

Fig. 1. Meramec Bridge near St. Louis is first of its type in United States.

Continuous Tied Arch Built in Missouri

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Contents in Brief—*First of its type in the United States, bridge over Meramec River near St. Louis has main span of 264 ft. and side spans of 192 ft. Stress analysis was accomplished by general method of least work, coupled with the determination of influence lines by the method of elastic weights instead of by solving simultaneous equations. Rolled H-sections are used for tie member as well as for all other truss members except top chord, which is a built-up section.*

OF THE MANY unusual highway bridges built in recent years few were more novel than one recently constructed over the Meramec River, a short distance south of St. Louis, by the Missouri state highway department. The bridge is appropriately called a continuous tied arch, and is believed to be the only bridge of its kind in the United States, although structures of this general type, but using plate rib rather than framed construction, have been built in Europe. Also a framed structure of this type was constructed over the St. Lawrence River in Canada in 1934 (*ENR*, May 17, 1934, p. 621), and a similar structure was studied

in connection with the East Bay crossing at San Francisco (*ENR*, Mar. 24, 1934, p. 371).

Since the Meramec River Bridge is located in a region that has been called the playground of St. Louis an effort was made to secure a structure of reasonable esthetic fitness. At the same time economic considerations were important, and accordingly, several types were studied, among them a series of three single-span plate-rib tied arches; a continuous plate rib tied arch; a three-span continuous truss; a statically determinate three-span continuous truss; a cantilever truss; and a self-anchored suspension bridge. Accurate estimates showed

the continuous tied arch to be the most economical. The cost of the substructure (two abutments of open-bent type on steel H-piles and two piers founded on rock) was \$114,013, and of the superstructure \$214,197. The bridge was designed under the 1935 A.A.S.H.O. specifications except that the wind load was increased one-third. M-20 loading was used.

Of three spans, 192-264-192 ft., the bridge is located on a dual highway and is provided with two 21-ft. roadways separated by a 4-ft. width of open grid flooring. The continuity of the trusses and the action of the arch tie produce a structure which is threefold indeterminate. A condition of single redundancy was also produced by the double intersection diagonals at the center of the arch truss. These double diagonals were used to permit a pleasing truss outline.

Stress analysis

The solution of the stresses for this type of structure may be accom-

plished by one of several methods, but the general method of least work was used to develop the three necessary equations. The procedure will be sketched below, and additional data will be found in a brief discussion that appears in the April, 1941, A.S.C.E. *Proceedings*, p. 680.

$$\text{The total work } W = \frac{1}{2} \sum \frac{S^2 l}{AE} \dots (1)$$

Let X_a , X_b and X_c represent the three unknown stresses, reactions, or parameters. Then,

$$\left. \begin{aligned} \frac{\delta W}{\delta X_a} &= \sum \frac{Sl}{AE} \cdot \frac{\delta S}{\delta X_a} = 0 \\ \frac{\delta W}{\delta X_b} &= \sum \frac{Sl}{AE} \cdot \frac{\delta S}{\delta X_b} = 0 \\ \frac{\delta W}{\delta X_c} &= \sum \frac{Sl}{AE} \cdot \frac{\delta S}{\delta X_c} = 0 \end{aligned} \right\} \dots (2)$$

But, $S = S_0 + S_a X_a + S_b X_b + S_c X_c \dots (3)$ where S_0 = the stress in the statically determinate structure, Fig. 3, due to the external loads only.

S_a = stress due to $X_a = 1$
 S_b = stress due to $X_b = 1$
 S_c = stress due to $X_c = 1$

Differentiating Eq. 3 with respect to each of the unknowns, X_a , X_b , and X_c ,

$$\frac{\delta S}{\delta X_a} = S_a;$$

$$\frac{\delta S}{\delta X_b} = S_b;$$

$$\frac{\delta S}{\delta X_c} = S_c.$$

Substituting these values in Eq. 2 the necessary three equations are as follows:

$$\left. \begin{aligned} \sum \frac{S_0 S_a l}{AE} + X_a \sum \frac{S_a^2 l}{AE} \\ + X_b \sum \frac{S_a S_b l}{AE} \\ + X_c \sum \frac{S_a S_c l}{AE} &= 0 \\ \sum \frac{S_0 S_b l}{AE} + X_a \sum \frac{S_a S_b l}{AE} \\ + X_b \sum \frac{S_b^2 l}{AE} \\ + X_c \sum \frac{S_b S_c l}{AE} &= 0 \\ \sum \frac{S_0 S_c l}{AE} + X_a \sum \frac{S_a S_c l}{AE} \\ + X_b \sum \frac{S_b S_c l}{AE} \\ + X_c \sum \frac{S_c^2 l}{AE} &= 0 \end{aligned} \right\} \dots (4)$$

These three simultaneous equations may be solved for the unknowns. However, the work of computation is reduced if the location of the coordinate axes is chosen so that the

