# Field Tests on a Prestressed Concrete Multi-Beam Bridge[1]

A. Roesli
A. Smislova
C. E. Ekberg, Jr. and
W. J. Eney
*Fritz Engineering Laboratory, Department of Civil Engineering, Lehigh University, Bethlehem, Pennsylvania*

This report describes a bridge test carried out by the concrete research group of Fritz Engineering Laboratory, Department of Civil Engineering at Lehigh University. It is part of a sponsored research program on prestressed concrete which has been carried on at the University since 1951.

The tested highway bridge with a clear span of 32 feet and a width of 27 feet is composed of 9 prefabricated, pretensioned concrete beams. Placed side by side, the beams are connected together by a steel bolt at midspan and have dry-packed continuous shear keys. The bridge was tested in the field under static and dynamic loading.

The purpose of these tests was to check the design criteria with special emphasis to determine the portion of the live load to be carried by each beam.

It was found that the bridge, designed under the assumption that each beam is to carry 80 percent of the right or left wheel loads of an H20-S16 truck, was very stiff. This is mainly due to an effective interaction of the beams which results in a bridge behavior approaching that of a plate.

The distribution of the live load was found to be very favorable. For a truck in the center lane, the middle beam carried approximately 34 percent of the right or left wheel loads. For a truck in the edge lane, the edge beam carried approximately 46 percent of the right or left wheel loads.

The action of the bridge due to a truck moving at 25 mph over the bridge was investigated. In the first series of tests, where the truck travelled in the center lane without any obstacles in its path, the maximum deflection was 114 percent of the corresponding static deflection. With the truck in the edge lane, the maximum deflection was 123 percent of the corresponding static deflection. In the second series of tests, where the truck travelled in the center lane with a 2-inch plank in its path, the maximum deflection was 156 percent of the corresponding static deflection. With the truck in the edge lane and travelling over the 2-inch plank, the maximum deflection was 300 percent of the static deflection.

## INTRODUCTION

● THE bridge test described in this report is a part of an extensive research program on structural members of prestressed concrete carried on at Lehigh University. The general purpose of this research program is to (1) check the validity of the design assumptions of structural members, (2) determine the effect of static and repeated loads, and (3) to furnish

[1] This work has been carried out as part of an investigation sponsored by the following: American Steel & Wire Div., U. S. Steel Corp.; Concrete Products Company of America; Lehigh University; Pennsylvania State Highway Department; Reinforced Concrete Research Council; John A. Roebling's Sons Corporation; U. S. Bureau of Public Roads.

data that may aid in the preparation of design specifications with the ultimate aim of contributing to the progress of prestressed concrete.

Two previous major reports (*1*, *2*) presented the study of the endurance tests of two full-scale bridge members. The important problem of the bonding characteristics of prestressing strands has been and is still being investigated as part of the program. As a sequel to the study of the performance of such individual bridge members, the testing of bridges composed of such members is a logical extension of this research program.

In such bridges, the main problem to be investigated is the interaction of the beams and the determination of the portion of the total live load each beam must carry. This investigation has been divided into three phases; theoretical studies (*3*), field tests on actual bridges, and laboratory tests on a small bridge. The tests described in this report cover the first of the field tests planned for the near future.

*Description of the Test Bridge*

The test bridge is shown in Figures 1, 2, and 3. It is located at the west end of the town of Centerport in Berks County, Pennsylvania on Route 06019, Station 354+58 and spans the Centerport Creek. The bridge beams were manufactured in November 1951 by the Concrete Products Company of America at their Pottstown plant and erection took place in December 1952. The bridge has a span of 33′6″ between centers of supports, a clear span of 32′ and a nominal roadway width of 25′4″. An 8-inch curb is provided on each side of the roadway. A 2-inch layer of bituminous material forms the wearing surface. The bridge is composed of nine prefabricated, pretensioned beams of the type previously tested at Lehigh University and described in Progress Report No. 5 (*1*).

The bridge was erected by placing the beams side by side on the abutments using a large truck crane. The beams had two vertical 2½-inch diameter holes cast in each end and these were used to align a star drill to make corresponding holes in the abutments. Finally, anchor bolts of ¾-inch diameter and 26-inch length were inserted and grouted to tie down all beams to the abutments. Steel guard rails were bolted to the outside of the curb beams.

The mortar used for the shear keys is com-

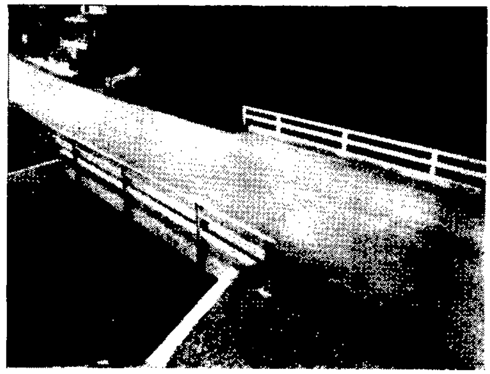


**Figure 1. General view of the test bridge.**

posed of two portions of sand, one portion of cement, and one portion of "Groutex." This latter material was added to the mortar to minimize its shrinking thus preventing cracking between the old concrete of the beams and the new mortar. The amount of water generally added is enough to make the mortar stick together when pressed between the palms of the hands. The mixture thus produced is then rammed into the shear keys with tamping rods.

Each beam is 36 inches wide, 21 inches deep, and has an overall length of 35 feet, 6 inches (Figure 4). The cross-section is rectangular except for the keyways on the sides of the beams near the top and the two hollow circular cores 12½-inch diameter in the center of the cross-section. Used to reduce the dead weight, these hollow cores extend the total length of the beam except for a 2-foot solid section at each end and a 10-inch solid section

**Figure 2. Side view of the bridge.**

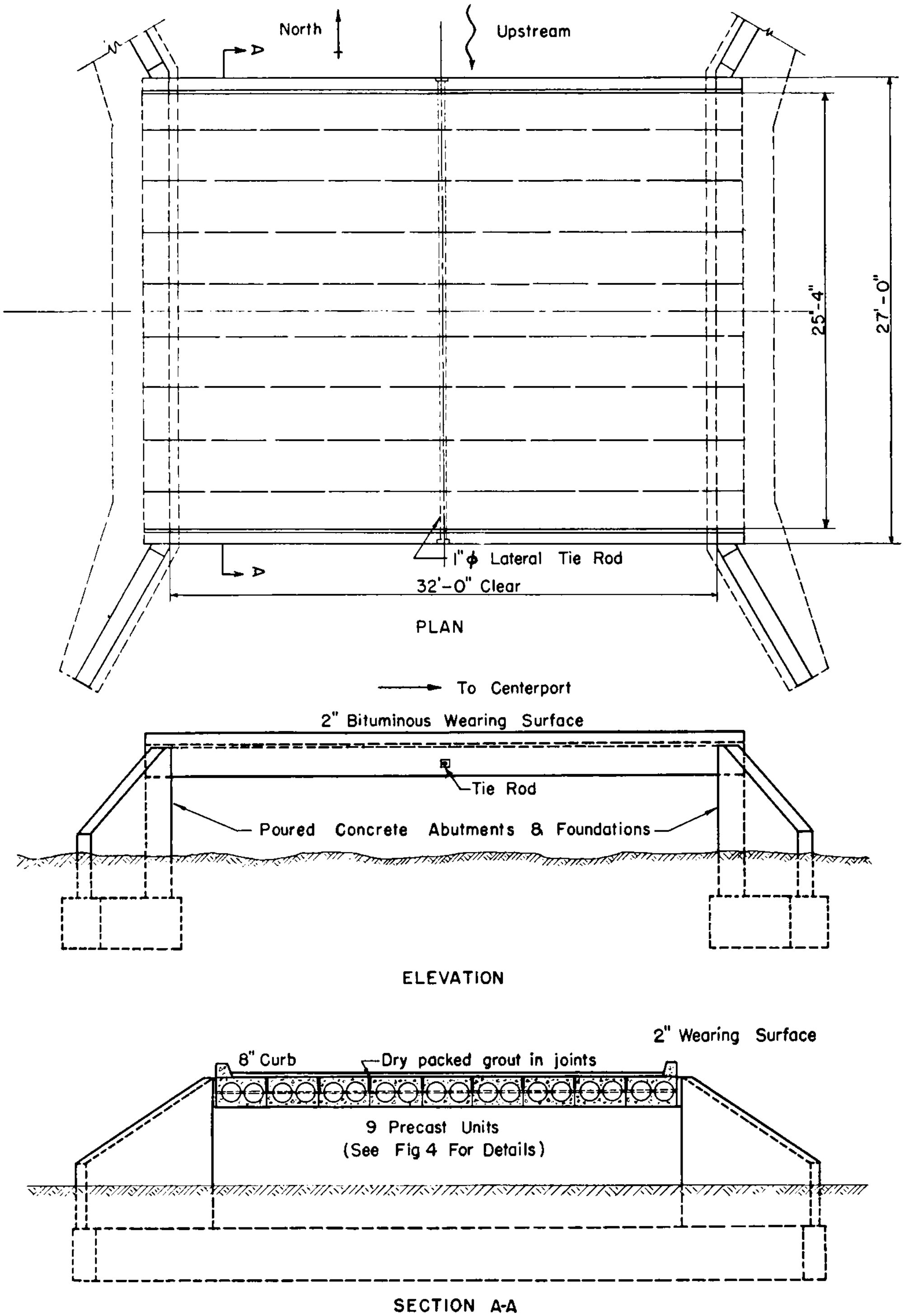
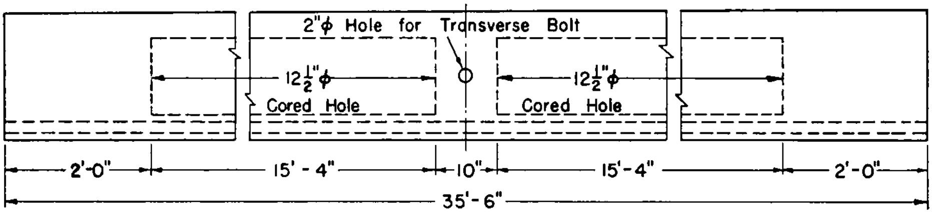
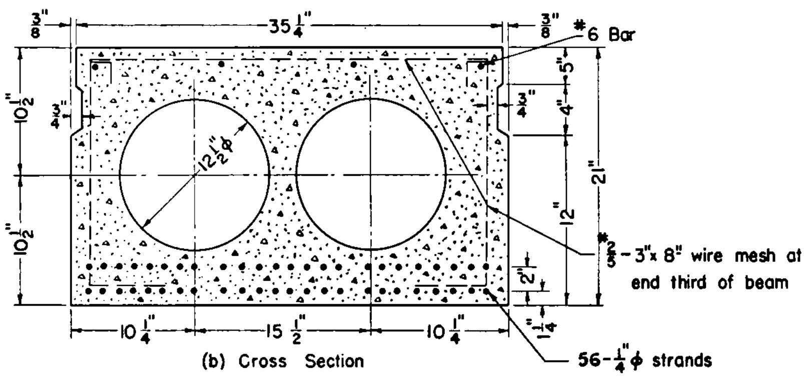



