to solve.

In our effort to eliminate the causes of collisions we should confine ourselves strictly to questions which are pertinent to the problem. In my judgment the wreck-resisting qualities of steel and wooden cars should not enter into consideration, because to anticipate the continuation of this feature of railroad operation, with a view toward the construction of wreck-proof cars and equipment, would be equivalent to a suggestion to the public that they should not expect to obtain satisfactory relief from preventable railroad accidents.

A notable feature in practically every report of collisions is the recital that one or several employees failed to do something which they should have done, and if they had obeyed the rules of the company the collision and consequential casualties would not have resulted. In this regard there is a marked contrast in sensibility to duty and appreciation of responsibility to society between the railway employees of this country and those of European railways. Whenever the European railway employee fails in performing his prescribed duty in train operation, and his failure of duty results in death or injury to persons, he is held accountable to the state, and it is an interesting fact that there are even less fatalities in connection with the operation of railways in Germany than with that of the agricultural pursuits of that country.

NECESSITY FOR AUTOMATIC TRAIN CONTROL NOT ESTABLISHED.

The necessity for automatic control of trains is not established until we have exhausted all means of prevention for errors in train operation now at our command. Some justification will then exist for seeking other fields for a remedy.

The automatic train-control device, if its realization was within the range of possibility, would at the very best be only an auxiliary to and of secondary importance to the signal system. This is so because past experiences have proven that practices not essential to the safe operation of trains are, as a general rule, not given the careful attention that the primary measures receive.

Except, perhaps, in a very few conceivable special cases, it is a question whether grave danger does not lurk in the introduction of a mechanical means that tends to make an automaton of a railway employee. This device is likely to make the employee careless of the responsibilities which he has assumed. It may cause him to feel that he is a mere supernumerary who has been practically relieved of responsibility in the handling and control of the train, vigilance over track, signals, flags, and in fact will, to a certain extent, encourage the omission of many of the duties and requirements so essential and necessary to insure the maximum of safety in train operation.

The automatic train-control device might shift the responsibility of safe train operation from the high-grade and longexperienced engineman or train operator to the less experi-

CENTRAL LONDON RAILWAY, ENGLAND.—The Central London Railway bill proposes to authorize the construction of railways from Shepherd's Bush through Chiswick to a junction with the London & South Western Railway at Gunnersbury, and to sanction working agreements, etc., to be made with the London & South Western, and the raising of additional capital for necessary expenditures.

^{*}Abstract of paper submitted as the Report of the Committee on Safety Appliances at the annual convention of the National Association of Railway Commissioners, Washington, D. C., November 19-22, 1912.

The Paulins Kill Viaduct.

A Large Concrete Viaduct on the new D. L. & W. Cut-off.

E. S. HEALY, '12.

A great deal of attention has recently been attracted by the Hopatcong Slateford cut off of the Delaware, Lackawana and Western Railroad. It is one of the largest pieces of work accomplished in the east in many years, and includes two of the largest concrete viaducts in the country. The construction is all on an immense scale, no expense having been spared to make the alignment and gradients The work throughout is of the finest quality. The total perfect. cost will be about \$10,000,000, or \$350,000 per mile. All of the bridges are of reinforced concrete, with but one exception. There are 70 structures in all with a total volume of 250,000 cu. yds. of concrete and 2500 tons of reinforcement. The viaduct over the Delaware River is the largest and most interesting from an engineering point of view, it being 1470 ft. long and containing 51,500 cu. yards of concrete. The Paulins Kill Viaduct is a close second being 1100 ft. long and containing 41,000 cu. yds.

This bridge deserves attention not only on account of its size and excellent construction but because of its remarkable beauty architecturally. The pleasing outline combined with its height and fine workmanship make it a source of pleasure to every engineer who sees the structure.