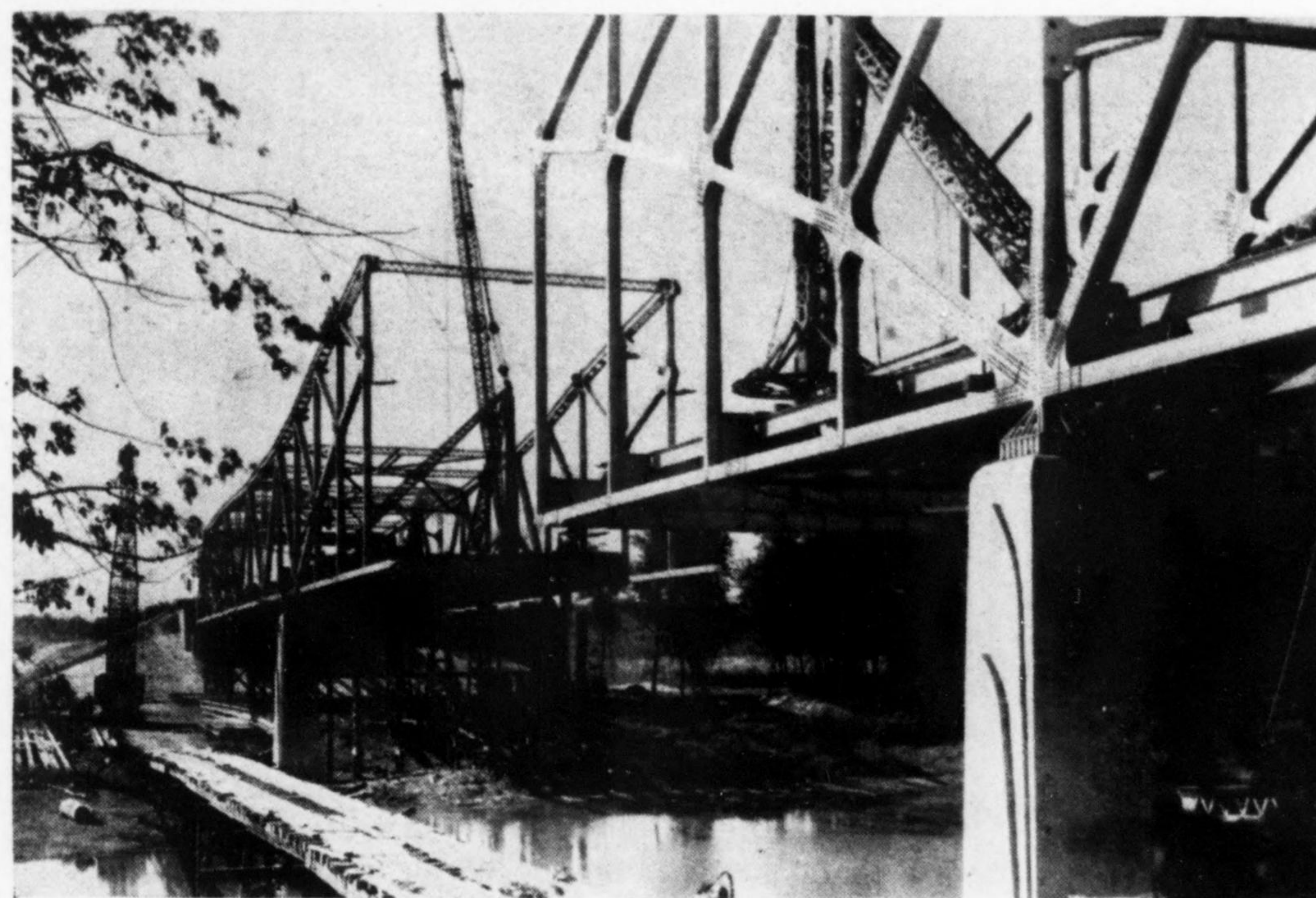


Fig. 2. Center span was erected by cantilevering using a deck traveler after the side spans had been built on falsework by a crawler crane.

terms with different subscripts will vanish. We wish to make

$$\left. \begin{aligned} (a) \sum \frac{S_a S_b l}{AE} &= 0 \\ (b) \sum \frac{S_b S_c l}{AE} &= 0 \\ (c) \sum \frac{S_a S_c l}{AE} &= 0 \end{aligned} \right\} \dots (5)$$

Each equation now contains only one unknown from which we write,

$$\left. \begin{aligned} X_a &= - \frac{\sum \frac{S_0 S_a l}{AE}}{\sum \frac{S_a^2 l}{AE}} \\ X_b &= - \frac{\sum \frac{S_0 S_b l}{AE}}{\sum \frac{S_b^2 l}{AE}} \\ X_c &= - \frac{\sum \frac{S_0 S_c l}{AE}}{\sum \frac{S_c^2 l}{AE}} \end{aligned} \right\} \dots (6)$$

The conditions expressed in Eq. 5 will be satisfied if the axes are located as shown in Fig. 3, a.

The intersection of the axes is located by Eq. 5, (c). The stresses S_c due to the force $X_c = 1$ acting at a distance y above the arch springing may be expressed thus,

$$S_c = y S_a + S_H \dots (7)$$

where S_H is the stress in the two-hinged arch shown in Fig. 3e, due to $H = 1$. Substituting this value of S_c in Eq. 5, (c) and solving,

$$y = - \frac{\sum \frac{S_a S_H l}{AE}}{\sum \frac{S_a^2 l}{AE}} \dots (8)$$

It would be a simple matter to place a unit load at the various panel points of the structure shown in Fig. 3a, and compute the stresses S_0 . Influence lines may then be computed for the redundants as indicated in Eq. 6. A more expeditious method, however, is to load the statically determinate system shown in Fig. 3, successively with the elastic weights due to the stresses S_a , S_b and S_c , and calculate the bending moments at the various panel points due to these elastic weights. If we divide the bending moment values at the various panel points by the denominators of Eq. 6 we have the influence lines for X_a , X_b and X_c , respectively. By this method the influence lines shown in Fig. 4 were computed after which an influence line was computed for each member of the structure.