Figure 3. General arrangement of bridge.




(a) Side View




(b) Cross Section

**Figure 4. Details of beams.**

at the center of the span where the lateral tie rod goes through the beam. The 8-inch curb was poured after the release of the prestress in the edge beam proper and anchored to it by means of hooked dowels placed for this purpose.

*Design of the Beams*

The beams were designed according to the AASHO 1949 Specifications and the "Specifications for Prestressed Precase Reinforced Concrete Bridge Deck" dated May 1, 1952, and prepared by the Pennsylvania Department of Highways. The design live load was a H20-S16-44 standard truck, having a minimum rear axle spacing of 14 feet. The values for static loading were increased by 30 percent to take the effect of impact into consideration. It was assumed that each beam carried ⅘ of a wheel load with the remaining ⅕ distributed among the adjacent beams. Each beam was prestressed by 56 high-tensile wire strands (manufactured by American Steel & Wire Co.) with a nominal diameter of ¼ inch. The total area of the strands was 1.97 square inches and their location is shown in Figure 4. Initially the strands were prestressed to 135,000 psi. A loss of 20 percent of the steel prestress was assumed for shrinkage, plastic flow, elastic shortening, and creep. Four No. 5 reinforcing rods were placed longitudinally near the top of each beam and supported vertical stirrups and a wire mesh.

The contractor reported that a cylinder strength of 3300 psi at release of the prestress and a minimum of 5000 psi at 28 days was required. There are no records substantiating this data.

## TEST PROGRAM AND PROCEDURE

*Test Program*

The program included principally static and dynamic tests. All testing was carried out during the week of July 19, 1954.

*Static Tests.* The purpose of the static tests was to determine the percentage of live load carried by each beam of the bridge. This was accomplished by measuring the deformed shape of the bridge loaded with two different types of trucks to be described later. The loading of the bridge was performed by positioning these trucks successively at the quarter-point and midspan in both the edge and center traffic lanes. These positions are

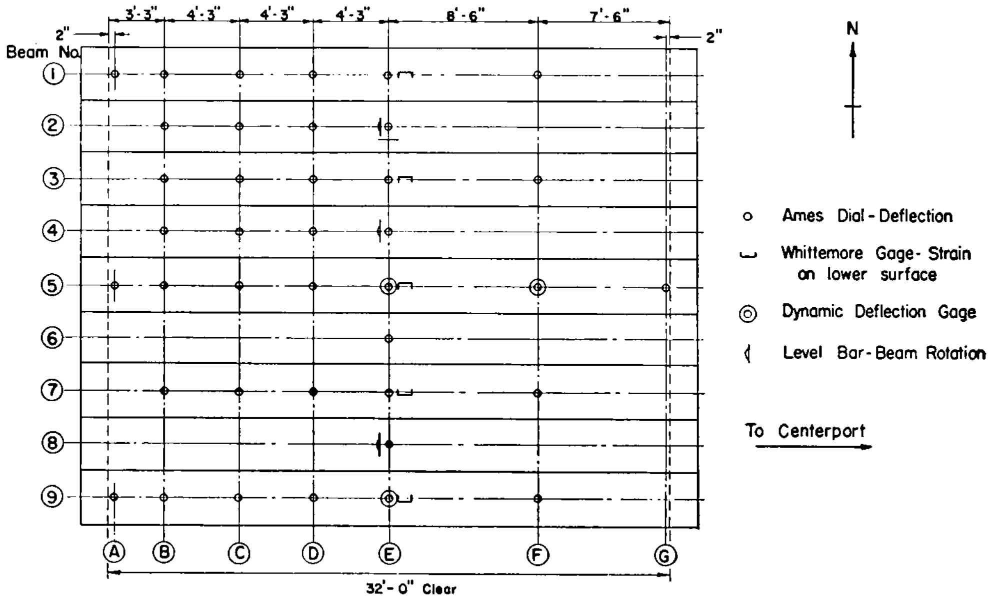



**Figure 5. Instrumentation.**

given in the several figures showing the deflection surfaces (See Figures 14 to 25).

*Dynamic Tests.* These tests were intended to provide some information regarding the general behavior of the bridge under dynamic loading. No attempt was made to study the lateral load distribution under this type of loading. The deflection at three critical points on the bridge was observed while a truck was driven over it at a speed of 25 mph. A 2-inch plank was later placed across the bridge at midspan along the path of the truck.

*Test Procedure*

*Instrumentation.* The instrumentation is shown in Figure 5 and consisted of deflection gages, level bars, a Whittemore gage, and electronic equipment to record the deflections under dynamic loading.

Deflection gages: 39 Ames Dial deflection gages, least count ranging from $1/1000$ inch to $1/10{,}000$ inch, were located as shown in Figure 5. These gages were placed in such a manner that emphasis was given to the deflection of

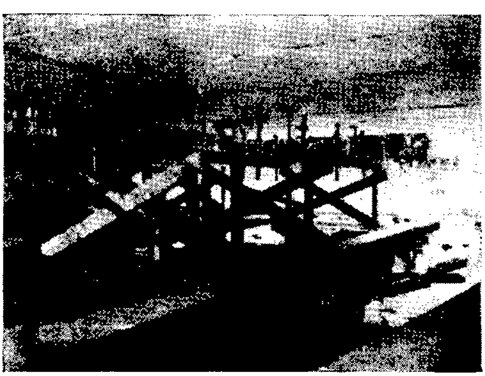


**Figure 6. General view of the test installation.**

**Figure 7. Detail of the installation. (From left to right: Whittemore gage for strain measurements; Ames gage for the deflection; dynamic gage.)**

each beam at midspan and to the accurate determination of the deformed shape of the northwest quadrant of the bridge. The remaining gages were used to check the symmetrical behavior of the bridge. A simple timber scaffolding, shown in Figure 6, was erected to provide the supporting structure for the gages and was completely independent of the bridge.

Level bars: The transverse rotation of three different beams at midspan was independently measured by means of level bars. A level bar consists of a 20-inch aluminum bar having a sensitive level-bubble rigidly attached and is provided with a simple pin support at one end, and a micrometer screw-support at the other.

Whittemore gage: Strain readings were taken at midspan of several beams. Due principally to the small change in readings upon application of the load and the large influence of the temperature, these strains were too inconsistent to be of any use.

