Testing of a Model Curved Steel Girder Bridge

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This paper was presented at the AISC National Engineering Conference in Boston, Mass., in April, 1966.

TESTS OF THREE $\frac{1}{8}$-scale curved girder bridge models are being conducted in the Civil Engineering Department at the University of Rhode Island at Kingston, with the purpose of confirming analytical solutions. This is a report on one of these tests, a three-girder, two span model of a 160 ft long prototype bridge. The model actually simulates a highway ramp for a typical city interchange.

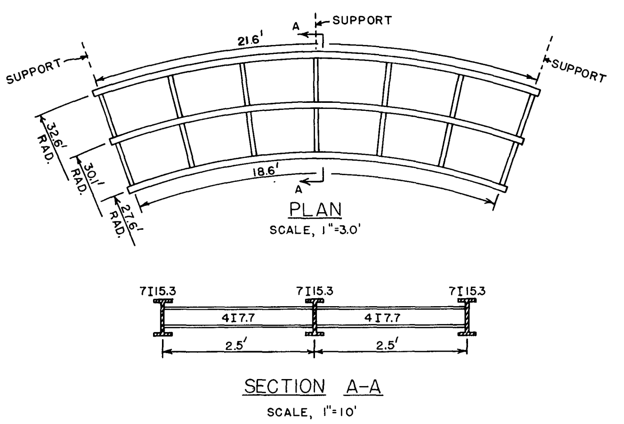

Fig. 1. Bridge Model

BRIDGE DESCRIPTION AND TESTING PROCEDURE

A drawing of the model bridge is shown in Fig. 1. The main girders are each 7I15.3 rolled beams, while each diaphragm is a 4I7.7 rolled beam. The curved length of the middle girder is 20.1 ft. In this particular bridge, a total of twenty-one shear connectors were used; they were $1\frac{1}{2}$ x $1\frac{1}{2}$ x $\frac{1}{4}$ angles $\frac{3}{8}$-in. high. The entire bridge was welded together. After the steel model had been fabricated it was stress-relieved by annealing in a large oven. The bridge model was placed upon reinforced concrete piers in the laboratory, and it was loaded by hydraulic jacks acting against loading frames. The model was first tested without a roadway slab, and then with a $1\frac{1}{4}$-in. thick reinforced concrete slab. See Fig. 2.

The slab was reinforced with $\frac{1}{2}$-in. hardward cloth, or in engineering parlance, 0.05-in. diam. rods, $\frac{1}{2}$-in. on centers. We reasoned that we could get good shear connection between the slab and the top flange, which was embedded in the slab, from the fact that the flange was curving in the concrete; and so, in an attempt to prove this theory, a minimum of shear connectors were used. The slab was poured with a mortar of sand, cement and water. It tested at an average ultimate unit stress of 3,800 psi.

Figure 3 illustrates how measurements were taken. Load was measured by a pressure dial connected directly to the hydraulic system of the jack. Dial indicators were used at several places to measure vertical deflections and torsional rotations of the bottom flange. SR-4 electric strain gages were used to measure strains in the web and flanges; there were some 200 of these used on the bridge model.

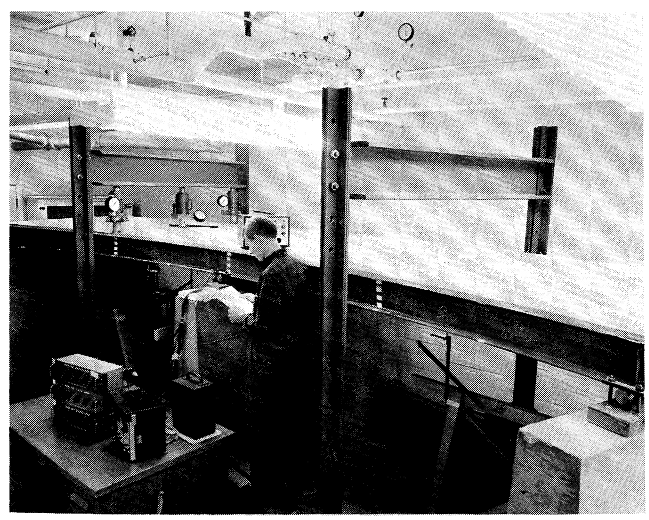

Fig. 2. Bridge

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TESTS

Many tests were run on the bridge with loads applied at various points on the spans. Two typical loadings, showing neither the best nor the worst results, were chosen for this paper, as shown in Fig. 4. The first loading was applied at the quarter-point of the span, while the second loading was applied at the half-point of the span. Results of the testing were compared with theoretical analyses developed at the University of Rhode Island by Professor Francis H. Lavelle.[1] In the figures which follow, test results are shown by solid lines, while theoretical analyses are shown by dotted lines. Moreover, **I.G.** means the girder nearest the center of curvature, **O.G.** means the farthest girder, and **M.G.** means the middle girder.