Trusses

Slightly over 1,087 tons of steel were required for the Meramec Bridge. A Warren type of truss was selected as being the most suitable for use in the side spans, but for the arch span, Pratt type bracing was used in order to get a satisfactory slope for the diagonals. (Fig. 5). The upper chord of the truss consists of a plate and angle section. Where the compressive stress was low top and bottom lacing was used,

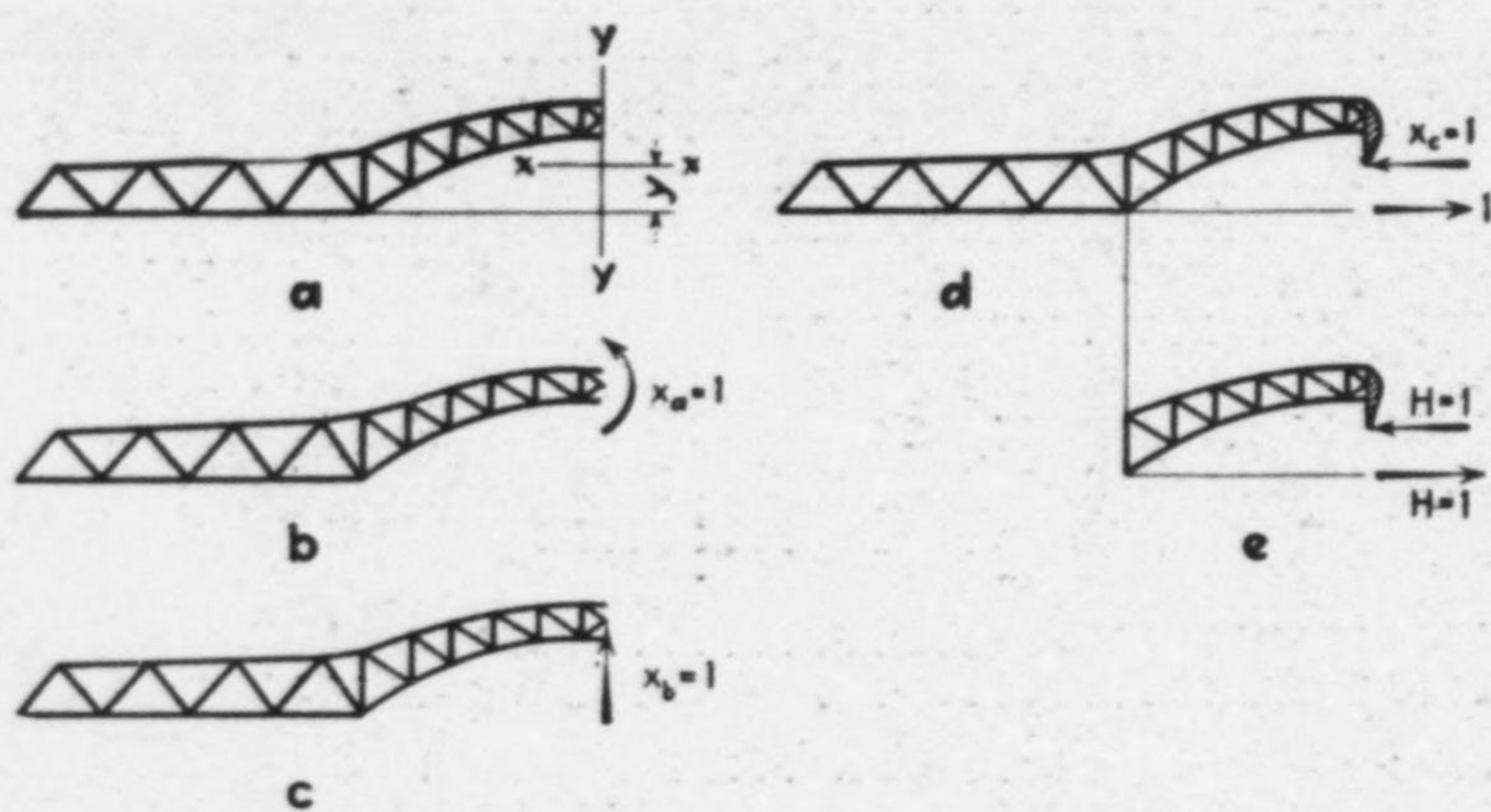


Fig. 3. By cutting the continuous truss at the center a statically determinate structure is obtained, which yields the equations necessary for computing the unknown stresses.

where the stress was tension only, tie-plates were used; and where the compression stress was important a cover plate was used on top and lacing on the bottom.

For the web system, lower chord, and arch tie 14-in. wide flange sections were used. The details were

made up using $\frac{1}{2}$ -in. gusset plates. For some of the members it was necessary to use $\frac{1}{2}$ -in. plates riveted to the flanges of the wide-flanged sections. These plates were then in the plane of the gusset plates to which they could be spliced. At the ends of the side spans and over the main piers

two thicknesses of gusset plate were required. All gusset plates were curved to eliminate the sharp, unsightly angles produced by straight-cuts.

