A TEXT-BOOK

ON

ROOFS AND BRIDGES.

PART III.

BRIDGE DESIGN.

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CHAPTER XIX.

A HIGHWAY BRIDGE FOR ELECTRIC-RAILWAY TRAFFIC.*

ART. 132. WEIGHTS OF ELECTRIC CARS.

THE usual live load for computing the trusses of a highway bridge is that of a crowd of people on the roadway, and values for different classes of structures are given in Chapters III and VII, the latter containing a design in which the weights of electric cars are also considered. The rapid introduction of electric railways renders it important that highway bridges near large towns should be proportioned with this traffic in view, and accordingly an example of a recent structure is here presented.

The following additional information regarding the weights of electric cars is given as a guide in preparing specifications, but it should be borne in mind that these are liable to increase as the traffic becomes more developed.

A street car with a body 16 feet long and platforms each 3½ feet long mounted on a four-wheel truck is about the shortest used, and when fitted with a single-motor equipment, which answers the purpose when the grade does not exceed 4 per cent, weighs from 10 000 to 13 000 pounds. The standard car as used by electric railways for city use has a car body 18 feet long and platforms 4 feet in length. When provided with double-motor equipment this car weighs from 14 000 to 19 000 pounds. These lengths are sometimes increased to 20

* Prepared, except Art. 132, from data furnished by H. O. DUERR, Manager of the Lehigh Valley Construction Company.

feet and 5 feet respectively. A trail car with a 16-foot body weighs about 9000 pounds. Four-wheel trucks have wheel bases of 6, 6½ and 7 feet, the latter being the usual one on the city lines.

For cars mounted on double trucks the lengths of body most generally adopted are 22 and 25 feet. These pivotal trucks are spaced about 18 feet between centers, and the wheel base of each truck varies from 4 to 5 feet. When equipped with double motors suitable for these cars, which are mostly employed on inter-urban lines, the weight is 19 000 to 22 000 pounds. The smaller cars of this type with trucks spaced 12 to 13 feet between centers run as low as 12 000 pounds in weight, and the larger cars may have bodies as long as 32 feet, the maximum spacing of trucks being about 24 feet. Vestibuled ends increase the weight about 800 pounds.

The maximum carrying capacity of street cars may be estimated at about 4 passengers per linear foot of car including platforms. In Art. 65 reference is made to motor and trail cars of the double-deck type, the weights given applying to the heaviest probably yet constructed for electric railways. The carrying capacity of these cars is considerably larger than the preceding estimate for single-deck cars.

For most bridges it will generally be found that the dead load of a crowd of people will require heavier trusses than electric cars alone, since under present methods but one or two of these are on a span at the same time; the stringers and floor beams, however, are usually increased in size under the wheel loads of motor cars

ART. 133. GENERAL DESCRIPTION.

The bridge chosen for illustration is one over the Lehigh River between West Catasauqua and Hokendaqua, Pa., completed in 1894 by the Lehigh Valley Construction Company,

Fig. 65.

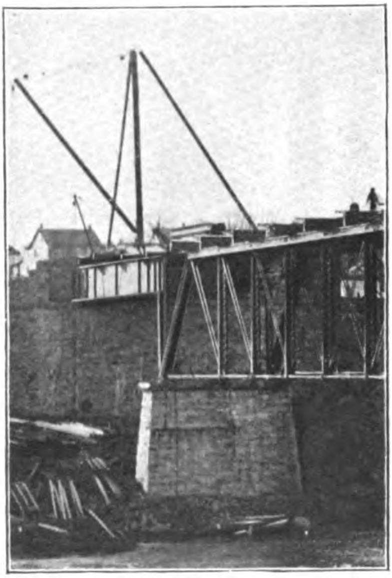


Fig. 66.

HIGHWAY BRIDGE OVER LEHIGH RIVER,
HOKENDAUQUA, PA.