Dynamic deflection gages: One of the three dynamic deflection gages used in these field tests is shown in Figure 7. It consists of a small cantilever beam fixed to a base plate which was mounted on the timber scaffolding. A short vertical rod was connected to the free end of the cantilever and made contact with the concrete beam in such a way that the cantilever deflected with the beam. Two SR-4 strain gages mounted on the top and the bottom of the cantilever provided the means of measuring its deformation which was in proportion to the deflection of the beam determined by laboratory calibration. Figure 8 shows a two-channel Brush-recorder which registered the readings.

*Loading.* Two trucks, shown in Figures 9, 10, 11 and 12, were used to apply the live

**Figure 8. Brush equipment for the dynamic test.**

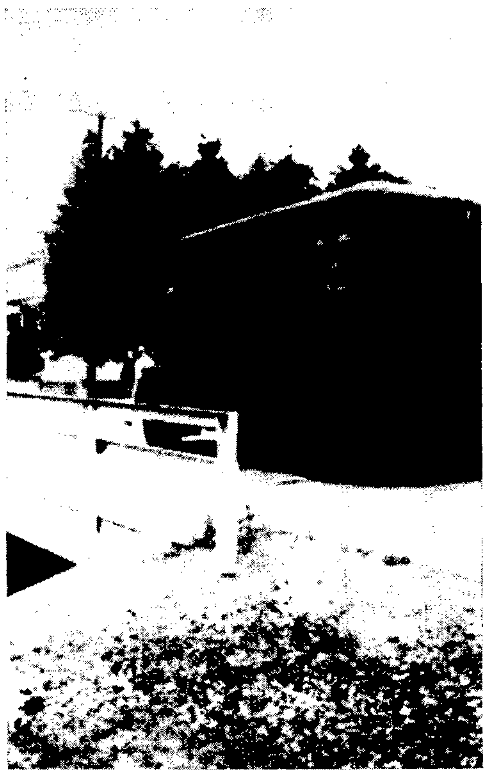


**Figure 9. Scale truck (total weight 37,600 pounds).**

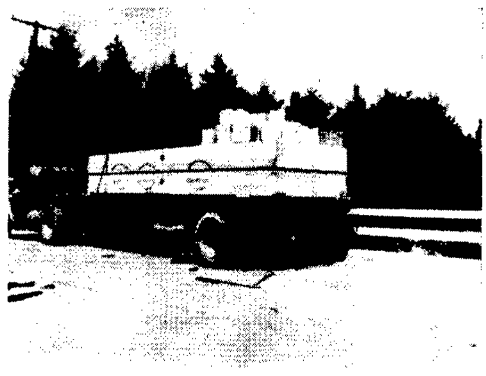


**Figure 10. Tractor trailer truck loaded with bridge members and movable weight from scale truck; total weight of rear axle 47,700 pounds.**

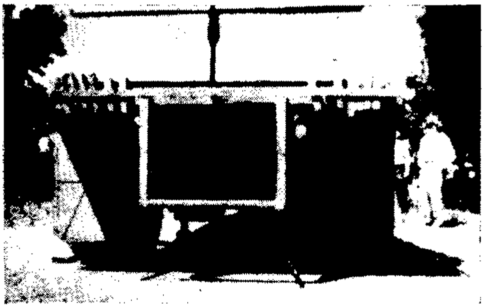


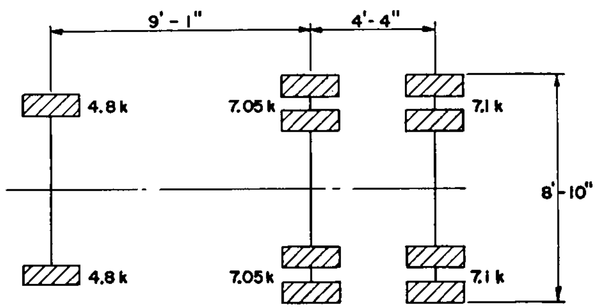
Figure 11. Tractor trailer truck jacked up to transfer load of 47,700 pounds on single beam of bridge.

loads on the bridge. The scale truck was used for static tests only, whereas the tractor trailer truck was used for both static and dynamic testing.

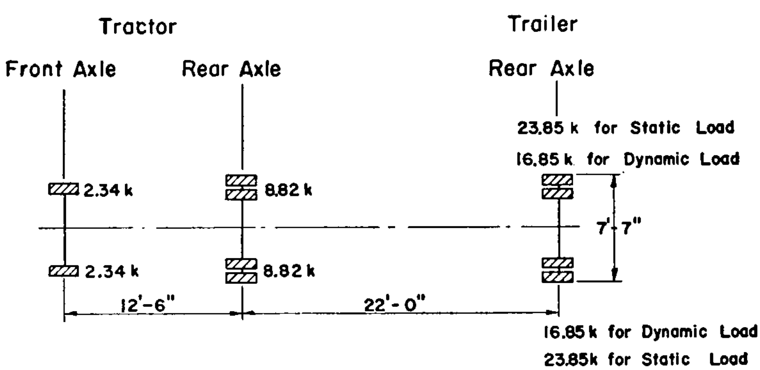
Scale truck: The total weight of this three-axle truck is 37,900 pounds, including 17,250 pounds made up of removable weights. The wheel locations of the truck are shown in Figure 12(*a*).

Tractor trailer truck: This truck carried a 47,700-pound rear axle load for static testing (Figure 10), and a 33,700-pound rear axle load for the dynamic tests. The weight changes were made possible in the field by a small truck crane. The pertinent axle dimensions and weights are shown in Figure 12(*b*).

In all static tests except where the tractor




(a) Scale Truck




(b) Tractor-Trailer Truck

Figure 12. Dimensions and axle loads of truck.

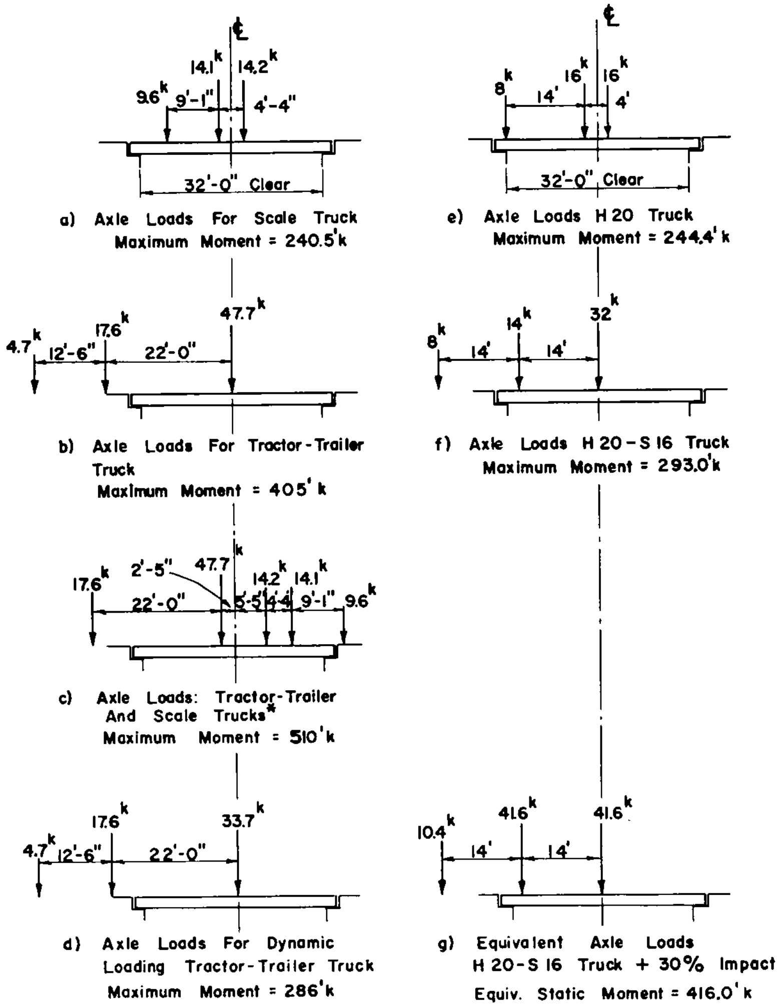



**Figure 13.** Standard H20 and H20-S16 lane loadings compared with lane loadings for test trucks. (See also Figure 24.)

trailer truck was used with the scale truck, the rear axle loading was applied to the bridge by a pair of jacks. For the center lane position it was possible to concentrate 47,700 pounds on the middle beam as shown in Figure 11. For edge lane positions, the jack reactions were taken by the second and third beams from the outside.

Comparison of trucks with standard AASHO loading: Figure 13 shows how the test loading compared with the AASHO loading on which the design of the bridge was based.

## TEST RESULTS

### *Static Tests*

*Deflections.* As the bridge tests were carried out on warm summer days, the variation in temperature during the day affected the readings extensively. To minimize these effects, frequent zero readings were taken with no load on the bridge and the intermediate readings were corrected, assuming a linear variation of the temperature change between two consecutive zero readings.