The hangers in the arch span were also made of 14-in. wide flange sections. Cable hangers were consid-

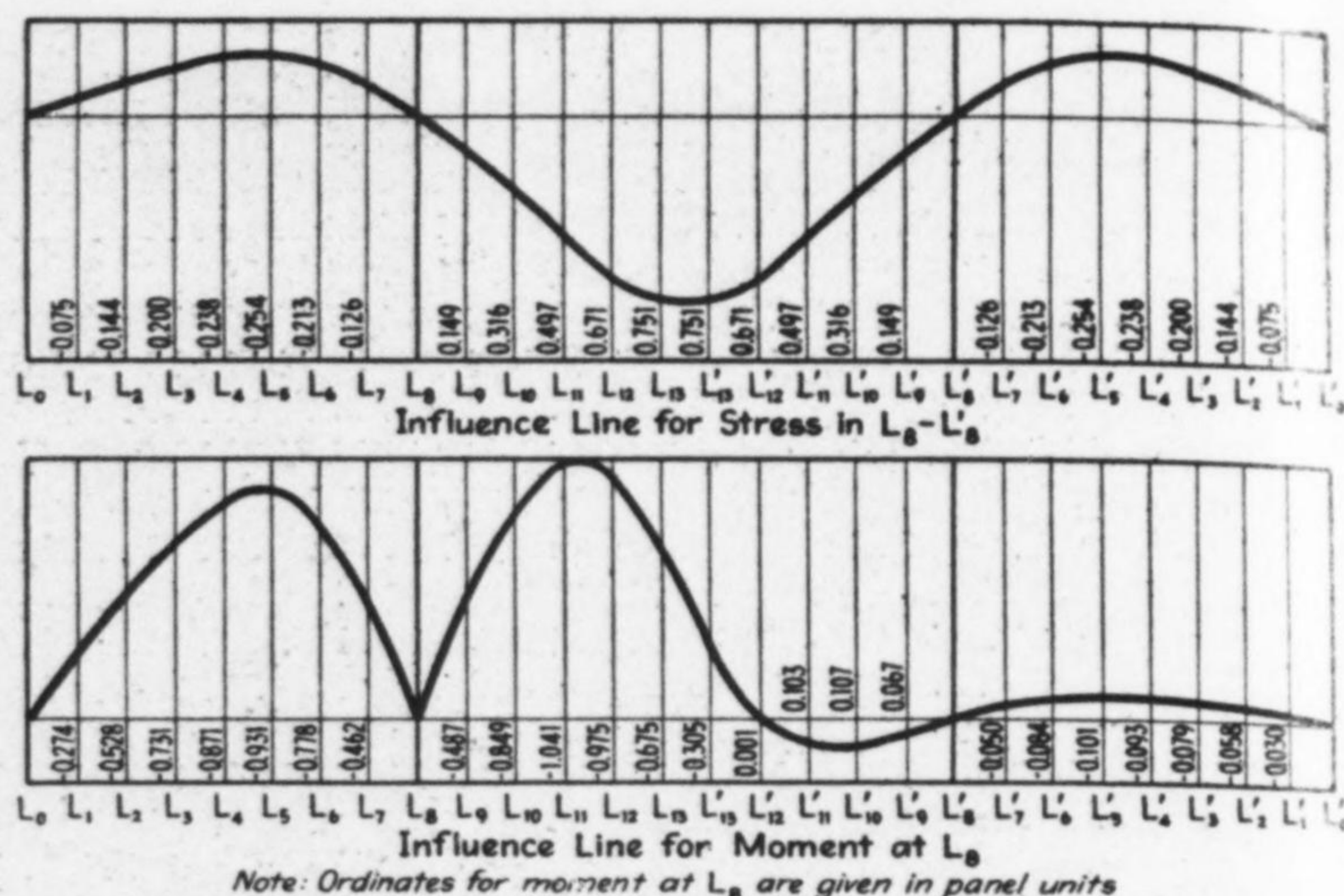
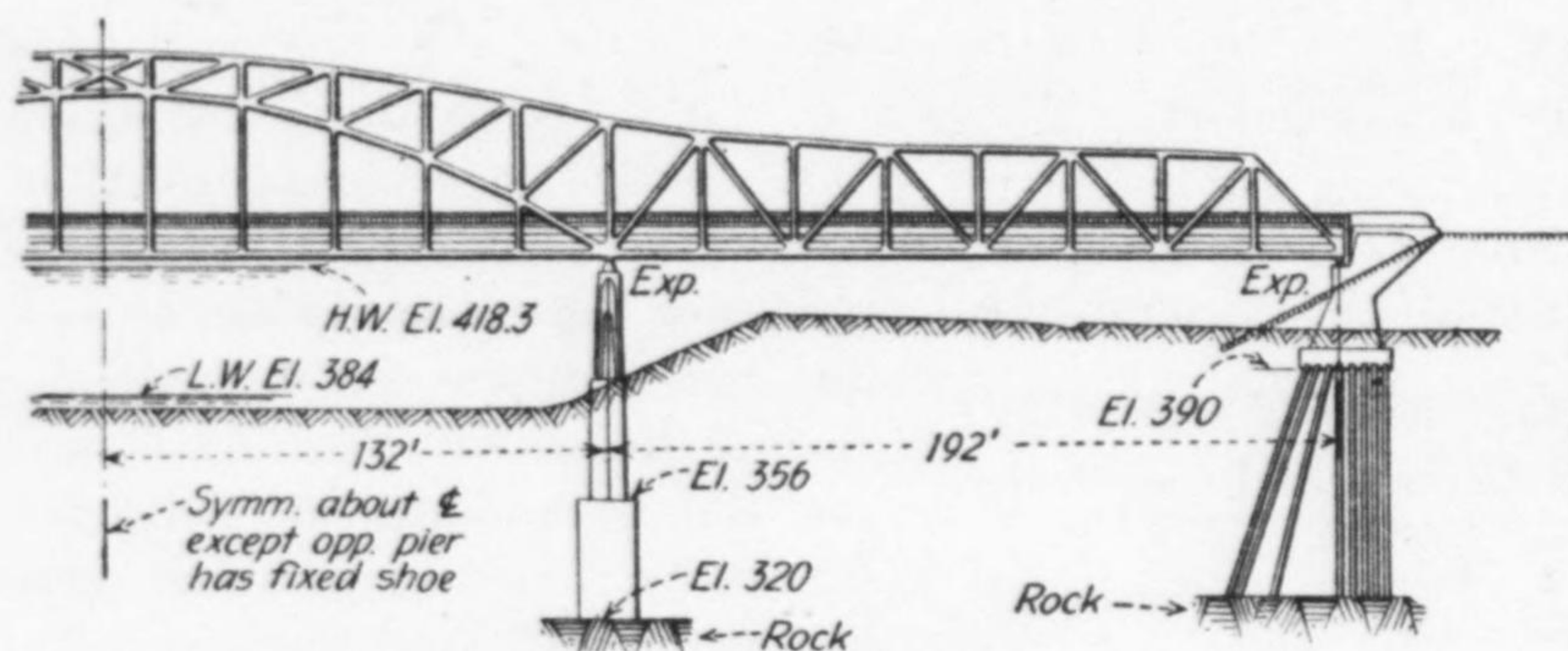
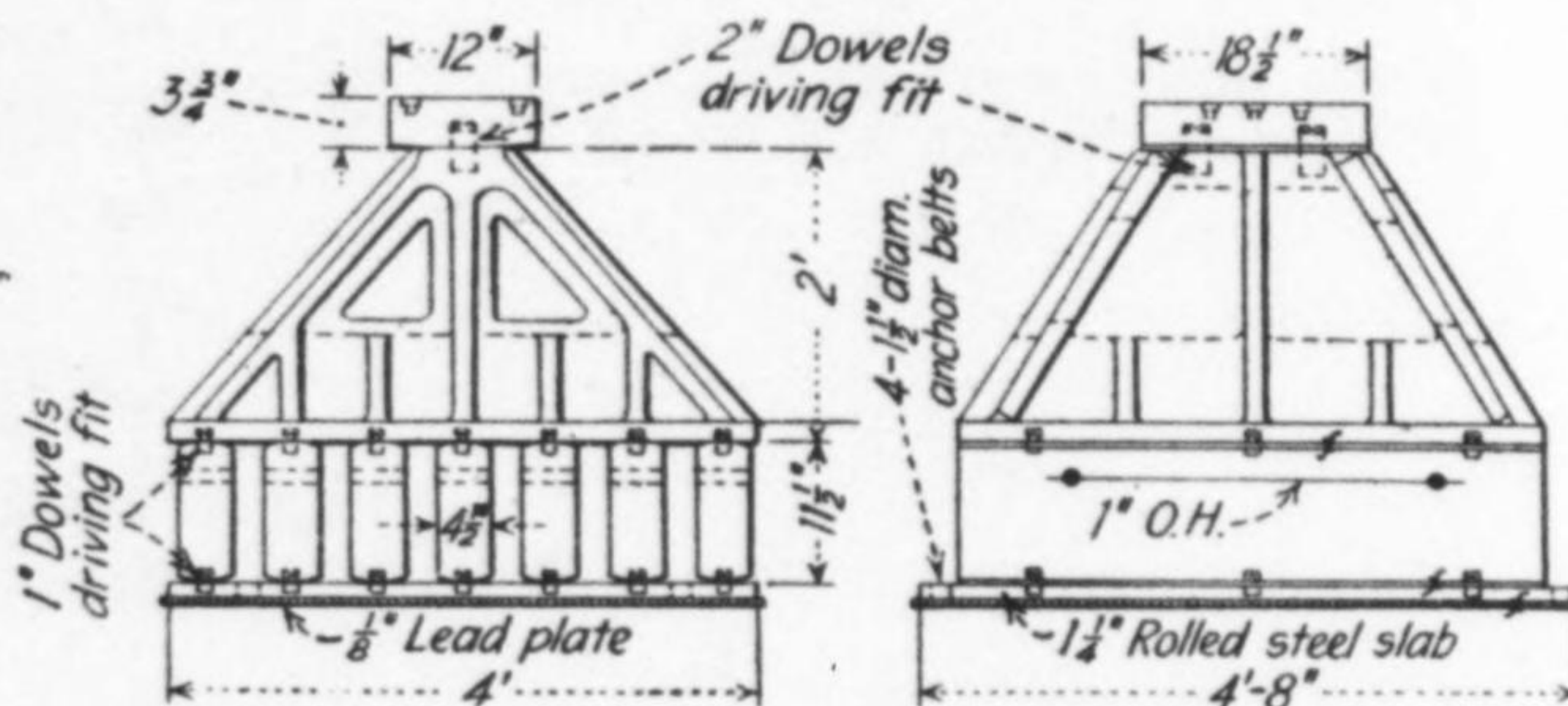