DEFLECTIONS

Figure 5 shows deflections of the girders in inches for two 10 K loads, one on the outside girder and one on the inside girder at the quarter-point of the span. Figure 6 shows the results of the same type loading except the two loads are at midspan. Notice first the differences in the model without the slab and then with the slab; in every case, except the relatively small deflection of the inside girder with the quarter-point loading, the deflections

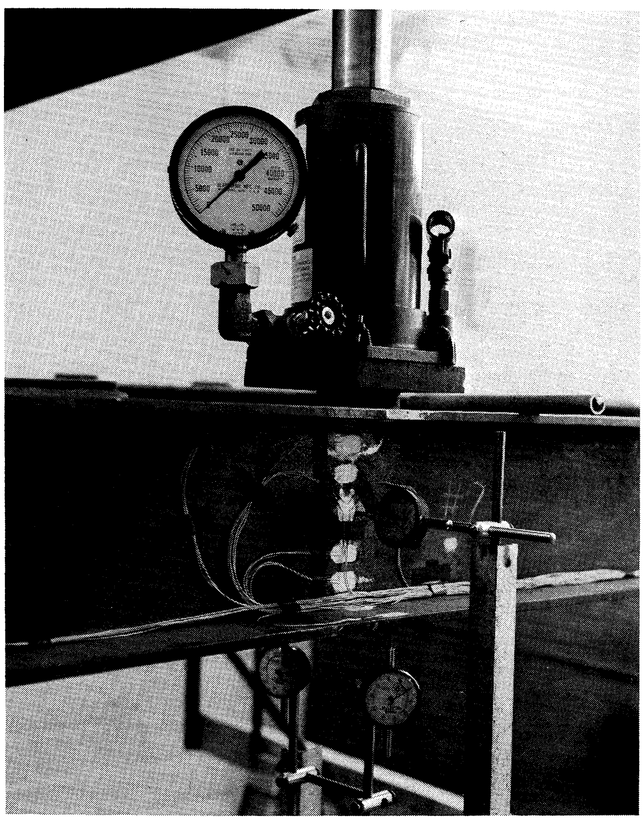

Fig. 3. Measuring Devices

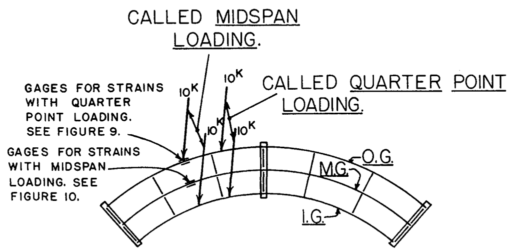

Fig. 4. Loading Plan for examples which follow

are less with the slab. Also, the difference between the test results, and the analysis are less with the slab, the maximum difference with the slab being about 12 percent. In every case, with the exception of the quarter-point loading for the inside girder, the analysis gives conservative results.

TORSIONAL ROTATIONS

Figures 7 and 8 show torsional rotations of the girders with the same two loadings—quarter-point and midspan. These figures show that test results exceed analysis results; this is the only case in our testing where this happens. Also, the shapes of the analysis curves for the inside girder are different from those for tests.

It is difficult to determine what the torsional stiffnesses are, although it is known that the individual members are torsionally weak. At this time, it is felt that not enough is known of this phenomenon to draw any conclusions from the results of the girder torsional rotations. All other results show fairly good agreement; it seems reasonable to conclude that these large discrepancies are not significant from a design point of view.

STRESSES

Figures 9 and 10 show stress distributions. The one with the quarter-point loading (Fig. 9) is for a section in the outside girder at midspan, while the one with midspan loading (Fig. 10) is for a section in the middle unloaded girder at midspan. See Fig. 4. To get the test results strains were measured by SR-4 strain gages and converted to stresses by multiplying these strains by the modulus of elasticity of the steel. To get the theoretical stresses Professor Lavelle's computer analysis was used to obtain the torques and moments at all joints; then using the work of Mr. Han-Chin Wu[2] who developed a method of determining normal stresses caused by warping, a computer program for theoretical stresses was developed.

Mr. Wu used for J, the torsional constant for a cross-section, the usual formula, $J = \Sigma \frac{1}{3} b t^3$, where b is the long dimension of each rectangular area, and t is the mean thickness. Varying J makes little difference to values of moment, but it does make a very real difference in torque. More study to determine a more reasonable value of J might be very fruitful, but it is a difficult problem.