It was stated earlier that vertical deflections

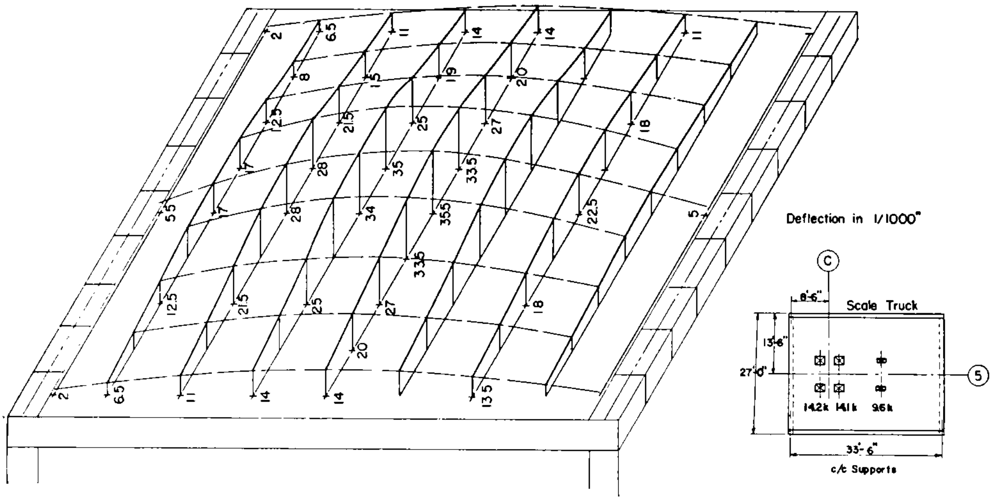



Figure 14. Deflection values for load position with the scale truck in the center lane, and the resultant of the rear axles at the quarter-point.

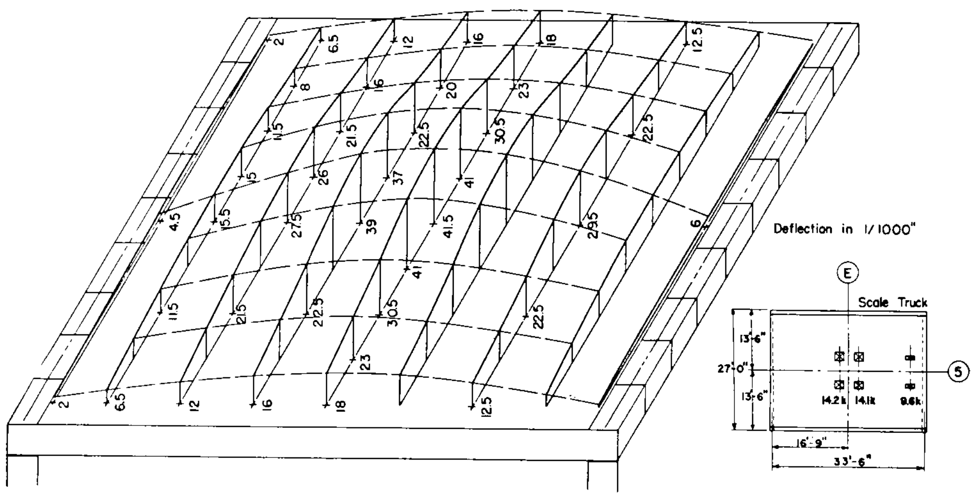



Figure 15. Deflection values for load position with the scale truck in the center lane, and the resultant of the rear axles at midspan.

were measured at close intervals in the northwest quadrant of the bridge and that control gages were placed only at critical points in the other quadrants. By placing the truck loads at points symmetrical to each other with respect to the bridge axis and utilizing the relation existing between symmetrical and reciprocal deflections, the deformed shape of the complete bridge deck was obtained. The symmetrical deflections were checked with the control gages, and were found to be close to the values of their symmetrically opposite points. To reduce the magnitude of the deviation between readings, average deflections were calculated for the different symmetrical loading positions. The resulting deflections are plotted in Figures 14 to 25 which show the deformed shape of the bridge in isometric views. Positive deflections are plotted upwards and their magnitudes are shown at the gage points in thousandths of an inch. In the right-hand corner, a plan view indicates the type and the location

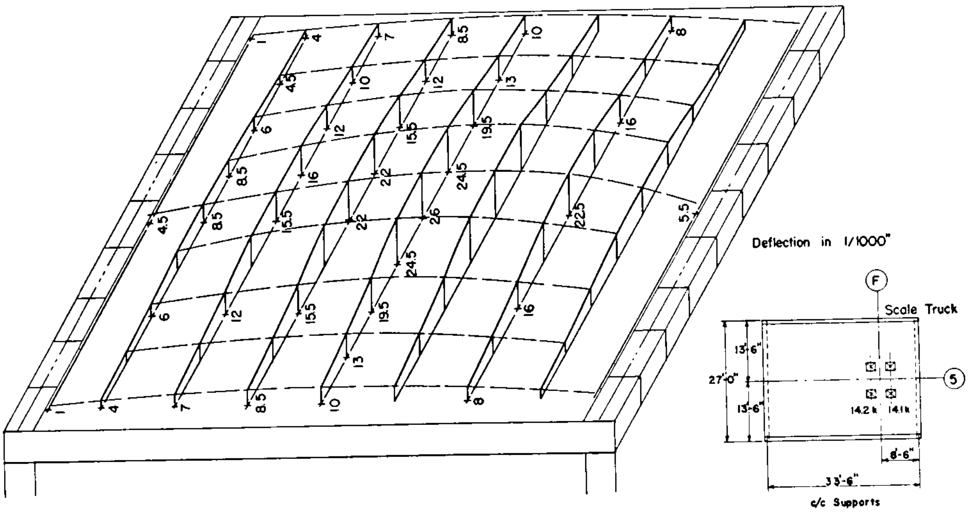



**Figure 16. Deflection values for load position with the scale truck in center lane, and the resultant of the rear axles at the three quarter points. The front axle is off the bridge.**

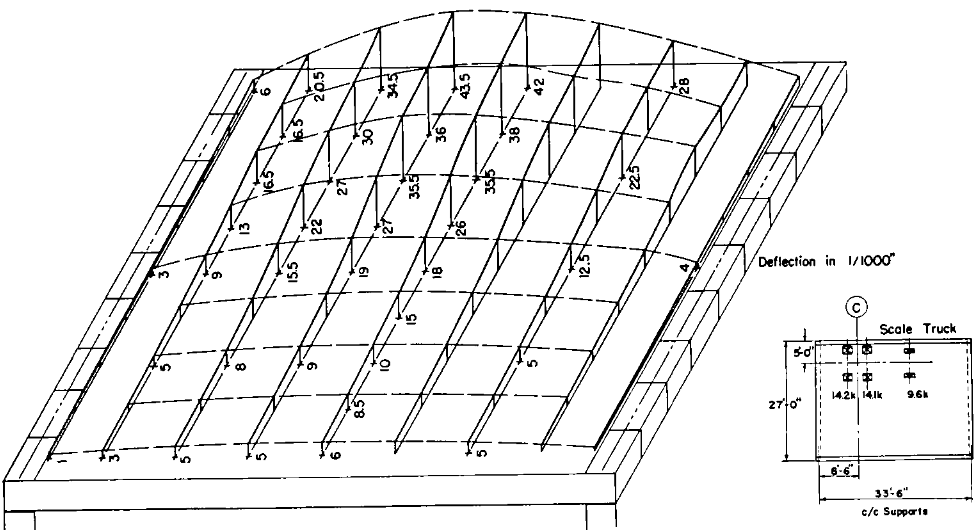



**Figure 17. Deflection values for load position with the scale truck in the edge lane, and the resultant of the rear axles at the quarter points.**

of the loading. The deformed shape of the bridge deck is described in each of the figure legends.

From a study of these figures, one notices that the largest measured deflection is 0.087 inch which was observed at midspan of the upstream edge beam under a loading of the tractor trailer truck and the scale truck placed back to back at midspan of the edge lane (Figure 25). This deflection produced by a bending moment of 148 percent of the design moment (without impact) represents $\frac{1}{4690}$ of the bridge span.

