Rigid Frame Highway Bridge Study

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This report describes the experimental and analytical study of a rigid frame highway bridge (on Interstate 64 near Charlottesville, Virginia). Experimental data included strains and deflections at midspan of the girders and strain data in the vicinity of one of the haunches. These data, along with calculated values of bending moment based on the measurements, provided a basis for evaluation of the design and for comparison with subsequently calculated analytical data.

The test structure shown in Figures 1 and 2 is 65.8 m (216 ft) long and consists of five, three-span, welded rigid frames. The two interior supports are inclined I-shaped columns framed integrally with the welded haunched girders and supported on concrete footings with anchor bolts attached to the web in such a manner as to allow free rotation. The ends of the bridge are simply supported on shelf abutments with allowance for longitudinal movements. The structures (Figure 2) were designed for an HS20-44 live load by using A-36 structural steel in accordance with the 1965 AASHO specifications. Construction was completed in late 1969, and testing took place in September 1972.

TEST PROCEDURE AND INSTRUMENTATION

The test vehicle was a three-axle diesel tractor semi-trailer loaded to simulate an HS20-44 loading. A total of 35 test runs were made. Ten crossings (two runs in each of the five lanes) were made at a crawl speed of 4.8 to 8 km/h (3 to 5 mph), and one run was made in each of the five lanes at speeds of 24, 48, 64, 80, and 97 km/h (15, 30, 40, 50, and 60 mph).

SR-4 wire strain gauges were placed at flange positions and rosette gauges on the haunch web on the westbound bridge. In addition, deflection gauges were installed at midspan of the five frames (Figure 3). Signals from pneumatic traffic tubes, installed on the approach on either side of the bridge span, provided a means of locating the test vehicle during the interval of testing, relating its position to the resulting stresses and deflections, and calculating the average speed of the test vehicle.

RESULTS

The output of the strain gauges, deflection gauges, and pneumatic tube signals was recorded as continuous traces on oscillograph tapes. Measured strains were converted to approximate stresses from the characteristics of the gauges and an assumed modulus of elasticity of 207 GPa (30 million lbf/in^2).

Midspan stresses and deflections of each frame are given in Tables 1 and 2 for various positions of the test vehicle. Distribution factors corresponding to each loading lane are also included.

ANALYTICAL RESULTS

A theoretical analysis of the rigid frame bridge was conducted to verify the experimental data collected and to provide additional stress and deflection information in regions where experimental data were lacking. Such a theoretical analysis also provides a basis for evaluating the design procedures used and, it is hoped, additional

Figure 1. Test structure on I-64 over US-250 east of Charlottesville, Virginia.

Publication of this paper sponsored by Committee on Dynamics and Field Testing of Bridges.

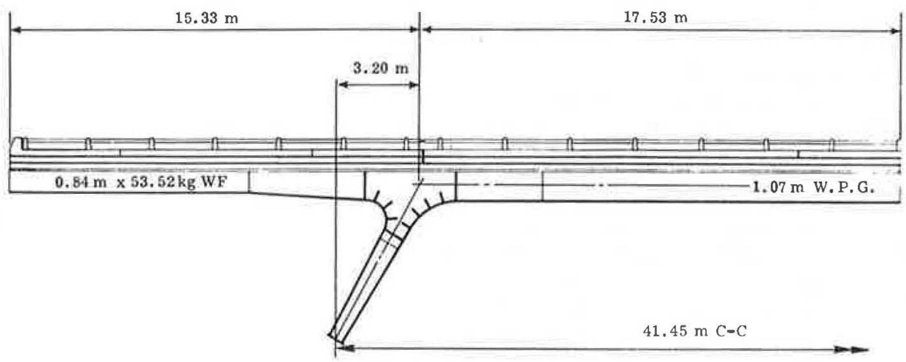

Figure 2. Partial elevation of test structure.

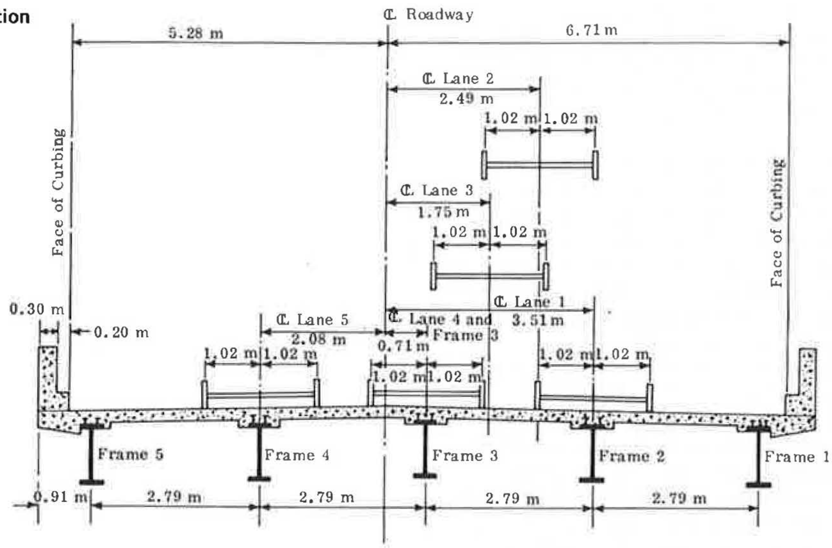

Figure 3. Transverse section and lane locations.