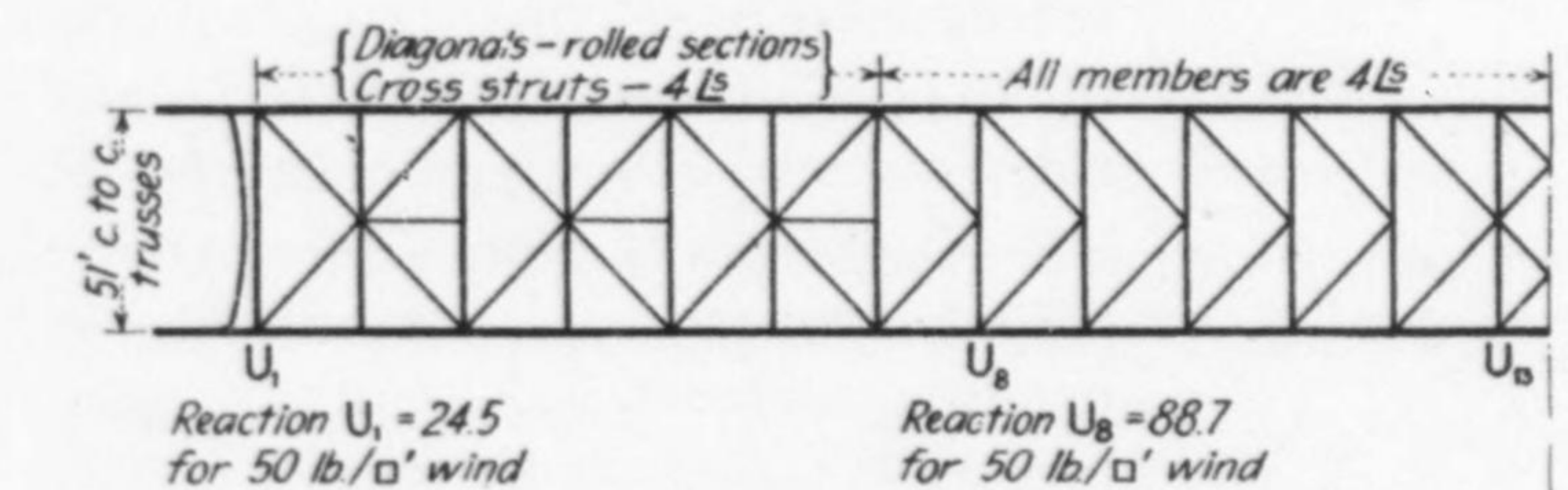
Fig. 4. Typical influence lines calculated from elastic weight loading of the structure shown in Fig. 3. Such influence lines were computed for each member in the bridge.



