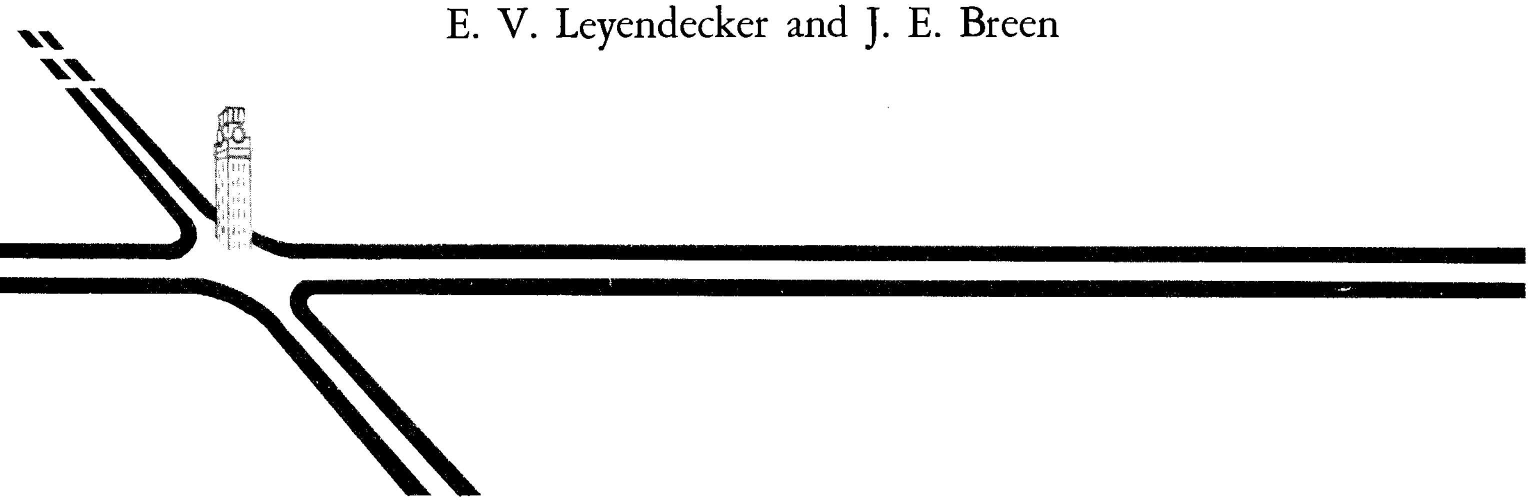
BEHAVIOR OF CONCRETE SLAB AND GIRDER BRIDGES

By

E. V. Leyendecker and J. E. Breen



SUMMARY REPORT 94-3F (S)

SUMMARY OF

RESEARCH REPORT 94-3F

PROJECT 3-5-66-94

COOPERATIVE HIGHWAY RESEARCH PROGRAM
WITH TEXAS HIGHWAY DEPARTMENT
AND
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SUMMARY REPORT 94-3F (S)

Introduction

Report 94-3F is the final in a series which summarizes a detailed investigation of the behavior of pan-formed concrete slab and girder bridge systems, which are widely used by the Texas Highway Department. The initial report treated the detailed techniques developed for the utilization of reduced scale models and also reported on the degree of correlation between the model tests and the full-scale prototype testing. The second report treated the techniques employed and the results obtained in the field testing of the full scale prototype bridge.

Detailed results of a research program to study the behavior of 40-ft. simple span pan-formed concrete slab and girder bridges (see Fig. 1) are presented. The investigation was carried out using approximately 1/6-scale direct models of the bridges (including substructure); these model tests were supplemented by full-size field testing as well as analytical procedures. Four accurate models were tested at service loads, moderate overloads, and ultimate load levels in order to fully document the behavior of the structures for the full range of load conditions. Patterns of load distribution similar to those shown in Fig. 2 were obtained using both strain gages and deflection measurements. The main variables in the investigation were angle of skew, load level, and grade and quantity of reinforcement.

Comparisons are made with the service load AASHO load distribution factors for design of slab and stringer bridges, and with distribution factors computed from an orthotropic plate solution using a discrete element mathematical model. Design recommendations are made for computation of ultimate load capacity. The overall objectives of the investigation were as follows:

(a) To investigate the behavior at service loads, moderate overloads, and at ultimate loads of typical pan-formed concrete slab and girder bridge spans, using reinforced microconcrete structural models.