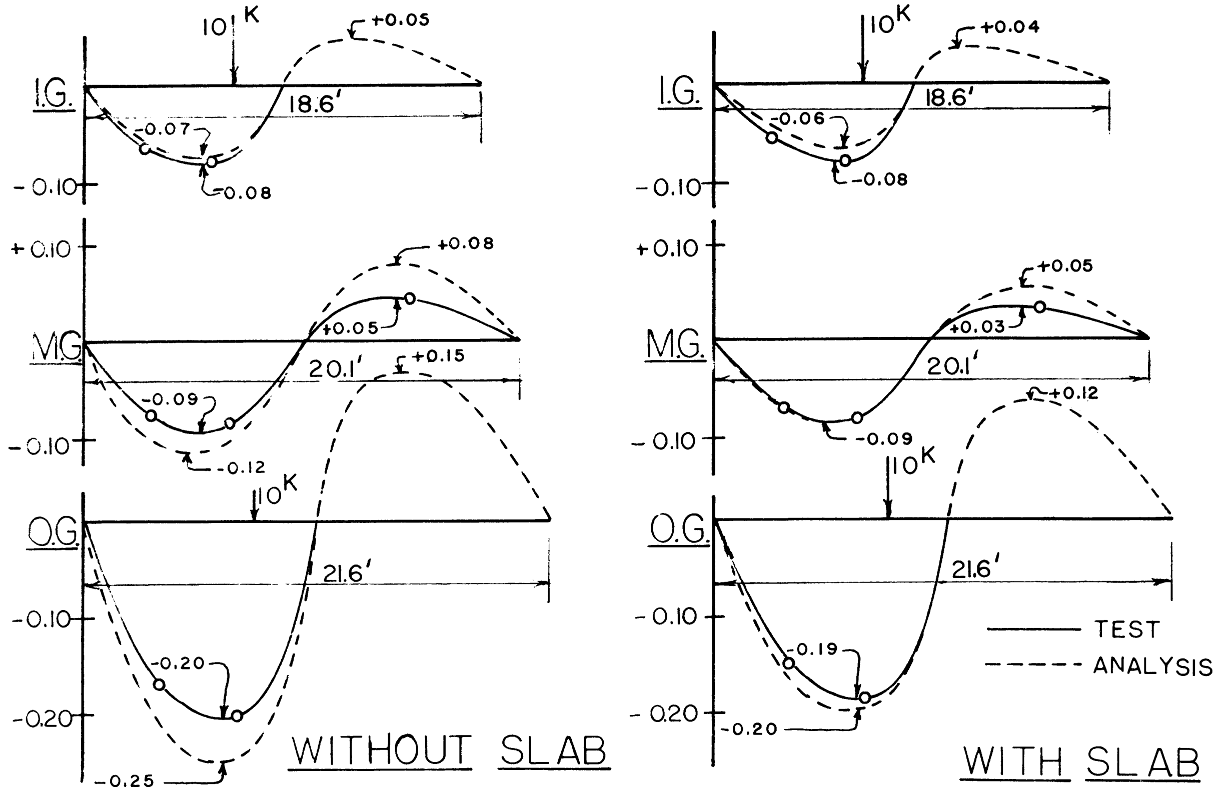

Fig. 5. Deflections—inches

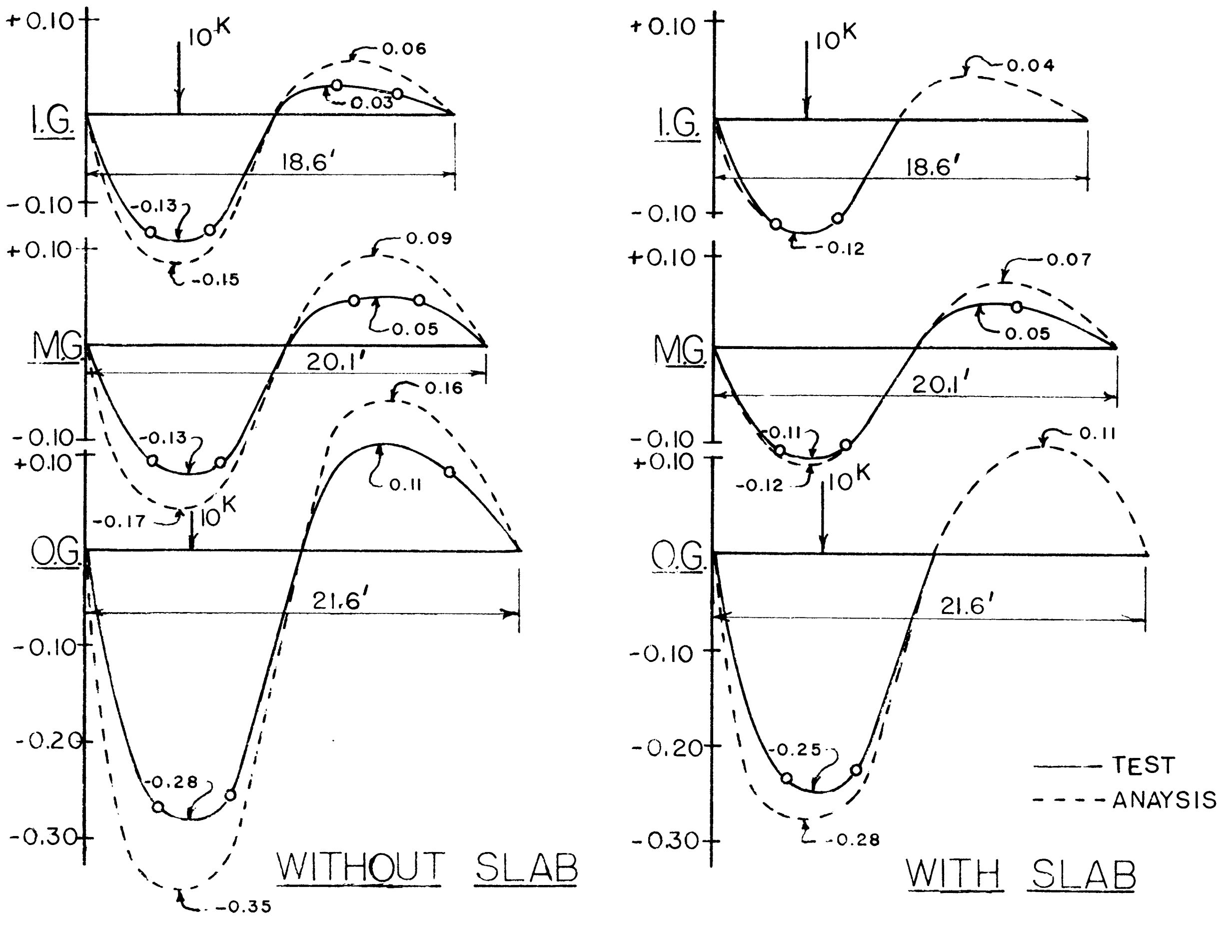