H. O. DUERR, Manager and Engineer. Beginning on the west side at Hokendaqua, it consists of one plate-girder span of 60 feet over a highway, three pin-connected spans of 158 feet each over the Lehigh river, one similar span of 158 feet over the Lehigh Canal, one lattice-girder span of 56 feet over the Central Railroad of New Jersey, and one plate-girder span of 36 feet over a highway in West Catasauqua. It is a deck strucrure throughout, the roadway for wagons and electric track being 25 feet wide, with a sidewalk 5 feet in width on the north side. These lengths of spans are from center to center of piers, so that the total length of the bridge is, very closely, 784 feet.

In Fig. 65 is shown the plate-girder span on the western end and part of one of the pier spans, while Fig. 66 shows a view the central river span, both being from photographs taken during the erection. Plate XVIII gives the shop drawing of the end post and end chords of one of the pin spans, on a scale one third of that of the original. Fig. 67 shows a floor beam with the arrangement of the floor timbers and railing.

The two abutments and six piers contain about 2500 cubic yards of masonry, the piers in general being 5 feet wide and 30 feet long on top, their elevation being such as to give sufficient clearance above the highest known water mark, and a clear headway of 20 feet above the railroad tracks.

The four main spans have trusses 20 feet deep and 18 feet apart between centers. The east end of the east pin span is on a skew about 77 degrees, the lattice truss and eastern plate girder having the same skew on both ends. The western plate girder has also a skew of 70 degrees with the abutment.

The material in the trusses and floor beams is mild steel with an ultimate strength of from 56 000 to 65 000 pounds per square inch. The floor joists and planks are oak. The total amount of steel used was 700 000 pounds, and of lumber

140 000 feet board measure, which makes the dead weight of the bridge about 1500 pounds per linear foot.

The material was rolled at the mills of the Pennsylvania Steel Company, Steelton, Pa., and the bridge work was manufactured at their shops from drawings made by H. O. DUERR.

The cost of the bridge was about $42 000, of which $11 000 was for the masonry work, $29 400 for the superstructure, and $1600 for general expenses. This is at the rate of nearly $54 per linear foot for the total, or about $37.50 per linear foot for the bridge structure proper. The cost was divided as follows: $17 600 was paid by Lehigh County, $17 600 by Northampton County, $1800 by the Central Railroad of New Jersey, and $5000 by the electric Railway Company whose line crosses the bridge.

ART. 134. PLANS AND PROPOSALS.

The Lehigh River at the site of the bridge is the dividing line between Northampton and Lehigh counties, the former being on the east side of the river. The people of the vicinity being desirous of a bridge petitioned the courts of the two counties, which appointed viewers to determine whether a bridge was necessary and, if so, to select a site. The viewers after hearing the testimony reported that a bridge was necessary, and stated the location that it should occupy.

The county commissioners were then given the matter in charge for the purpose of constructing the bridge. After conferring with the railroad and canal companies they decided that the structure should be built over the canal and the railroads on both sides of the river as well as over two public roads, in order to avoid the grade crossings. The railroad companies agreed to build the spans over their tracks, thus saving the expense of watchmen. As the Lehigh Valley tracks on the west side are about 300 feet from the river it was decided to build abutments and fill in this distance between them rather than to span it with iron ; hence the bridge over those tracks is a separate construction not included among the seven spans mentioned in Art. 133.

The county commissioners then appointed F. E. SCHALL, bridge engineer of the Lehigh Valley Railroad, to stake out the site and get up the general data and specifications for the purpose of inviting proposals from masonry contractors and bridge companies to bid upon the work. This important matter of having an engineer is often neglected in the erection of county bridges, but, as mentioned in Chapter IX, it is a very necessary step in order to secure a good bridge.