(b) To confirm the observed behavior at service loads by full-scale testing of a prototype structure.

(c) To evaluate the effectiveness of the end diaphragms in participating with the bent caps to carry slab loads.

(d) To make recommendations regarding the adequacy of present design provisions based on these test results.

The overall study consisted of the following principal test specimens:

(a) *Model SG-1.* 1/5.5-scale model of a 0° skew, 40-ft. span.

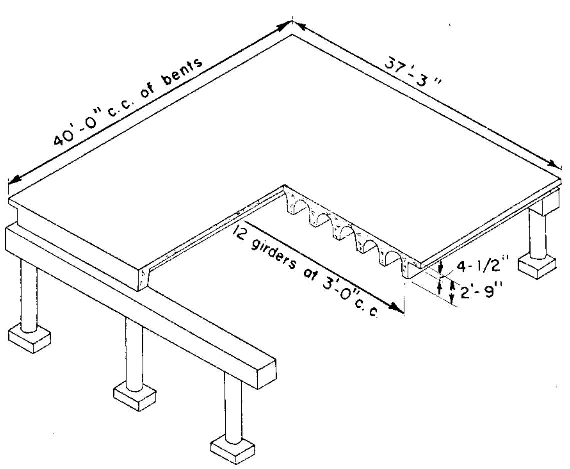

Fig. 1. Typical CG Series Span, CG-0-35-40 (0° Skew Shown).

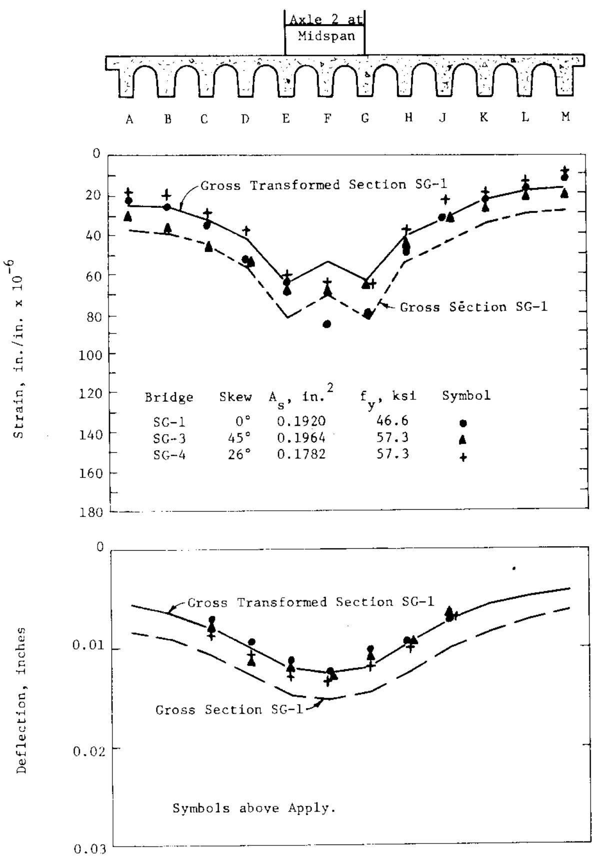

Fig. 2. Midspan Strains and Deflections for H-20 Truck at E4-G4.

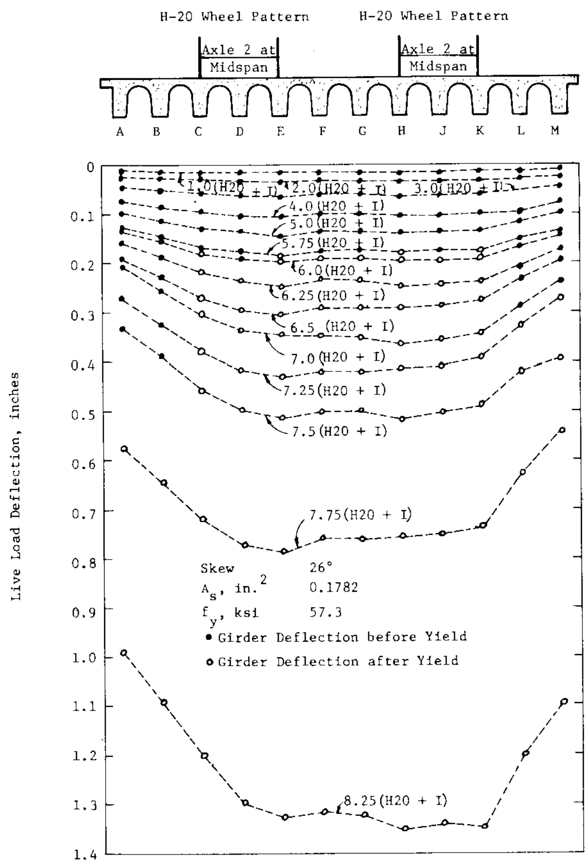

Fig. 3. Midspan Deflection for SG-4 during Ultimate Load Cycle.