A deflection of 0.071 inch was observed in the middle beam when the rear axle of the tractor trailer truck was placed at midspan and jacked up over the center lane (Figure 21). This deflection caused by a bending moment of

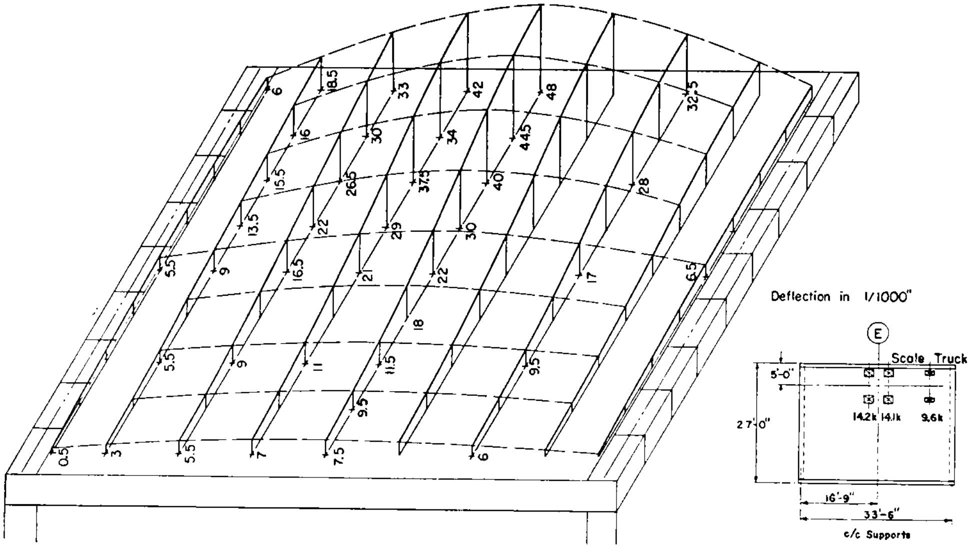



**Figure 18. Deflection values for load position with the scale truck in the edge lane, and the resultant of the rear axles at midspan.**

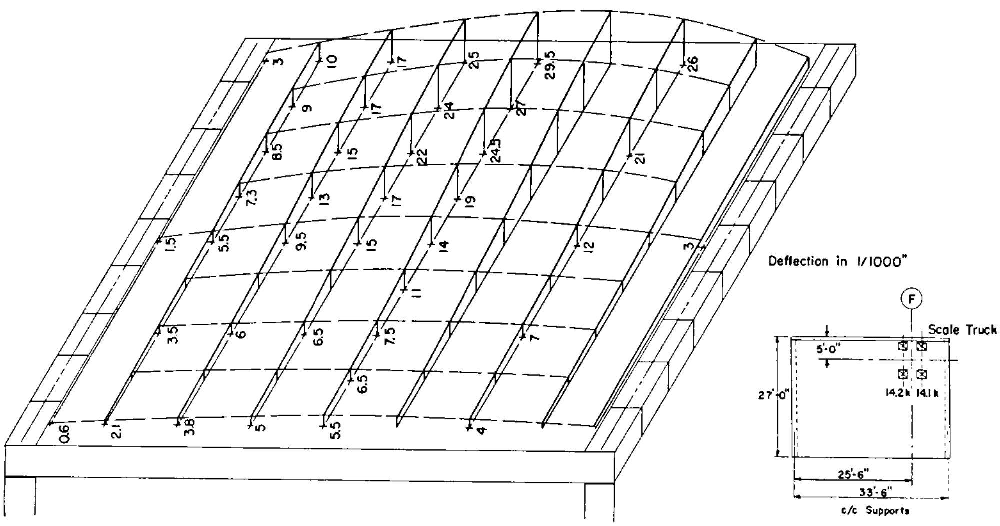



**Figure 19. Deflection values for load position with the scale truck in the edge lane, and the resultant of the rear axle at the three quarter points. The front axle is off the bridge.**

118 percent of the design moment without impact is $1/5710$ of the bridge span. These deflection-span ratios clearly indicate that the bridge is very stiff.

*Level Bar Readings.* In Figure 26 the measured transverse rotations are plotted for two of the most severe loading conditions that were imposed. These rotations are plotted to proper scale so that comparisons can be made with the tangents to the transverse elastic curves. The close correlation between the tangents to the elastic curves and the measured beam rotations suggest that there was very little, if any, relative slip between adjacent beams.

*Cracking.* Inspection by naked eye of the bridge prior to the test revealed the absence of

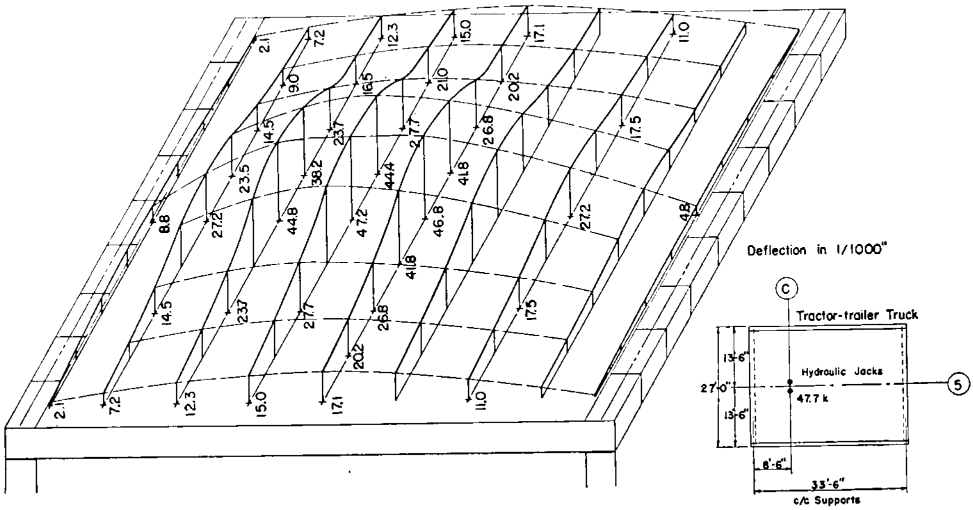



**Figure 20. Deflection values for load position with the rear axle of the tractor trailer truck jacked up at the quarter point in the center lane concentraitng the axle load on the center beam.**

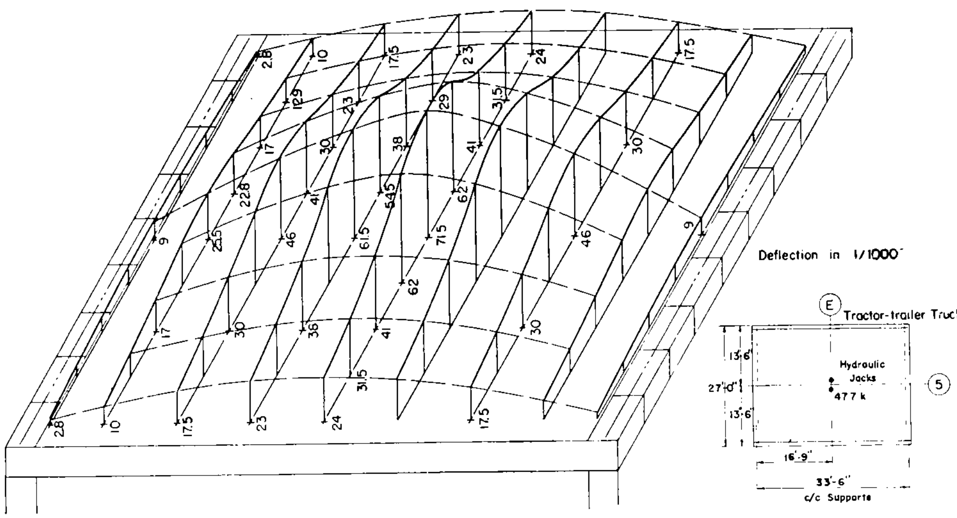



**Figure 21. Deflection values for load position with the rear axle of the tractor trailer truck jacked up at mid-span in the center lane, concentrating the axle load on the center beam.**

shrinkage or any other cracks. To aid in detecting the formation of cracks as a result of superimposed loads the underside of the test bridge was whitewashed. However, no cracking was noticed under the action of any of the applied loads. The type of construction of the bridge did not permit the inspection of shear keys to determine if they were affected.

*Lateral Load Distribution.* The lateral load distribution coefficients were simply based on the deflection ratios for the various transverse gage lines. It is realized that the exact coefficients can be obtained only by considering the bending moments produced in each beam; however the values obtained are perhaps accurate enough for all practical purposes.