Fig. 6. Deflections—inches

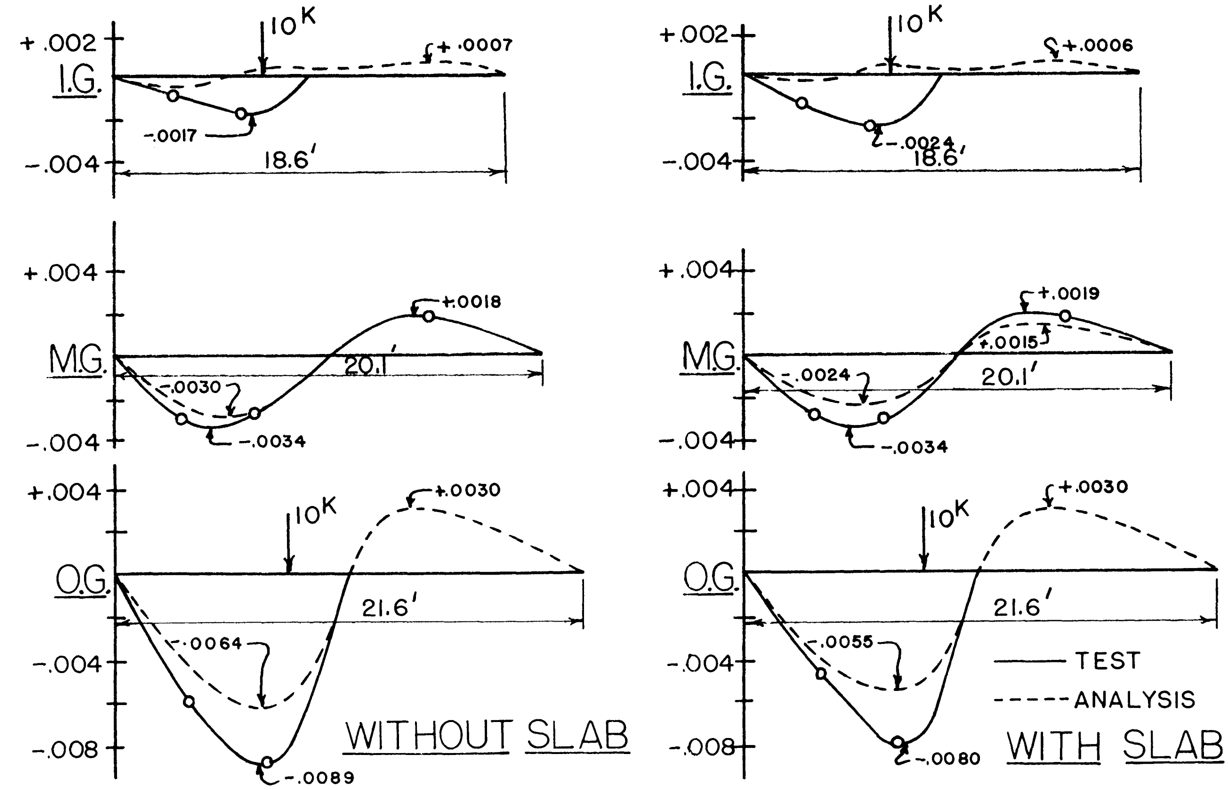

Fig. 7. Rotations—radians

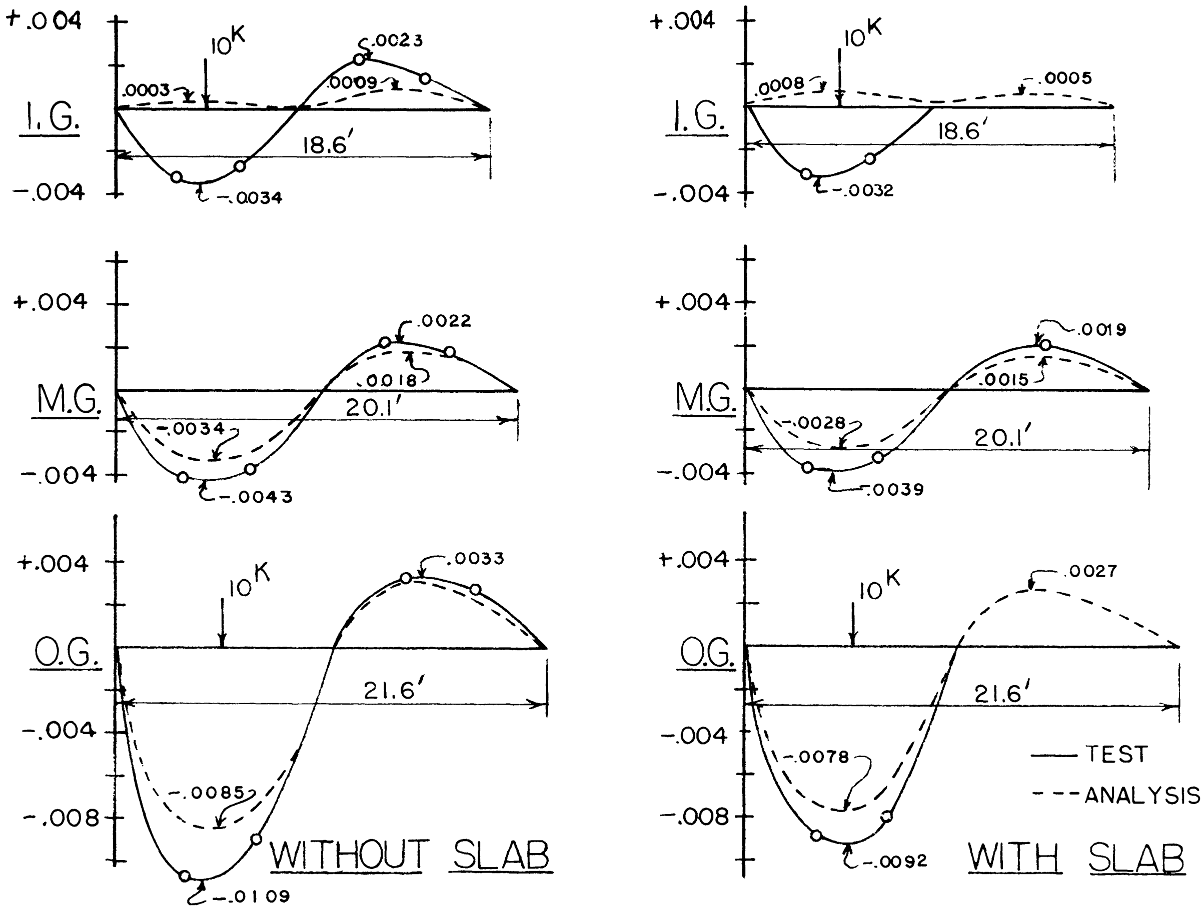