(b) *Model SG-2.* 1/5.5-scale model of a 45° skew, 40 ft.-10 in. span.

(c) *Model SG-3.* Duplicates SG-2 in all respects except for the main flexural reinforcement, where a reduced area of high strength steel (f_y = 60 ksi and f_s = 24 ksi) was substituted for intermediate grade steel (f_y = 40 ksi and f_s = 20 ksi).

(d) *Model SG-4.* 1/5.5-scale model of a 26°-34′ skew, 41 ft.-9 in. span.

(e) *Prototype CG-1.* Full-size prototype bridge of a 26°-34′ skew, 41 ft.-9 in. span.

Conclusions

Although this investigation was restricted to a particular bridge system, the following conclusions are warranted based on measurements and analysis procedures documented in the report:

(1) The AASHO service load distribution factors are overconservative when compared to the service load test results, which indicated:

(a) Single Wheel Loads—There are no specific AASHO recommendations for a single wheel load. Test results indicate that a distribution factor of S/5.5 can be used for an exterior girder, S/9.0 for the first interior girder, and S/10.0 for other interior girders.

(b) Single Truck Loads—The curent AASHO specifications use a value of S/C = S/6.0 for interior girders for a single truck load. Test results indicate that a distribution factor of S/5.98 can be used for the first interior girder, S/7.22 for the second interior girder, and S/8.6 for the other interior girders. AASHO specifies S/C = S/3.0 for the exterior girders when the load is directly above. Test results indicate S/4.5 may be used.

(c) Multiple Truck Loads—The current AASHO specifications use a value of S/C = S/5.0 for two or more vehicles on the bridge. Test results indicate this factor to be correct for triple truck loads. However, a factor of S/6.56 is indicated for a double truck loading.

These service load distribution factors are reasonable regardless of skew angle or percentage of longitudinal steel, within the range of variables included in this study.

Service load distribution factors may not be valid at ultimate load. Design based on service load distribution factors smaller than ultimate load distribution factors should be checked using the general failure mode for safety at ultimate load.

(2) Test results indicate that the transverse steel rarely exceeded the design stress until failure occurred. At failure the steel usually yielded as a secondary effect.

(3) Under both maximum moment and maximum shear loadings the bridges exhibited a primary mode of failure by yielding of tension steel in the most heavily loaded girders (see Fig. 3). These girders are defined by a distribution zone boundary extending from the edge of the loaded surface and inclined 30° from the horizontal, as shown in Fig. 4. The

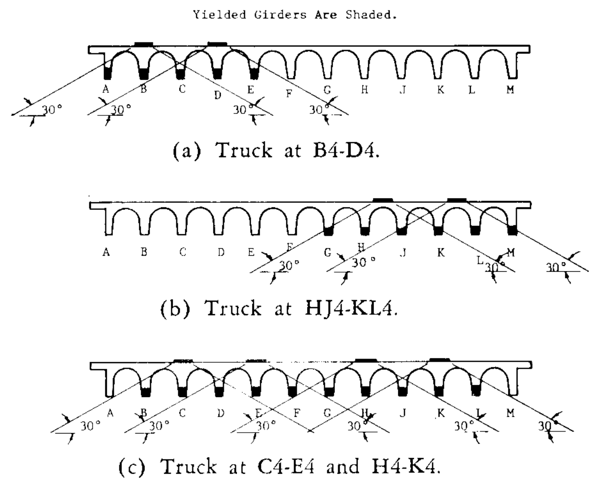

Fig. 4. Estimating Girders with Steel Yielding at Ultimate.