In asking for bids the commissioners fixed the elevation of the abutments and piers, and allowed bidders the privilege of submitting their own designs as to length of span and depth of truss. The bridge was to be constructed according to COOPER'S Highway Bridge Specifications, Class B, the live load to be as follows: a weight of 80 pounds per square foot of floor and sidewalk, or concentrated loads of 16 000 pounds upon four wagon wheels on a base of 8 feet, and an electric-motor car weighing 27 000 pounds on a wheel base of 6 feet followed by a trailer weighing 20 000 pounds on the same wheel base.

There were seventeen bidders for the superstructure, whose offers ranged from $18 670 to $34 000. All of the proposals embraced the plan of one span over the canal and either three or four spans over the river. The proposals were referred by the commissioners to their engineer for examination, and out of the seventeen only about six were found which were in accordance with the specifications.

After receiving the report of the engineer and thoroughly discussing the designs of the bidders the contract was awarded to the Lehigh Valley Construction Company at $26 027.50, for the seven spans as described in Art. 133.

The masonry work was let by the commissioners for $11 000, and a few alterations in the plan of the superstructure being thought advisable these were agreed upon for an addition of $3373.50 to the original contract price.

Detail drawings of the superstructure, embracing 19 sheets each 30 × 40 inches, were made in June and July, 1893, and the work of its manufacture let to the Pennsylvania Steel Company. Plate XVIII gives one of these sheets, in which, however, the lower chord, skeleton truss diagram and title have been moved from the original position in order to facilitate the photographic reduction.

ART. 135. STRESSES AND SECTIONS.

On Plate XVIII is seen a skeleton diagram of the Pratt truss of the four main spans of this bridge, and in Fig. 67 the cross section of the floor. The trusses are eighteen feet apart between centers, and the sidewalk is on the north side of the bridge. From the south end of the floor beam to the center of the south truss the distance is 3 feet 6 inches. One rail of the railway track is 7 inches south of the center of the south truss, and the other is 4 feet 3 inches north of the center of that truss. The total length of the floor beam is 30 feet 3 inches, and the center of the north truss is 8 feet 9 inches distant from the north end of the floor. With these dimensions the student will be able to apportion the live loads between the two trusses. It will be found that the uniform load of 80 pounds per square foot produces the maximum stresses in both trusses and floor beams.

The depth of these spans is 20 feet between centers of trusses, and their length between centers of end pins is 155 feet 8 inches, which is divided into nine panels. The dead load per linear foot per truss being assumed at 750 pounds and the live loads as stated in Art. 134, the stresses may be computed by the student and the sections be checked. The following are the stresses and sections for a few of the members, the former being in pounds and the latter in square inches. The stresses are for the truss between the roadway and the sidewalk, which receives the heavier load, but in construction the other truss was built of the same size in all respects.

Member.	Dead-load Stress.	Live-load Stress.	Area.	Make Up.
L_0L_2	+45 000	+ 83 800	9.38	2 bars 5″ × $\frac{15}{16}$″
L_2L_4	+101 000	+188 000	20.00	4 bars 5 × 1
L_4L_6	+112 000	+209 000	22.50	4 bars 5 × 1$\frac{1}{8}$
U_1L_2	+51 500	+99 200	10.63	2 bars 5 × 1$\frac{1}{16}$
L_1U_1	+6 000	0	0.60	1 rod $\frac{7}{8}$″
U_1U_2	−76 800	−146 000	21.90	See Plate XVIII
U_4U_6	−112 000	+209 000	31.00	See below
L_0L_2'	0	± 19 000	1.23	1 rod 1$\frac{1}{4}$″
U_1U_2'	0	± 29 200	4.20	1 angle 4 × 3 × $\frac{3}{8}$
U_2L_2	−39 000	−75 300	15.60	See Plate XVIII