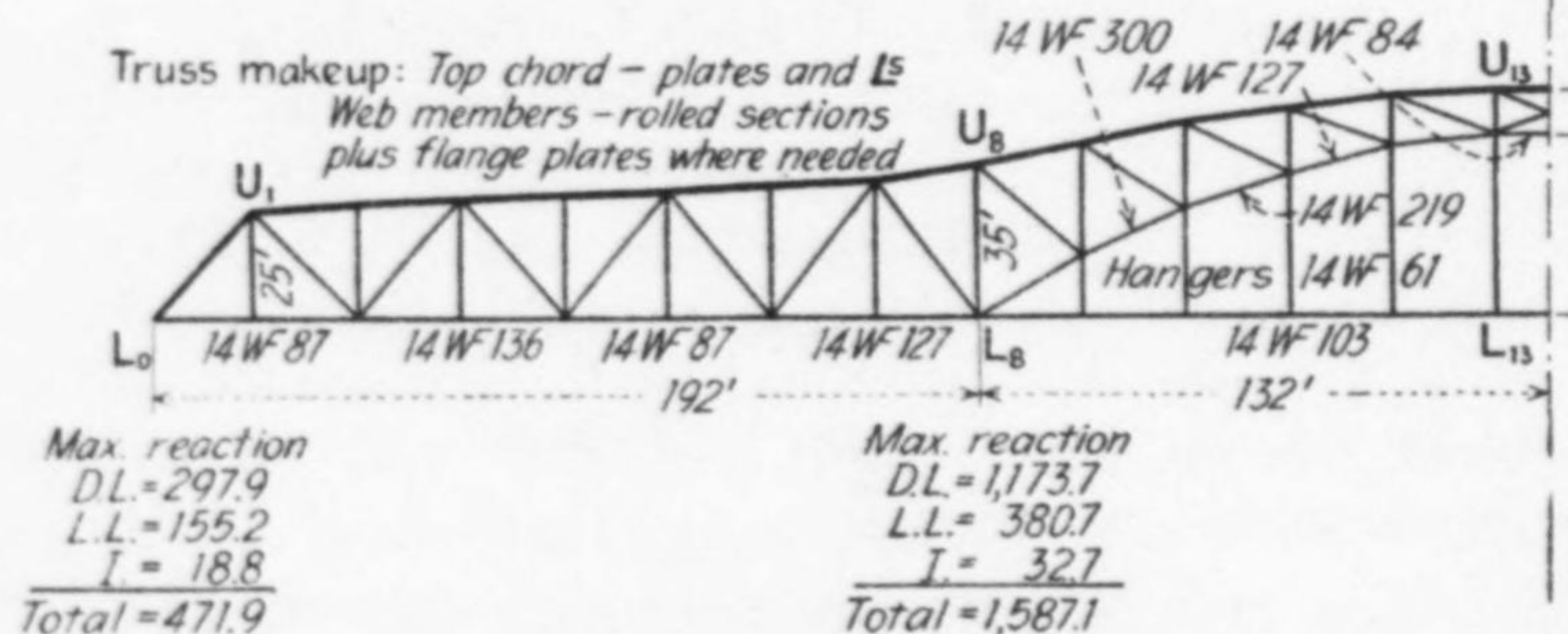
HALF GENERAL ELEVATION



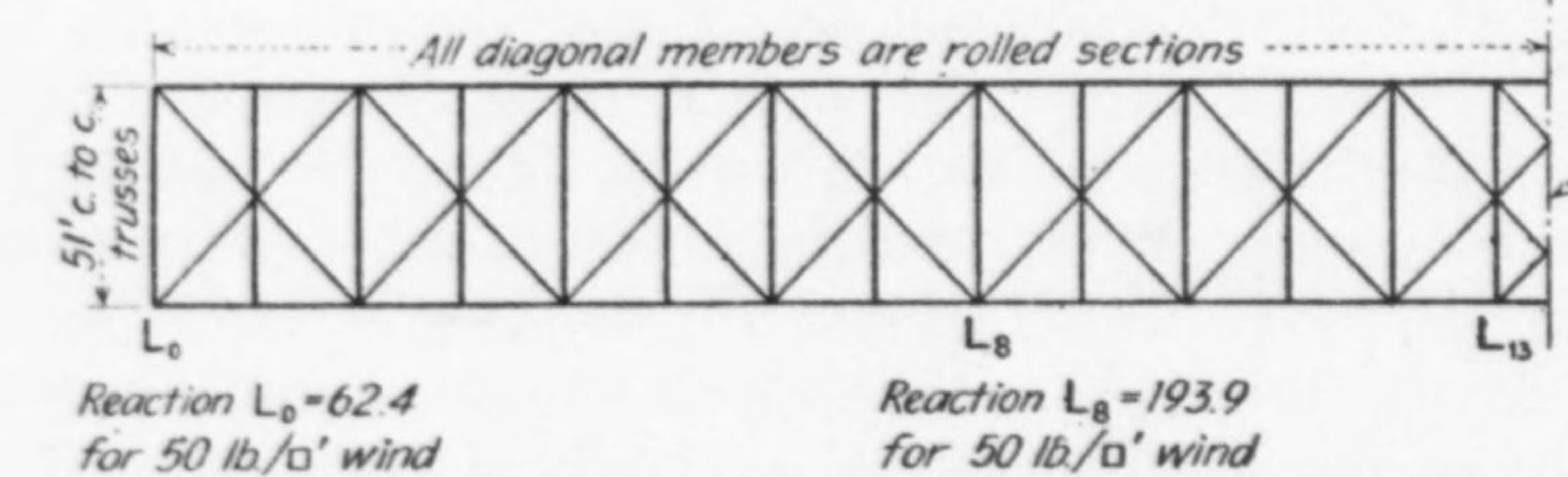
DETAILS OF EXPANSION SHOE



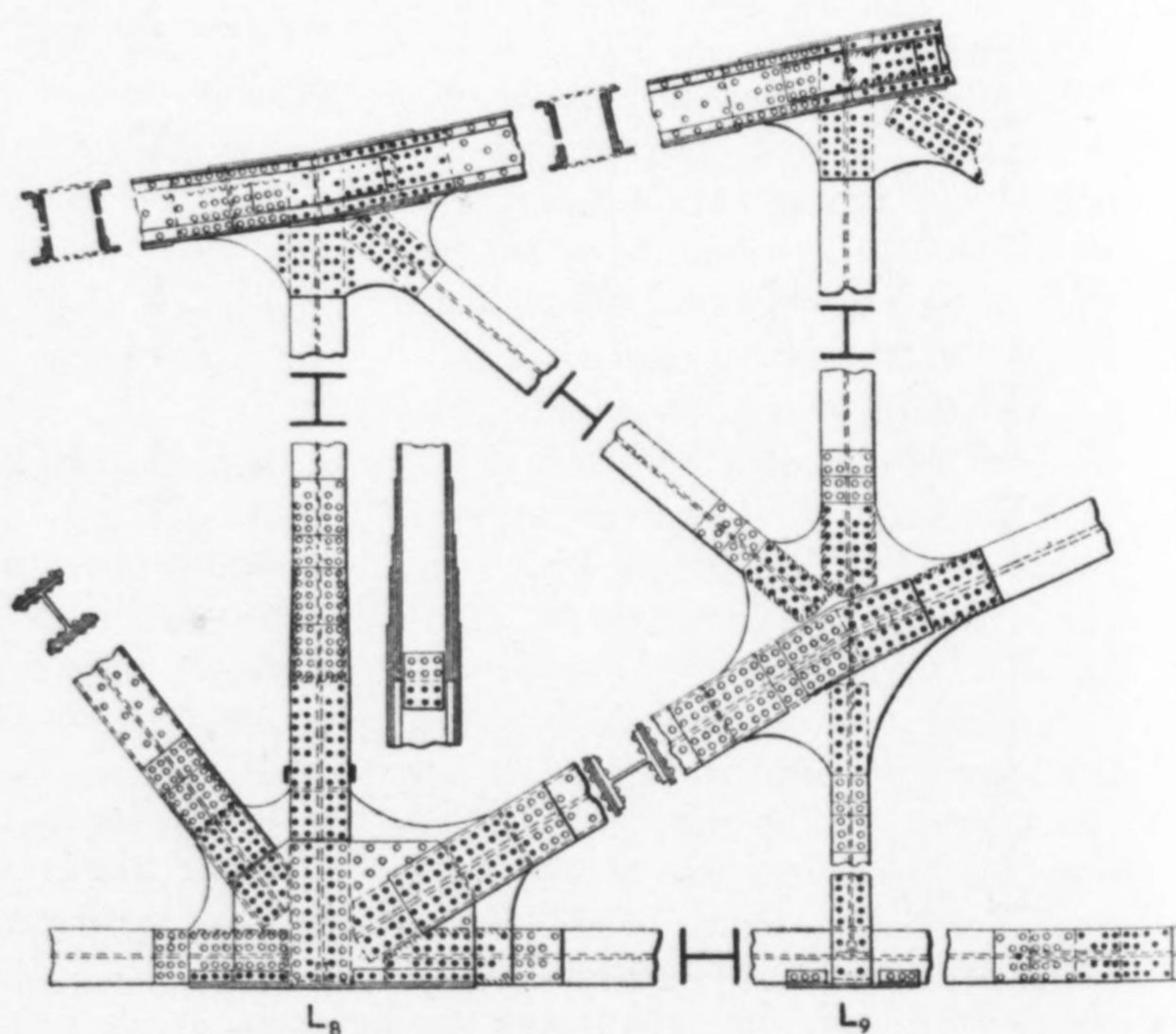
HALF PLAN OF UPPER LATERAL BRACING



HALF ELEVATION TRUSS



HALF PLAN OF LOWER LATERAL BRACING



TYPICAL TRUSS DETAILS

Fig. 5. Structural details of continuous tied arch bridge over Meramec River near St. Louis.

ered, but were found to cost more than the rolled sections which were also designed to support the lower arch chord laterally between the upper and lower lateral systems.

Lateral systems

Both the upper and lower lateral systems were also analyzed as three-span continuous systems. The lower lateral system is designed to take tension only, and the sections consist of wide-flange tees. For the arch span a *K* system of lateral bracing was used, consisting of four angles connected by tie-plates and lacing.

A rather shallow plate portal was used as it was felt that it would present a more pleasing appearance, when seen while approaching the bridge, than the conventional framed portal, Fig. 6.

The bridge was designed to have sway frames over the main piers only. However, sway frames were later placed at panel points U_4 , U_6 , U_{10} and U_{12} . No lateral bracing is used in the plane of the lower arch chord.

Cast steel bearings

The trusses are placed 51 ft. c.c. and have a maximum end reaction of 472 kips and a maximum reaction on the piers of 1,587 kips. The fixed shoe is placed on pier No. 1, and with this arrangement it was necessary to design one of the main pier shoes and both end shoes for expansion movement. All pins were eliminated and the truss bearing plate was curved to a 20 ft. radius and fastened to the flat surface of the cast steel shoes by 2-in.-dia. dowels. It is believed that this method is more economical and efficient than the method of using pins to connect the truss and shoes.

The main pier expansion shoe rests on seven structural steel rollers $11\frac{1}{2} \times 4\frac{1}{2}$ in. \times 4 ft. long which set on a rolled steel base plate. The castings were made up in cellular form, so as to reduce the bending stresses and to distribute the loading more uniformly on the concrete bearing surfaces.

Floor system

It was found that a 24-ft. panel length gave a minimum weight of metal in the floor system and that the weight of floorbeams was just equal to the weight of the stringers. Each dual concrete roadway is sup-



Fig. 6. Solid, shallow portal is a feature of the bridge. The center section dividing the roadway is covered with an open steel grid.

ported by five 21-in. wide flange sections, spaced 5 ft. on centers, which frame into the 5 ft. deep girder type floorbeams.