The viaduct is located at the point where the railroad crosses the Paulins Kill being about five miles south of the Delaware Water Gap and two miles east of the Delaware River. The old road continues on the west side of the river, crossing to New Jersey several miles south of the new location. The new line leaves the old at Slateford, Pa. At Portland, about two and one-half miles west of the river, it turns on a long three degree curve and crosses the Delaware, thence continuing on practically a straight line several miles east. It then curves to the south and joins the old line again at Hopatcong, near Dover, New Jersey.

Paulins Kill is a small stream, about twenty feet wide in the summer time but subject to floods that cover the entire meadow over which the viaduct extends. The railroad after crossing the Delaware continues in practically a straight line eastward, with only a moderate fill to the Paulins Kill valley. A long 50 ft. embankment approaches the bridge from the west. The country seems to be completely dominated by the immense structure and the embankments at either end.

The viaduct is 1100 ft. long, made up of five 120 ft. barrel arches and two 100 ft. arches. It is 36 ft. wide and the elevation of the parapet is about 100 ft. above that of the valley. All the arches are of semicircular construction, the radius of the intrados of the larger arches being 62 ft., and that of the extrados 72 ft. The arch rib is 6 ft. thick at the crown. The smaller arches are next the abutments. The radius of the intrados is 50 ft., the 5 ft. thickness of the crown giving a radius to the extrados of 60 ft. Each arch is surmounted by spandrel arches of $12^{t}-6^{tt}$ spans, The transverse spandrel walls vary in thickness from 3 ft. to 3 ft. 6 in. and in height from about 39 ft. to



Placing of Centering, Paulins Kill Viaduct.

60 ft. The parapet is 5 ft. high and the ballast is carried to within about six inches of the top, the elevation of the rail being the same as that of the top of the parapet.

Above the springing line the pilasters, spandrel walls, floors and arch barrel are heavily reinforced and constructed of class "B" mixture, (I cement, 3 sand and 5 crushed stone). The reinforcement is entirely of Johnson square bars varying in size from $\frac{3}{4}$ in. to $\frac{1}{2}$ in. The 120 ft. arches are reinforced by I in. longitudinal bars spaced 9 in.

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The Paulins Kill Viaduct.

c. to c. at 3 in. from both the soffit and back. These are met by $\frac{3}{4}$ in. transverse bars spaced over about half of the arch 2 ft. c. to c. but closing up near the crown to 9 in. The 100 ft. arches are similarly reinforced with $\frac{3}{4}$ in. and $\frac{1}{2}$ in. bars. All longitudinal bars are imbedded about 10 ft. in the skew backs. The spandrel walls are reinforced by $\frac{1}{2}$ in. and $\frac{3}{4}$ in. bars, the vertical bars spaced 1 ft. c. to c. and the horizontal bars 2 ft. c. to c. The floors are reinforced concrete slabs 3 ft. thick on which is laid about 4 ft. of ballast. Expansion was allowed for in the deck by rather interesting expansion joints. One-half inch joints were provided at each side of alternate pilasters. Longitudinal rails were imbedded in the pilaster forming the lower surface of the joint and providing a bearing and sliding surface for transverse rails which were embedded in the deck. The tracks are of



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standard guage placed 13 ft. center line to center line, the roadbed being 28 ft. wide. Drainage is taken from the roadbed by an 8 in. pipe, which also takes the water from the back of the arch. The water is collected by a groove along the center of the back. This is intended to take away any water which may rain in the sides or get through the floor and thus prevent discoloration on the face.

The piers are rectangular 20 ft. by 42 ft. The water seldom flows around the base of the pier so no break water was necessary. All piers extend to solid rock, and vary in extreme height from 55 ft. to 13 ft. The piers are not reinforced below the springing line and are built of class "C" mixture. This is the same as the "B" except that large stones are imbedded in the grout.