Plate XVIII shows the arrangement of sections of chords and posts, and gives dimensions for the two end panels. The middle upper chord U_4U_6 is made up of a cover plate 17″ × $\frac{3}{8}$″, two web plates 14″ × $\frac{7}{16}$″, two upper angles 3″ × 3″ weighing 8.9 pounds per foot, and two lower angles 4″ × 3″ weighing 11.7 pounds per foot. The upper member U_0U_2 has theoretically no direct stress from the dead or live load, but 6000 pounds was estimated for wind and 8000 pounds for traction, and it is made up of one plate 8″ × $\frac{5}{16}$″ and two angles 3″ × 2$\frac{1}{2}$″ × $\frac{1}{4}$″. The strut U_0L_0 receives the maximum stress of 35 000 pounds, and is made up of two 8-inch channels weighing 12 pounds per foot.

The plate-girder span at the west end, shown in Fig. 65, has the north girder 54$\frac{1}{2}$ feet long over all and the south one 61 feet over all. The web in each is 71$\frac{3}{4}$ inches deep and $\frac{3}{8}$ inch thick with stiffeners 15 feet apart at the middle and decreasing to 3 feet 9 inches apart near the ends. The flanges are composed of two angles $5 \times 4 \times \frac{3}{8}$ inch, with a cover plate $12 \times \frac{7}{16}$ inch and 42 feet long. Rivets are $\frac{7}{8}$ inch diameter in $\frac{15}{16}$-inch holes, and the pitch is 6 inches at the middle of the girders, decreasing to 4 inches near the ends.

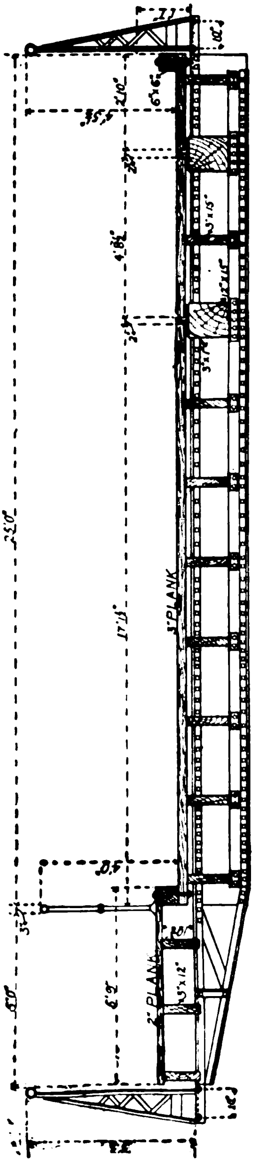


FIG. 67.

ART. 136. THE FLOOR SYSTEM.

The floor beam is 20 inches deep between backs of angles and has a web $19\frac{3}{4} \times \frac{3}{8}$ inch. It is without stiffeners except at points directly over the centers of trusses, where two are placed as shown in Fig. 67. The flanges are equal in size, each being made of two angles $3 \times 3 \times \frac{7}{16}$ inch, giving a gross section of 4.75 square inches and a net section of 4.02 square inches. The pitch of the rivets is 6 inches for 11 feet near the middle, decreasing to $2\frac{3}{4}$ inches over the trusses.

The joists and stringers rest upon brackets riveted to each side of the floor beam. The two stringers under the rails of the electric track are each 12×15 inches, and the maximum stress produced in them from the specified motor car is about 1040 pounds per square inch. The joists which support the floor plank are 3×15 inches. The roadway plank are of oak, like the joists and stringers, 3 inches in thickness, and bolted to a 6×6 inch guard timber at the ends. The clear width of the roadway is 24 feet between the guard timbers and 25 feet between the railings.

The sidewalk is 5 feet wide in the clear, its floor being of 2-inch plank and raised 6 inches above the level of the roadway. The side railings have vertical angle irons at each floor beam and a pipe top. A two-line pipe railing is also placed between the sidewalk and the roadway.

The tops of the rails of the electric track are on a level with the surface of the roadway, the planks being broken as seen in Fig. 57. At the track stringers, as these are lower than the joists, the planks rest upon oak pieces 3 × 1 inch on each side of the rail.