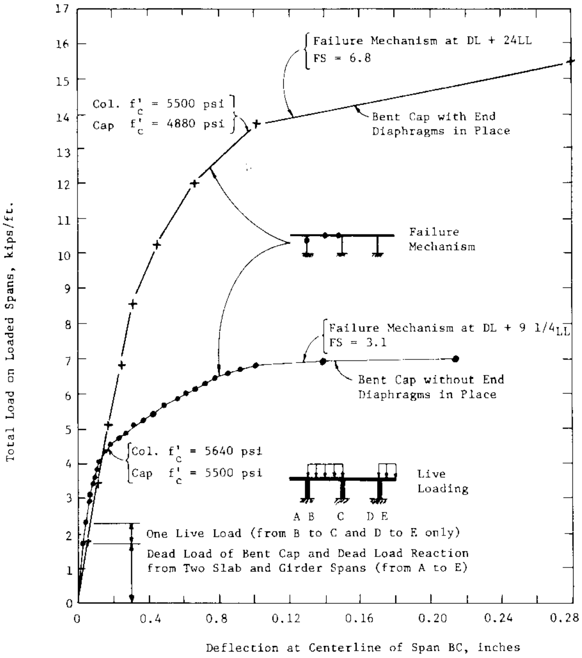

Fig. 5. Comparison of Capacity of Bents with and without End Diaphragms in Place.

main longitudinal steel will yield or be very close to yield in all girders in which the tensile steel layers are enclosed within such a 30° zone. This is referred to as the yield zone. Increased load will be transferred to the remaining girders. The transferred load is limited by the slab shear capacity in the transverse direction, unless the remaining girders yield before the shear capacity is reached.

(4) Ultimate load distribution factors should be based on the "yield zone" and the transferred load, P_T. However, the transferred load is difficult to evaluate generally, since it is dependent on load position and loaded length. For simplicity, conservative ultimate load distribution factors may be based on the girders within the yield zone after neglecting any transferred load. Ultimate load distribution factors based only on the girders in the "yield zone" indicate that S/7.5 is critical for single and double truck loadings.

(5) A shear test on model SG-2 (45° skew) resulted in the same failure mode described in (3), indicating that girder shear is not a design problem with the percentage of web reinforcement used.

(6) Punching tests directly over the crown indicate that single wheel punching is not a design problem for this section.

(7) Tests on the substructure, as shown in Fig. 5, indicate that the girder end diaphragms double the bent cap live load capacity.

(8) An ultimate load calculation procedure based on the failure mode described in (3) showed good accuracy resulting in the ratios shown in Table 1.

TABLE 1.
ACCURACY OF ULTIMATE LOAD CALCULATIONS

Bridge	Ultimate Test	Measured FS / Calculated FS	Measured M_{ULL} / Calculated M_{ULL}
SG-1	1	0.95	0.93
SG-2	1	1.13	1.23
	2	1.19	1.27
SG-3	1	1.12	1.16
	2	1.02	1.02
SG-4	1	1.17	1.22

(9) The overall factors of safety ranged from 2.25 to 3.50. The live load safety factors were rather large, ranging from 4.38 to 7.75.

(10) Using the Bureau of Public Roads load factor of 1.35 for dead load, the live load factors ranged from 3.78 to 7.15. These latter load factors are 1.68 to 3.18 times as large as the specified live load factor of 2.25.

(11) The use of the present AASHO service load distribution factors results in the excessive live load factors indicated in (10). The use of the ultimate load distribution factor given in (4) as S/7.5 is in the direction of reducing the excessive live load factors obtained in this study.

(12) The discrete element mathematical model of an orthotropic slab using gross transformed section properties is an adequate predictor of service load behavior for a right angle bridge, as can be seen in Fig. 2.

Implementing Research Results

The AASHO service load distribution factors currently used are excessive for this type of bridge in the case of single and double truck loadings.

An ultimate load approach is felt to be the most realistic design method for this type of bridge. It is recommended that design be based on the ultimate load distribution factor (neglecting transferred load) of S/7.5 for single and double truck loads. Assuming double truck loading, the use of the revised load distribution factors presented would reduce the average design load to be carried by the girders by 33 percent in ultimate load designs. Substantial reinforcement savings would occur even if present standard cross section dimensions are maintained.

The bent cap should be designed considering its interaction with the end diaphragms as a noncomposite beam. This will significantly decrease bent cap sizes.

The full text of Research Report 94-3F can be obtained from R. L. Lewis, Chairman, Research and Development Committee, Texas Highway Department, File D-8 Research, 11th and Brazos Streets, Austin, Texas 78701 (512/475-2971)