Fig. 8. Rotations—radians

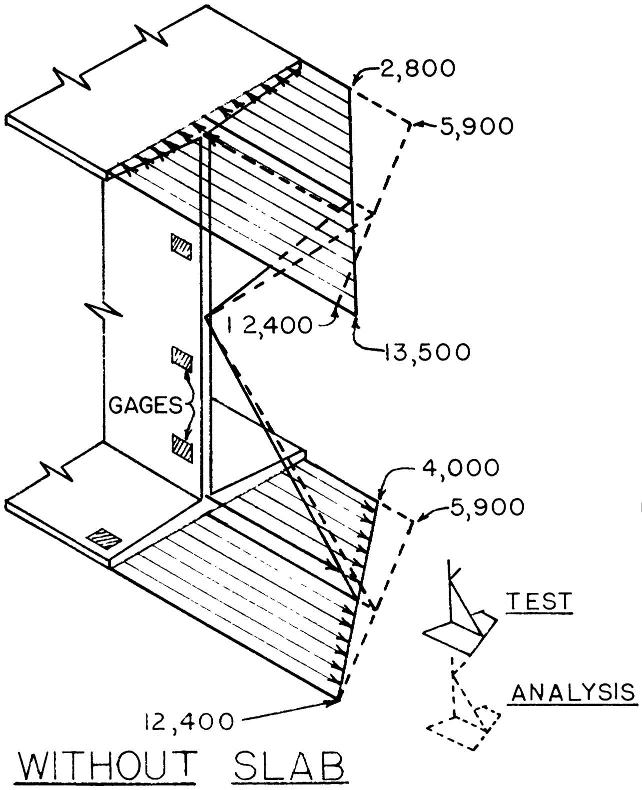

Fig. 9. Stresses, psi—with load at quarter pt.