Figure 27 shows the lateral load distribution curve obtained from the deflections for any longitudinal truck position when in the center lane. The cross-section of the bridge and the

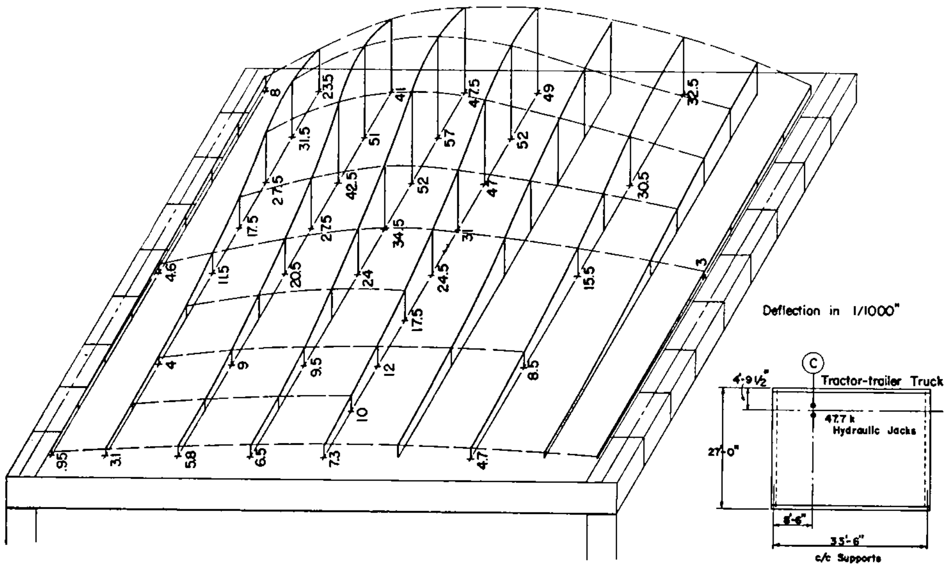



**Figure 22. Deflection values for load position with the rear axle of the tractor trailer truck jacked up at the quarter point in the edge lane.**

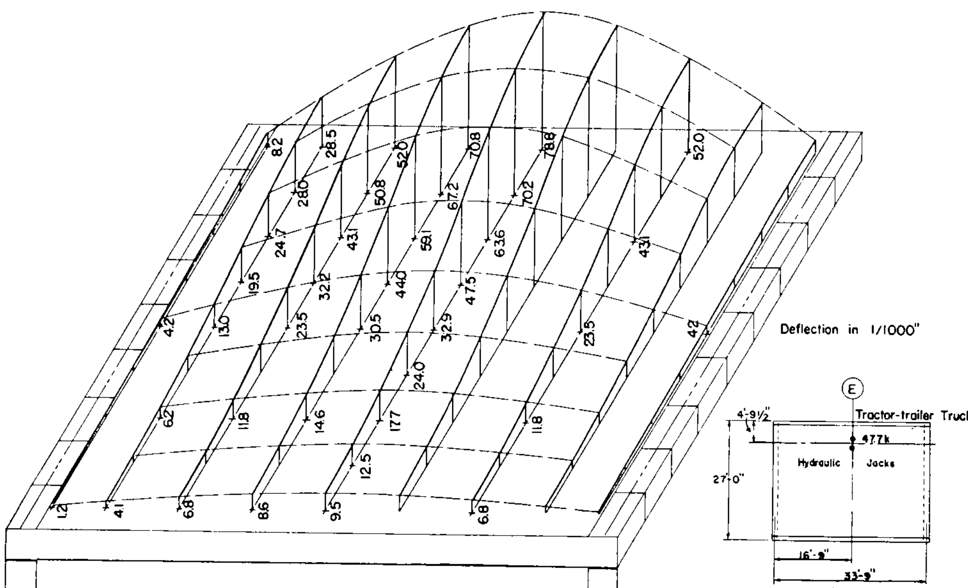



**Figure 23. Deflection values for load position with the rear axle of the tractor trailer truck jacked up at mid-span of the edge lane.**

lateral loading position are schematically indicated at the top of the graph. The position of the gage lines are marked and numbered from 1 to 9 on the abscissa. The ordinate scale denotes the percentage of the total applied load that is carried by each beam. The three curves designated by solid lines give values obtained from deflection measurements involving only the scale truck and the combination of both trucks back to back in the

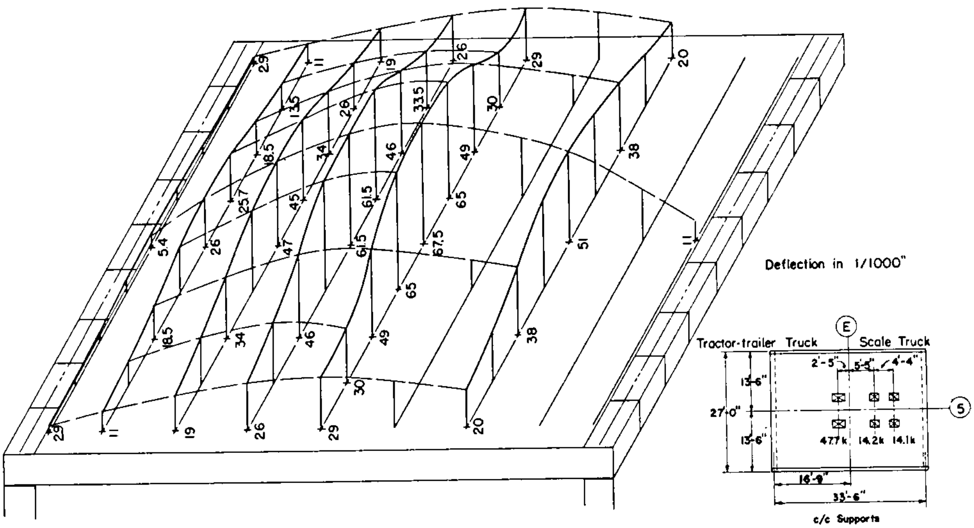



**Figure 24. Deflection values for load position with the tractor trailer truck and the scale truck back to back in the center lane at midspan.**

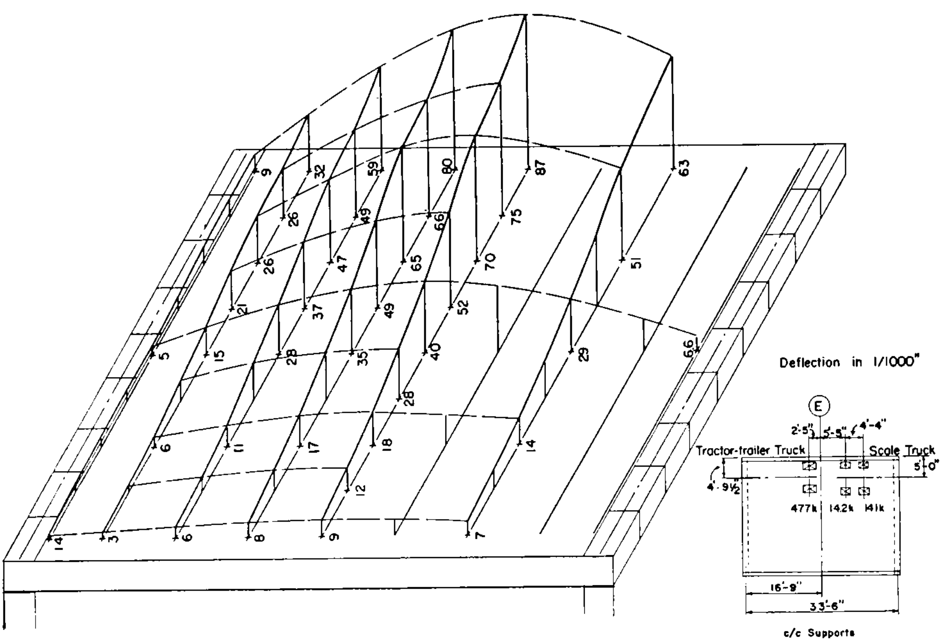



**Figure 25. Deflection values for load position with the tractor trailer truck and the scale truck back to back in the edge lane at midspan.**

center lane. The upper and lower curves designated by solid lines give maximum and minimum values, and the broken line that is connected to the maximum value curve gives values obtained by jacking the rear axle of the tractor trailer truck against the middle beam. The heavy solid line represents the average values obtained from scale truck and combination of both trucks; and the broken line connected to this curve repre-

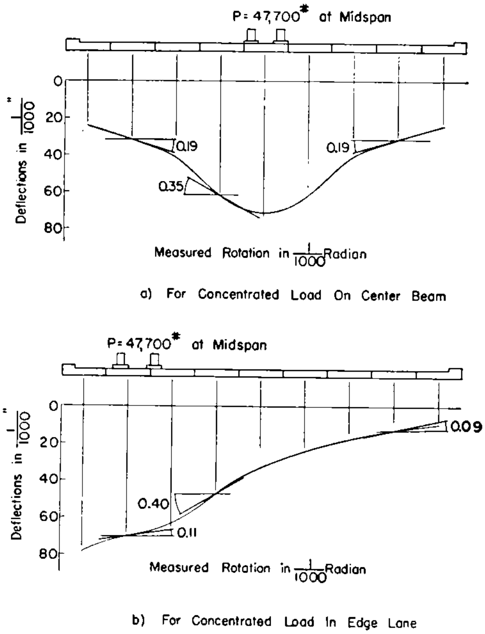



**Figure 26. Deflections and torsional rotations of beams at midspan.**

sents average values, taking into account the effect of concentrated load from the jacks applied to the tractor trailer truck.