The connections of these floorbeams to the truss were milled to a bevel equal and opposite to the rotation caused by the dead load deflection, to eliminate the secondary bending in the truss verticals and arch hangers, which would otherwise be induced.

Superstructure erection

The side-span steel was erected complete on pile falsework by a crawler crane operating on the ground, Fig. 2. When the steel erection had reached the main piers, the crane was then used to erect a stiff-leg derrick over each main pier. Steel erection then proceeded by the cantilever method from each main pier. No falsework was used in the main span. To connect the bridge at the center a method involving the lowering of the ends of the side-span trusses was used. The end shoes were removed and the ends of the side-spans were lowered about $4\frac{1}{2}$ in. onto blocking, allowing the whole truss to rotate on the pier shoes. The remaining steel was then connected and the ends of the side spans were jacked up and the end shoes replaced.

Personnel

The bridge was built by the Missouri State Highway Department, of which C. W. Brown is chief engineer and N. R. Sack is bridge engineer. The design was prepared by the writer, assisted by Ray Adams on the substructure. J. J. Krebs was

resident engineer in direct charge of construction.

Massman Construction Co., Kansas City, Mo. was the general contractor. The steel was fabricated by Stupp Brothers Bridge and Iron Works. William O'Donnelly was foreman for the contractor on construction.

Snow Promises Water in Plenty for California

PERIODICAL STUDIES of snow conditions in the mountains by California Co-operative Snow Surveys indicate an ample supply of water this summer throughout the state. This is reported by the State Division of Water Resources, which predicted (as of April 1) that for streams heading in the Sierra Nevada the flow will be 20 percent above normal. The snow pack was only slightly above normal in the north, but increased rapidly toward the south and was very heavy in all areas east of the San Joaquin Valley, where it was 30 percent above the seasonal average.

For individual streams, the runoff is predicted to range from 83 percent of normal in the American River to 180 percent of normal in the Kern River. In the drainage areas tributary to the Shasta Reservoir, the snow pack was 7 to 19 ft. deep, with an equivalent content of 39 to 109 in. of water. Runoff figures compiled by the U. S. Geological Survey indicate that if Shasta Dam had been completed, the flow past its site since Oct. 1, 1940, would have more than filled the reservoir to its capacity.