Table 1. Peak midspan deflections and load distribution based on deflections.

	Lane									
	1		2		3		4		5	
Frame	Deflection (mm)	Distribution (%)	Deflection (mm)	Distribution (%)	Deflection (mm)	Distribution (%)	Deflection (mm)	Distribution (%)	Deflection (mm)	Distribution (%)
1	5.75	29.5	4.25	21.5	3.50	16.9	2.00	9.5	0.25	1.2
2	7.50	29.5	5.75	29.1	5.25	25.3	3.75	17.9	1.75	8.3
3	5.25	26.9	6.00	30.4	6.50	31.3	6.50	30.9	5.25	24.7
4	2.50	12.8	3.00	15.2	4.00	19.3	5.50	26.2	7.00	32.9
5	0.25	1.3	0.75	3.8	1.50	7.2	3.25	15.5	7.00	32.9

Note: 1 mm = 0.0039 in.

Table 2. Maximum tensile stresses (lower flange midspan) and load distribution based on stresses.

	Lane									
	1		2		3		4		5	
Frame	Stress (MPa)	Distribution (%)	Stress (MPa)	Distribution (%)	Stress (MPa)	Distribution (%)	Stress (MPa)	Distribution (%)	Stress (MPa)	Distribution (%)
1	10.72	24.5	8.24	19.1	6.24	13.7	2.76	6.1	0.52	1.2
2	17.00	38.9	14.82	34.4	13.72	30.0	9.07	20.1	4.72	10.5
3	10.82	24.8	12.79	29.8	15.34	33.5	15.34	34.0	10.34	23.0
4	4.27	9.8	5.83	13.5	7.69	16.8	12.00	26.6	16.82	37.4
5	0.90	2.0	1.38	3.2	2.72	6.0	5.93	13.2	12.51	27.9

Note: 1 MPa = 145 lbf/in^2.

information regarding stress distribution in the haunch region of the bridge.

The analysis was performed by using a finite-element computer program in which a typical frame was represented as a series of flexural elements. The total rigid frame structure was subdivided into 16 elements, with two elements representing each end span, four elements modeling the center span, one element for each inclined leg, and three elements representing each haunch. The flexural characteristics of the actual structure were modeled as closely as possible. The stiffness matrices were formulated to represent the flexural characteristics of each of the elements by taking into account those elements in which there was a linear variation in depth. Also, modeling of the haunch incorporated the variation in depth and the extremely stiff nature of the central portion of the haunch. The inclined legs were assumed to be pinned at the base, and the bearings at the abutments were treated as roller supports providing no restraint against horizontal motion. Influence lines for deflections and moments at critical locations were determined.

The calculated deflection at midspan, using a theoretical loading based on the measured lateral load distribution, was determined to be 6.8 mm (0.27 in), and the experimental midspan deflection was measured to be 7.1 mm (0.28 in). Midspan moment due to the vehicle loading was calculated to be 473 kJ (350 thousand ft·lbf), and the experimentally determined midspan moment was approximately 454 kJ (335 thousand ft·lbf).

Variations in support conditions had negligible effects on the midspan moment but significantly affected moments in the haunch region. For example, permitting the deck to move horizontally may increase the positive moment in the haunch region by as much as 400 percent. Moments and deflections were also calculated for various haunch representations. Whereas differences in assumptions of haunch stiffness do have an effect on moments and deflections, the effect is not significant.

SUMMARY AND CONCLUSIONS

The conclusions drawn from this study are summarized below.

1. Midspan flexural stresses and deflections in the five frames were sensitive to the transverse position of the test vehicle on the concrete deck. As has also been demonstrated in studies of simple beam composite deck and steel stringers, live loads on the decks are by no means carried equally by the several components of the superstructure. However, AASHTO specifications for lateral distribution to stringers are highly conservative as design guides.
2. The live load stresses as experimentally determined were small compared to live load stresses calculated in the design.
3. The estimated values of the ratio of moduli of elasticity of steel to concrete and the effective width of the composite concrete slab have only a small effect on the section modulus of bottom fibers. Any reasonable estimates for these design parameters are very satisfactory for bridges of this type.
4. Influence diagrams for moments and deflections were not appreciably affected by various modelings of the haunch in the finite-element analysis.
5. Influence diagrams for midspan moments and deflections were not appreciably affected by various support condition assumptions at the abutments and slant legs; however, the influence diagrams for moments at either side of the haunch were greatly affected by the above-mentioned support conditions.