The curves of Figure 27 show that for a truck in the center lane the load carried by the middle beam should not exceed 20.5 percent of an axle load even if the wheels were so close together as to be concentrated directly over the beam. Thus, for example, if a truck with 10-kip axle loads were positioned with one axle at midspan and the other at quarterpoint, the loads carried by the middle beam should not exceed 2.05 kips at quarterpoint and 2.05 kips at midspan.

Figure 28 shows the distribution factors for loading positions in the edge lane. As can be expected, the edge beam carries in the case of axle loadings the largest percentage of load—namely, 20.6 percent on the average and 22.6 percent as a maximum. For the axle loading jacked up and concentrated over the second and third beam, the portion of the load supported by the second beam reaches a maximum value of 23.9 percent.

It should be mentioned that for loads applied at the quarterpoints the observed load distributions are generally less effective than

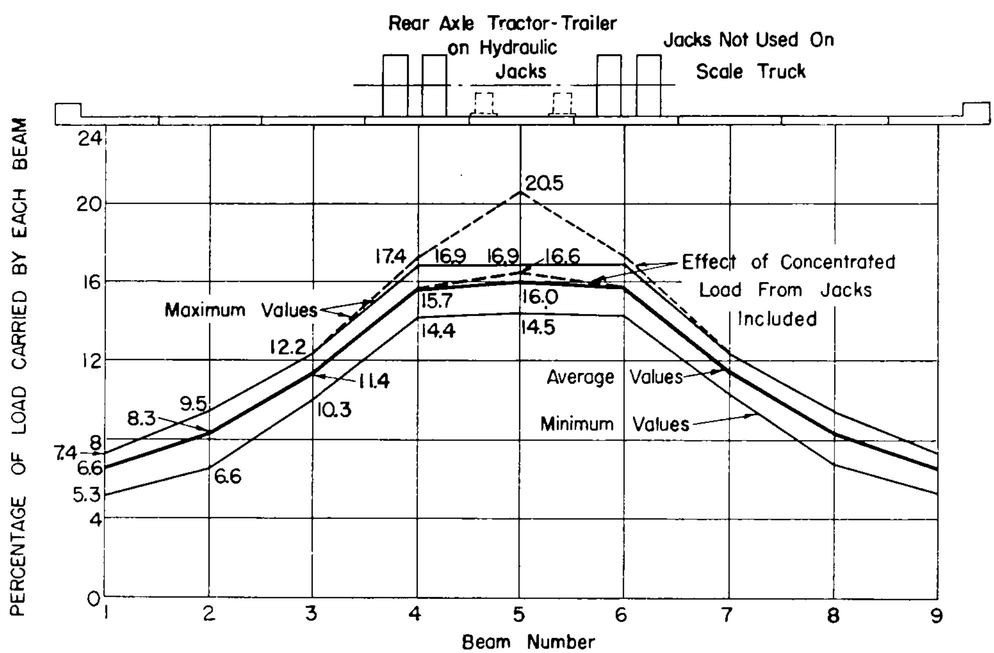



**Figure 27. Lateral load distribution from deflections, truck in center lane.**

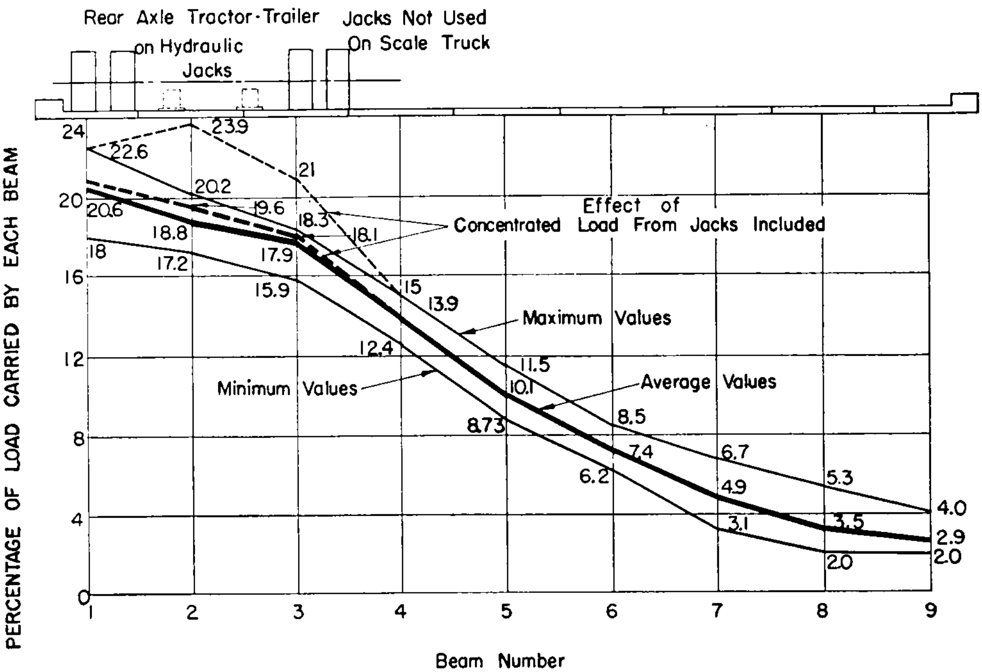



**Figure 28. Lateral load distribution from deflections, truck in edge lane.**

for loading positions at midspan. These deviations lie within the maximum and minimum value curves of Figures 27 and 28.

*Dynamic Tests*

Two sets of dynamic tests were run, one set with the tractor trailer truck travelling at 25 mph over the bridge, and the other with the same truck travelling 25 mph and striking a single 2-inch plank.

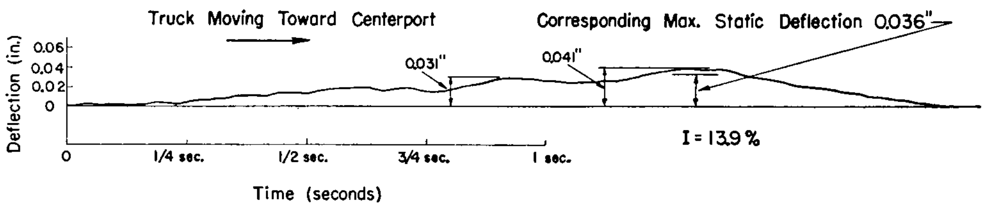
*Truck Moving Unobstructed at 25 mph Over the Bridge.* The upper graph in Figure 29 shows the time deflection curve recorded at midspan of the middle beam for the truck moving in the center lane of the bridge. A maximum deflection of 0.041 inch was determined when the trailer axle was at midspan. The corresponding static deflection for the same loading measured with the electric deflection gage was 0.036 inch. By comparing these two values it is evident that the dynamic deflection was 13.9 percent larger than the one caused by static load of the truck. If the impact fraction is defined as the increase in deflection due to a rapidly applied compared with a gradually applied loading, it is in this case 13.9 percent.

Figure 30(*a*) shows the time deflection curve recorded at midspan of the downstream edge beam for the truck travelling in the downstream edge lane, the outside tires about $1\frac{1}{2}$ feet from the curb. The maximum dynamic deflection recorded was 0.032 inch and the equivalent static deflection 0.026 inch resulting in an impact fraction of 23 percent. These impact fractions can be compared with the one prescribed by the 1953 AASHO Specification 3.2.12.c found as follows:

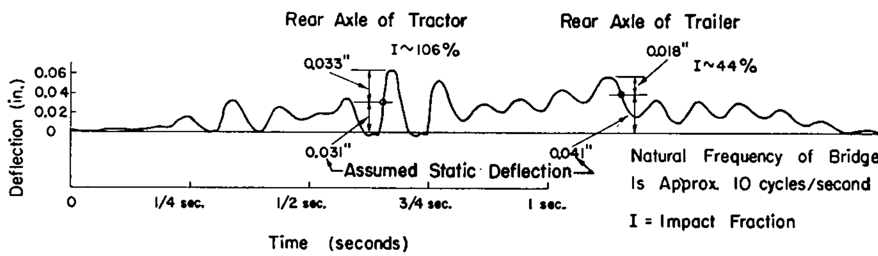
$$I = \frac{50}{33.5 + 125} = 31.5 > 30 \text{ percent maximum}$$

Study of the overall shape of the time deflection curve shows that only minor vibrations occurred as the truck travelled across the bridge. This is probably due to the smooth bituminous wearing surface and the relatively large degree of stiffness of the bridge.