ART. 137. METHOD OF ERECTION.

The masonry work was begun in July, 1893, and completed in December. The erection of the superstructure was started in the latter part of October and the bridge was completed on January 1, 1894. When the river spans were erected there was about four feet of water in the river, the bottom of which is of rock and gravel. The staging or falsework for the erection of these spans consisted of eleven bents, each of two 10 × 12 inch high posts with a 10 × 12 inch cap, braced crosswise by two 2 × 12 inch planks, all securely bolted together. On top of these bents a temporary floor was laid, the stringers for the permanent bridge being used for this purpose. About 25 000 feet of lumber was needed in the falsework for each span.

The cost of erection was low, as the facilities for delivering materials and lumber were of the best. The railroad being very near the site the material was unloaded by a derrick and moved to the west abutment on a short tramway, where it was hoisted by a portable engine and derrick. After one span had been erected the derrick was put on top of the bridge, as seen in Fig. 65, and the material then run out to the traveler, from which it was taken and placed in position.

The traveler, seen in Fig. 66, is an important and interesting piece of machinery. It consists of six bents made of oak posts 7 × 7 inches, and cross pieces 6 × 6 inches, mortised into a sill 10 × 10 inches. This sill was supported by four wheels which ran on a track made of old railroad rails, and thus the traveler could be easily moved backward and forward. On each post a crab was placed, thus giving six crabs with which to handle the material. The traveler being 35 feet long, the posts were 17 feet apart, thus bringing them near the panel points of the truss and enabling two panels to be erected at a time. This was particularly advantageous at the hip joint, where there is no vertical post on which to raise the top chord. This particular form and style of traveler is believed to have been first used by the erecting engineer of the Philadelphia Bridge Works, Pottstown, Pa.

The operation of erection was as follows: first, the lower chords were laid out in order on the falsework and the bed plates and shoes on the bridge seats; second, the end posts and first panels of the top chords were erected; third, the hip verticals and the ties for the first panel were put in place; fourth, the shoe and hip pins were driven; fifth, the first vertical post was erected; sixth, the lower-chord pins at the hip and first vertical post were driven, and the first lower lateral strut bolted in place. The traveler was now moved forward far enough so that the hip floor beam could be laid, then the upper laterals were put in for the first panel. The operation was thus continued as the traveler advanced, the stringers being laid panel by panel, the lower diagonal braces and sway bracing coming last in order. The span being in position, held by the pins and bolts, it was next swung free, and the riveters began their work.

The frame seen in Fig. 66, leaning against the pier in the foreground, is a hoisting arm which was attached to the traveler after the erection of the span and used to assist in putting up the falsework for the next span. As a bent was taken down it was floated around the pier, caught by the hoisting arm and drawn up into a vertical position.

The falsework for one span was put up in two days, and the material was handled, put into place, and the span erected in two and a half days, at a cost of $250. In this work a force of about 35 men was employed, divided into six different gangs. One gang unloaded the material and delivered it to the bridge, another hoisted it upon the bridge and transferred it to the point of erection, the third put the members in their proper places and fastened them with bolts, the fourth riveted the work together, the fifth laid the floor, and the sixth painted. These gangs were organized as early as possible upon starting the erection, and each was kept at the same work until the completion of the bridge. The matter of erection is a very important one which now receives much attention, as its cost is an item depending upon local conditions, cost of lumber and of labor, as well as upon the weather and the character of the river. In each particular case the problem of erection must be carefully studied, so as to reduce these uncertainties to a minimum, and render its cost very closely determinable in advance.

During the progress of the work it was under the constant inspection of the engineers representing the commissioners, and thus a first-class bridge has been the result. The plan of having a reliable engineer in charge of the letting and construction of bridges by town and county authorities is the only one by which safe and economic structures can be secured. When an engineer is in charge reputable builders will not have to cope with others who bid on one thing with the intention of constructing something very different, and every irregularity is checked on its first appearance. Any one can buy a bridge, but only an engineer can do so and secure proper stability and greatest economy.