The construction of the abutments is plainly shown in the photograph. It consists of three vertical walls connected by the floor and a tie wall crossing horizontally 20 ft. below the floor. The walls at the pilasters are 7 ft. 8 in. thick, the walls between the pilasters and the center wall are 3 ft. thick. The intermediate horizontal and vertical walls which show in the photograph are 3 and 4 ft. thick respectively. All the walls and the floors are reinforced with rods from $1\frac{1}{4}$ in. to $\frac{1}{2}$ in. in diameter. The heavier rods are at the top of the wall, vertical reinforcement is spaced 1 ft. c. to c. while the horizontal is 2 ft. c. to c. Rods were placed in every case 3 in. from the face of the concrete and required to lap or anchor at least 40 times their diameter. The west abutment is 100 ft. in length, the east 75 ft.

The construction work was begun on Oct. 15, 1908. Test holes were first driven at the site of each pier and continued from 15 to 25 ft. below the rock surface. In this way definite information could be given the contractor as to the nature of the excavations at the foundations. The same care was used in preparation for all the work on the line. The cut shows the piers completed and the centering for the arches commenced. A construction track was laid on both sides of the bridge and along its entire length. Sidings were built as the work The timbers and the concrete was handled by one demanded it. derrick placed at each pier. The photograph shows the arrangement of the derricks and the general construction of the centers. The center was supported on piles, driven 4 ft, center to center across the arch and arranged longitudinally. The vertical posts are 12 in. by 12 The horizontal timbers are chiefly 12 in. by 12 in. and 14 in. Cross bracing is 12 in. by 3 in. and 12 in. by 4 in. in. by 12 in. The lagging consists of 3 in. by 6 in. planks. The arch was intended to be loaded, as shown in the detail of the centering in

order to secure more uniform stress while building, but it was placed from the skewbacks to the crown. The centers were struck 28 days after the key was set. A large stone crushing and mixing plant was constructed at the work, but the cement and sand had to be brought by train. The contractors were Reiter, Curtis and Hill, who were in charge of the work on Section Six. The work on the viaduct was sublet to John Goll & Co. Work was completed on October 20, 1910, just about two years from the day of commencing.

The bridge was designed under Mr. Lincoln Bush, the late Chief Engineer of the railroad, by the bridge department of the railroad.



Construction of Viaduct from the West.

The dead load was computed at 150 pounds per cu. ft. for concrete and 100 pounds for ballast and fill. The live load used was Cooper's E. 50 as being about equivalent to two 170 ton Lackawanna engines followed by a train of 4500 pounds per ft. Impact was allowed for by the ratio: Impact \pm live load = live load + live load + dead. In the analysis of the arch the method of Mr. William Main was used as described in his '' Method of Elastic Arches.''

It might be of interest to give at this point a little history of the cut off. The Delaware, Lackawanna and Western Railroad was originally a coal road for transporting Pennsylvania coal to the Atlantic coast markets. It did not cross the Delaware River. The coal was



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at that time taken across New Jersey by canal. As the demand for coal increased the Warren Railroad was leased. This road extended from Portland, Pa., to Hampton Junction. Here the road was met by the Central Railroad of New Jersey and the coal carried by that line to the coast. The disadvantage of having no seaport was keenly felt by the railroad so in 18— the Morris and Essex Railroad was leased. This established the present line of the Lackawana Railroad. These separate lines across New Jersey were built with little capital, and heavy grades and sharp curves prevailed, The ruling grade of the old line is 1.14 %, having a rise and fall of 284 ft. There were 57 curves, including a large number of 5 degree and one 6 degree 54 min. curve.

In June of 1905 an investigation was started to determine the advisability of building a new line. Twelve lines were laid out on Geological Survey maps and in December of the same year a party was sent in the field and a satisfactory line laid out. In August of 1908 construction was begun on the new line. The ruling grade is .55%with a rise and fall of 11 ft. Of the fifteen curves only one is over 2 degree, that a 3 degree 36 min. The distance saved is about 11 miles. The earth work is excessive, about 6,300,000 cu. yds. of earth and 5,470,000 cu. yds. of rock have been excavated. One large fill across the Pequest Valley is 3 miles long and has an average height of 75 ft.

We wish to thank Mr. J. H. Clark for his kindness in supplying us with information and photographs.