*Impact Tests.* The impact tests were performed by driving the truck on the bridge at 25 mph and over a 2- by 10-inch plank placed flat across its path at midspan. Figure 29(*b*) shows the time deflection curve measured at midspan of the center beam for impact pro-

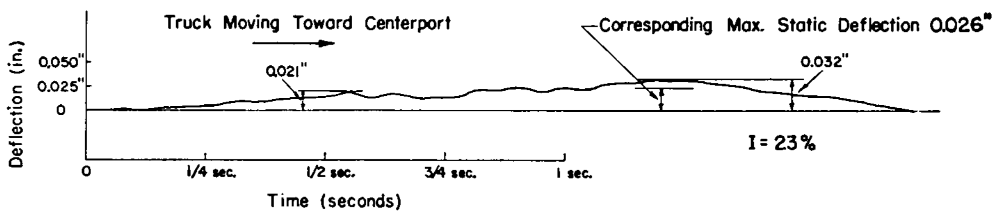



a) Tractor Trailer Truck Moving At 25 mph In Center Lane

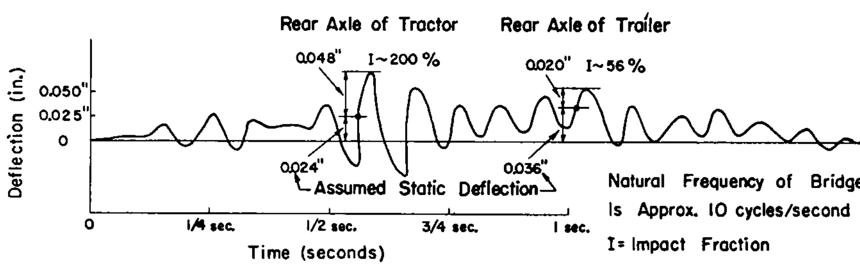



b) Tractor Trailer Truck Running Over Two Inch Plank At Midspan

**Figure 29. Dynamic deflection at midspan of center beam.**




a) Tractor Trailer Truck Moving At 25mph In Downstream Lane




b) Tractor Trailer Truck Running Over Two Inch Plank At Midspan

**Figure 30. Dynamic deflection at midspan of downstream edge beam.**

duced in the center lane. Figure 30(*b*) shows the time deflection curve measured at midspan of the downstream edge beams for impact produced in the edge lane. From these curves it can be seen that the natural frequency of the bridge is about 10 cycles per second.

It can be seen from Figure 31 that consistently in all the impact tests performed on

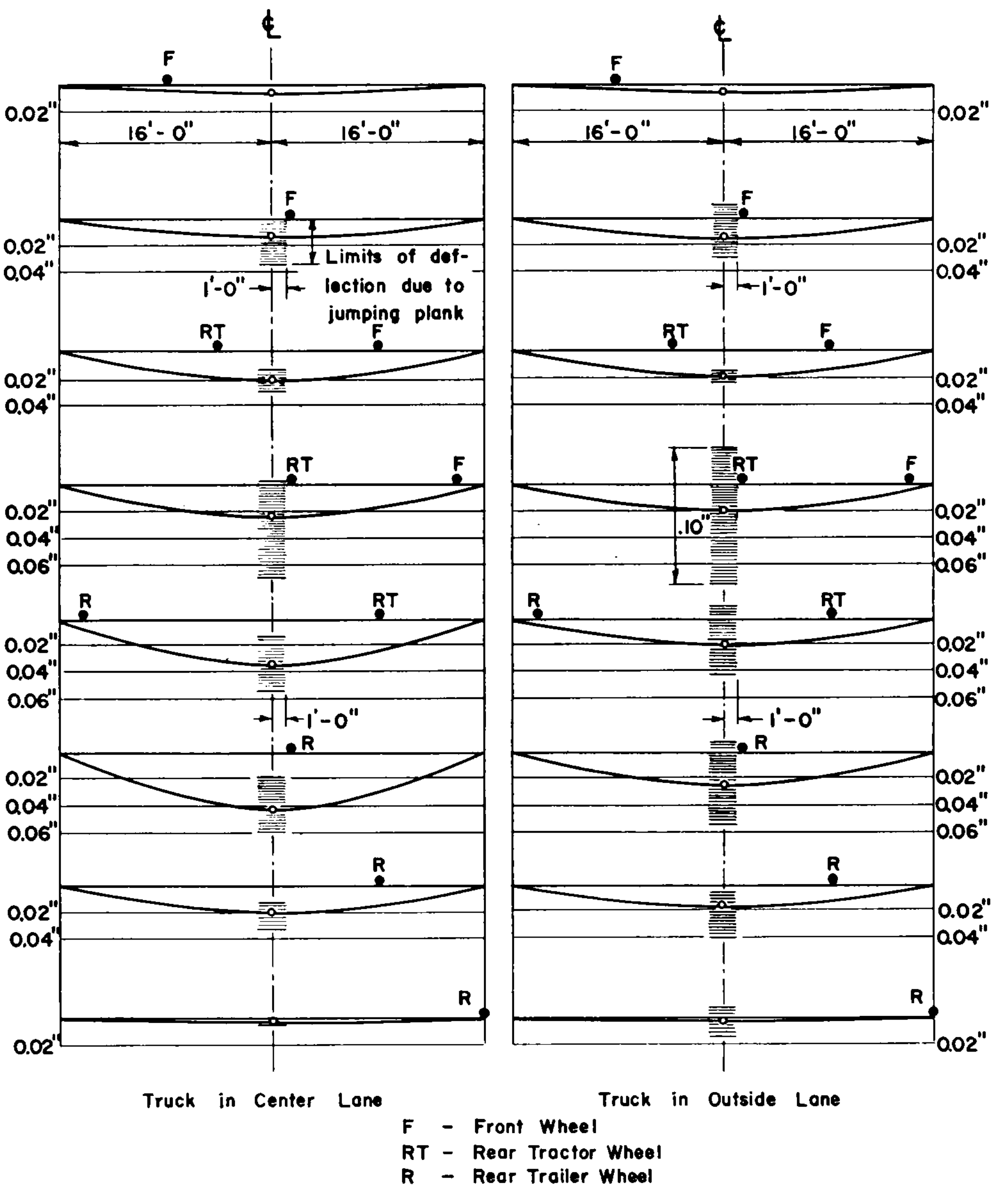



**Figure 31. Vertical deflections at midspan caused by truck running over bridge at approximately 25 mph.**

this bridge the less loaded rear axle of the tractor produced larger deflections than those of the heavier trailer axle. No attempt is made to interpret this observation except to point out that the mass of the bridge is about 3½ times larger than the total mass of the truck. Furthermore, the tractor trailer with its springs and shock absorbers forms a rather complicated dynamic system.

Due to the inevitable variations in the speed and the path of the truck in the different runs, an accurate superposition of corresponding points in the two graphs of Figure 29 and Figure 30 is not possible. The corresponding static deflections in the lower graphs were therefore approximately determined as the midpoint of consecutive minimum and maximum values. The increase in deflections due to the impact was then measured as shown in the figures and the impact fractions computed. For the truck in the center lane the impact fraction corresponding to the rear axle of the tractor was determined to be approximately 106 percent, whereas for the trailer axle it was approximately 44 percent. The corresponding impact fraction values for the truck in the downstream edge lane were approximately 200 percent and 56 percent, respectively.

## CONCLUSIONS

A 27-foot wide highway bridge with a roadway width of 25′4″ and a clear span of 32 feet (Figures 1, 2, 3) composed of nine prefabricated, pretensioned concrete beams placed side by side, connected by a single steel bolt at midspan and by dry packed continuous shear keys, was tested in the field under static and limited dynamic loading. The results of these tests are summarized below:

### *Lateral Load Distribution and Design of the Bridge*

The test results permitted an approximate determination of the lateral load distribution as follows:

1. For a truck in the center lane the middle beam carried approximately 17 percent of the total axle loads on the bridge or 34 percent of its left or right wheel loads (See Figure 27). When an axle load of 47.7 kips was concentrated on the middle beam at midspan through the use of jacks, the middle beam carried 20.5 percent of this load.
2. For a truck in the edge lane, the edge beam carried approximately 23 percent of the total axle loads on the bridge or 46 percent of the left or right wheel loads (See Figure 28).
3. A truck travelling at 25 mph over the bridge without any obstacle in its path produced only slight vibrations. With the truck in the center lane, the static deflection in the edge beam is increased by 23 percent (See Figures 29 and 30).
4. A truck running over a 2-inch thick plank at 25 mph caused deflection increases ranging between 56 percent and 200 percent of the corresponding static deflections.

### *General*

1. Although the bridge had been in service for over a year and a half, no cracks due to shrinkage, or other causes, or due to the application of the test loads could be detected on the beams.
2. The largest static loading applied in the edge lane, produced a bending moment without impact of 148 percent of the design moment and caused a maximum deflection in the edge beam of 0.087 inch or $\frac{1}{4690}$ of the span.
3. The action of the component beams, as determined through their recorded deflections and rotations in the transverse plane, supports the conclusion that the overall behavior of the bridge approached that of a homogeneous plate. This interaction was mainly due to the shear keys and the single transverse bolt. However, it was not irrefutably proved that the shear keys prevented any relative movement of the contact faces of any adjacent beams.

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