ART. 138. ACCIDENT CAUSED BY A FLOOD.

The history of this bridge will not be complete without an account of an accident which occurred since the above was

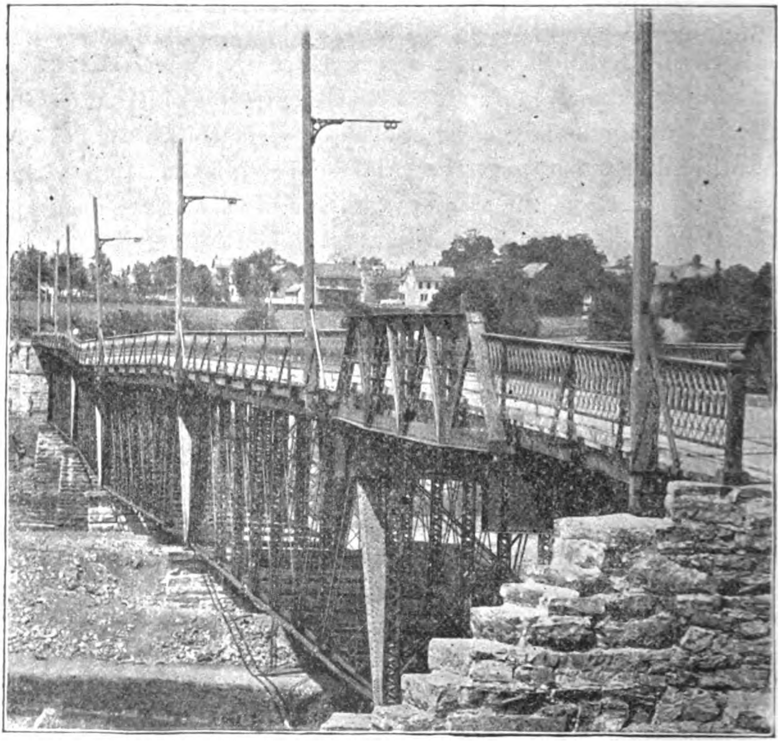
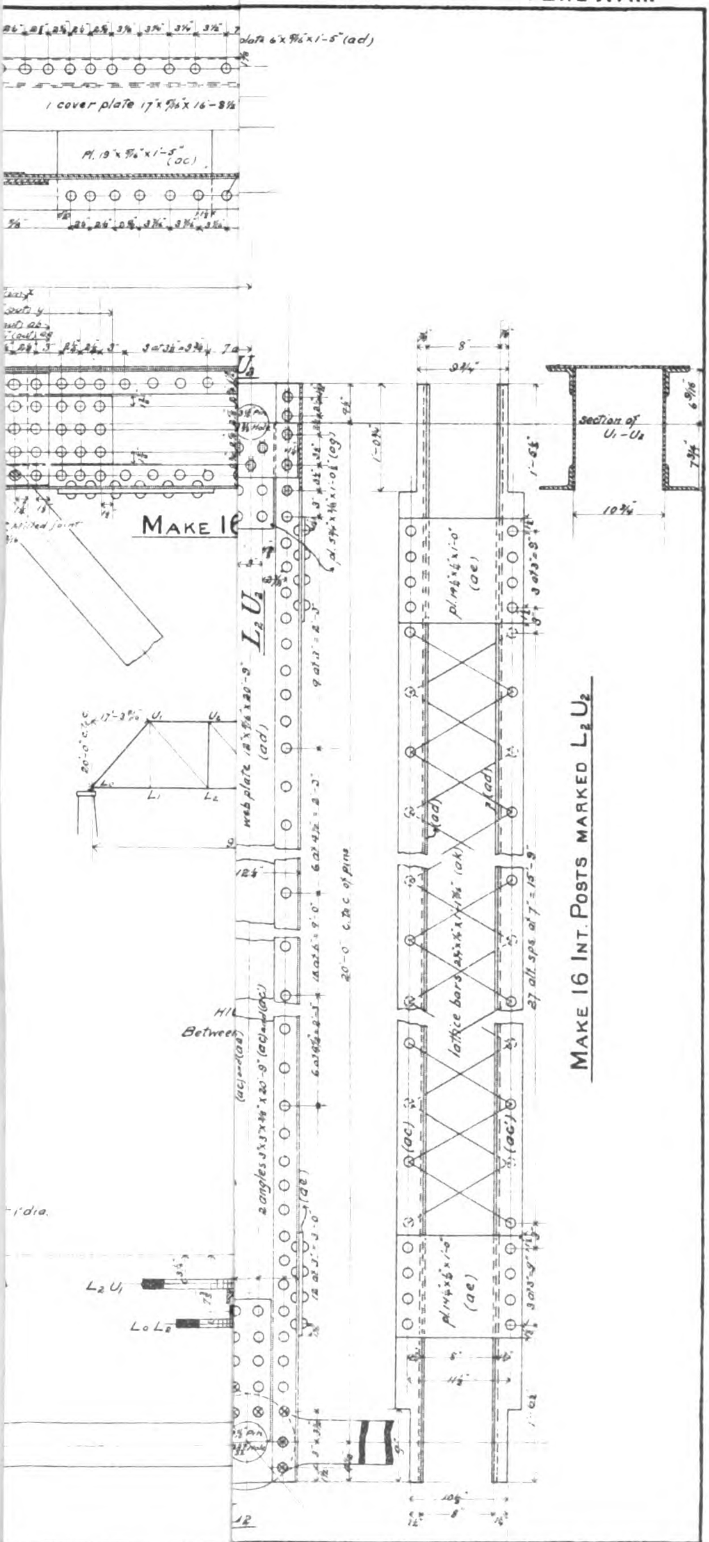