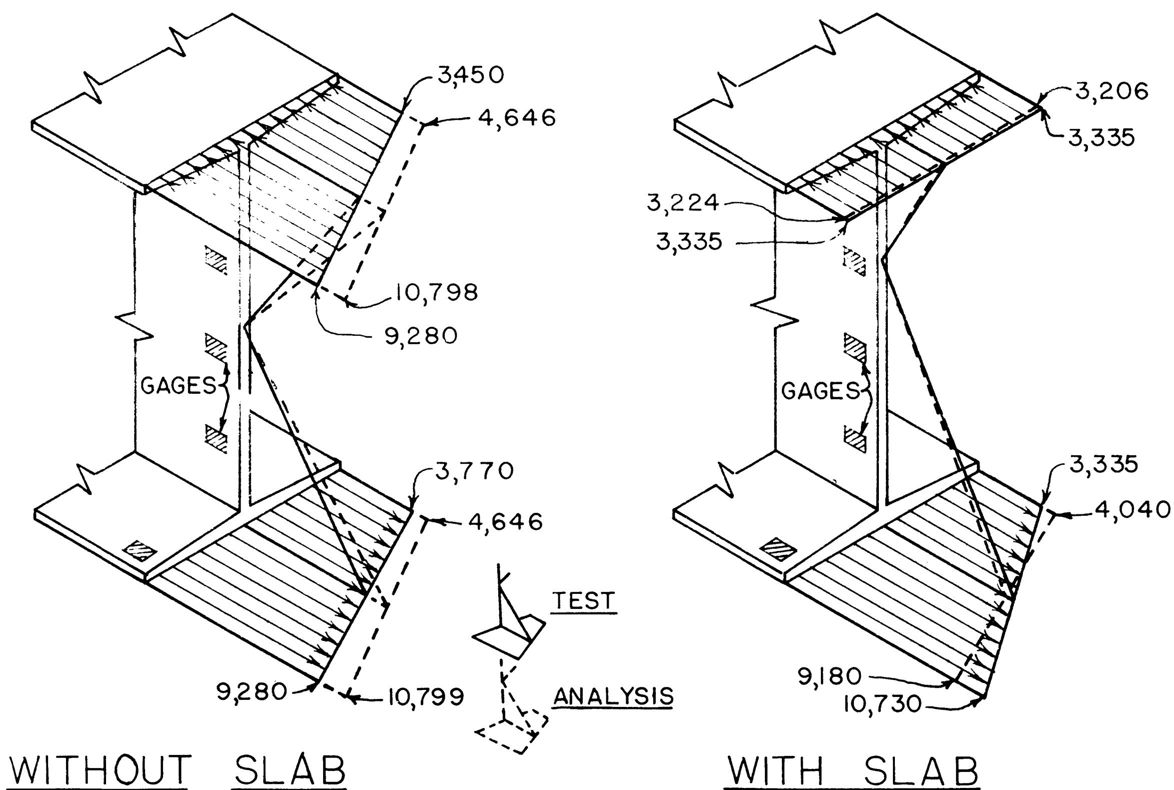

Fig. 10. Stresses, psi—with loads at midspan

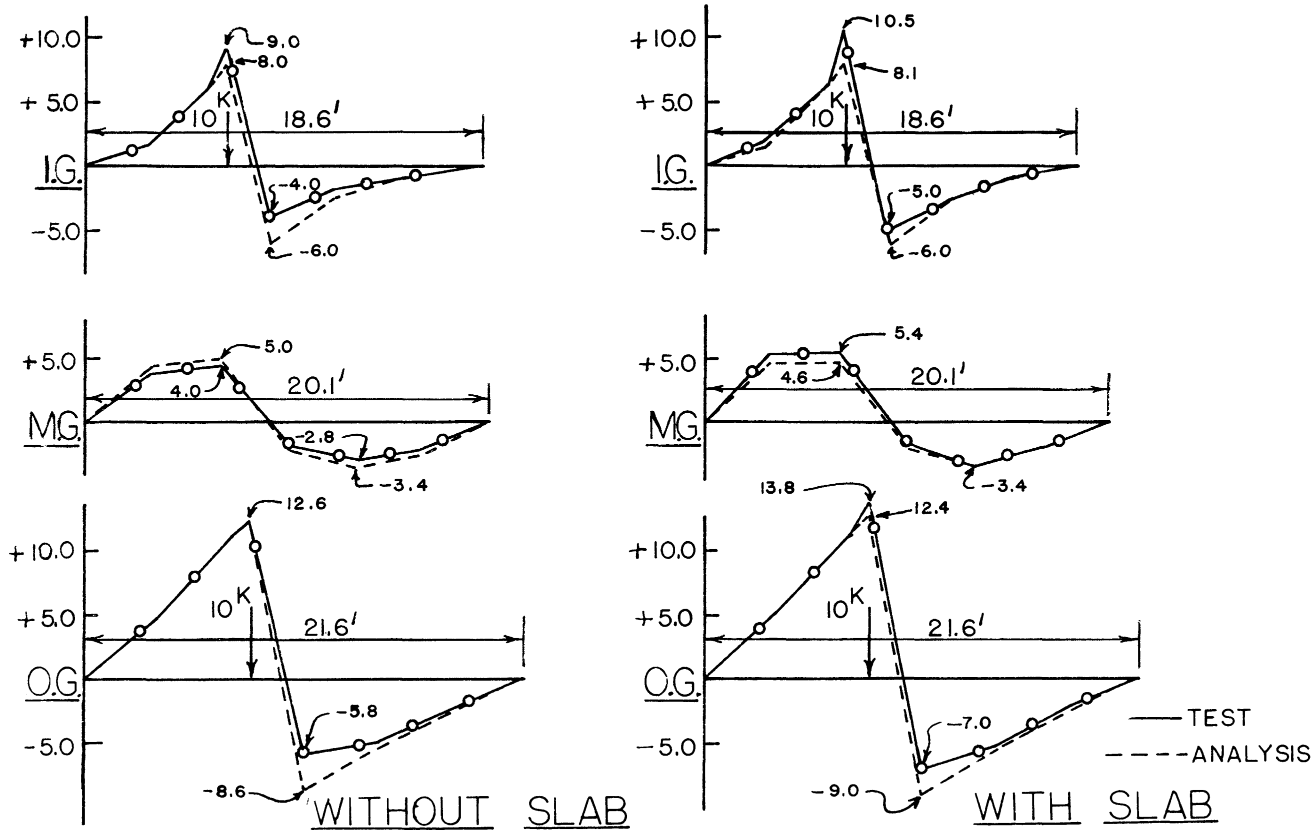

Fig. 11. Moment Diagrams—ft. kips

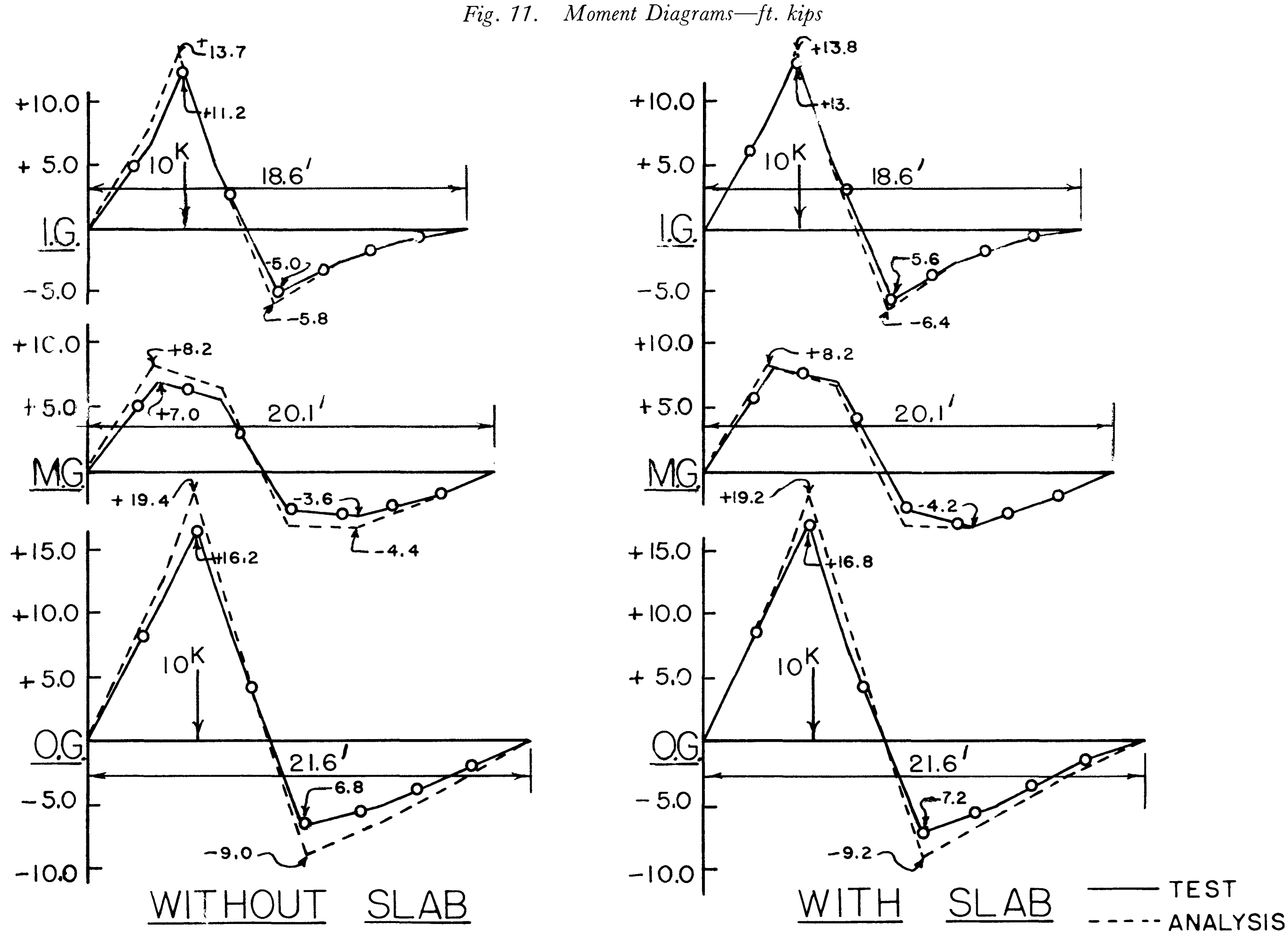

Fig. 12. Moment Diagrams—ft. kips

A study of the stresses in Figs. 9 and 10 shows that stresses in the bottom flanges are about the same without the slab and with the slab, but at the top flange the stresses are reduced when the slab is present. In fact the reduction in stress of the top flange in Fig. 10, where the girder is not loaded, is quite dramatic. Notice also that the neutral axis moves up when the slab is present. In this model bridge the bottom flanges were not strengthened with