FIG. 68.

written and while this book was in press. On May 21, 1894, the Lehigh River, swollen by a very heavy rainfall of two days, rose to a height of 14 feet above mean low water, forming the greatest flood since 1869. At the highest stage the water line on the piers of the bridge was slightly above the copings of the cutwaters. On the morning of May 21 it was observed that the down-stream end of the eastern river pier


1 cover plate
MAKE 16 INT. POSTS MARKED L2 U2
L2 U2
section of U1 - U2
lattice bars
web plate
2 angles

was sinking, and this continued through the day accompanied by a slight sidewise motion, the entire displacement of that end being nearly 2 feet vertically and about 6 inches laterally. Fig. 68, from a photograph taken a few days later, shows the cracking of the pier and the tipping of the trusses of the two adjacent spans which threw the floor and railing over the pier nearly 3 feet out of line. It also shows the buckling of the lower chords in one of the end panels adjacent to the pier. The upper lateral system was also badly distorted, some diagonals being buckled and others highly stretched. Undoubtedly the bridge was saved by the resistance of these laterals aided by the portal bracing and the stiffness of the floor.

The pier which failed had its foundation on gravel, and care had not been taken to protect it by riprap. Under ordinary circumstances it might have safely stood for many years, but the failure teaches that unusual conditions must not be left out of sight.

Soon after the accident the county commissioners contracted with the Lehigh Valley Construction Company to rebuild the pier, and to make the necessary repairs to the superstructure, the Company to furnish all materials and labor at cost and to receive twenty five per cent thereon for superintendance and the use of tools. The two adjacent spans were jacked up on four bents placed under panel points, the pier taken down nearly to the water line, a cofferdam built around it, the remainder of the pier taken out, and its reconstruction on a good foundation is in progress as the last pages of this book go to press, July 30, 1894.