welded plates as is generally done in composite design, this is the reason that the stresses in the bottom flanges are not reduced when the slab is placed.

MOMENTS

Figures 11 and 12 show moment diagrams. Test curves shown were obtained by separating the bottom flange stresses due to moment from those due to torque; that is the same as getting the average bottom flange stresses from Figs. 9 and 10. Moments were easily computed from the stress diagrams due to moment. Theoretical moments were obtained directly from Professor Lavelle's computer analysis. Results are good.

SUMMARY

Our objective as stated in the beginning was to try to prove that Professor Lavelle's analysis is accurate. Results from testing this three-girder model bridge indicates that the analysis is conservative and accurate within limits tolerable to design.

ACKNOWLEDGMENT

The United States Bureau of Public Roads, and the Rhode Island Department of Public Works have jointly sponsored this work.

Tower Iron Works of Seekonk, Mass., have fabricated our bridge models, at cost to them.

REFERENCES

1. *Lavelle, Francis H. and Boick, John S.* A Program To Analyze Curved Girder Bridges, *Engineering Bulletin No. 8, University of Rhode Island, Dec. 1965.*
2. *Han-Chin Wu*, Normal Stresses in Beams Due to Non-Uniform Torsion, *Thesis submitted for the Master of Science Degree at the University of Rhode Island, 1965.*