LONG-TERM SERVICE PERFORMANCE OF LIGHTWEIGHT CONCRETE BRIDGE STRUCTURES

W.R. Brown III, PE and Torbjorn J. Larsen, PE
Florida Department of Transportation, Gainesville, Florida 32602
Thomas A. Holm, PE
Expanded Shale, Clay and Slate Institute

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INTRODUCTION

The long-term field performance of structural lightweight concrete bridge members constructed in Florida on U.S. Route 19 at Fanning Springs in 1964 was evaluated in an in-depth investigation conducted in 1992. Comprehensive field measurements of service load strains and deflections were measured in 1968 and 1992 and compared to the theoretical bridge responses predicted by a finite element model that is part of the Florida Department of Transportation bridge rating system.

SUWANEE RIVER BRIDGE AT FANNING SPRINGS

The bridge at Fanning Springs (Figure 1), crossing the Suwanee River, incorporates a four span precast prestressed lightweight concrete framing system with a specified girder compressive strength of 34.5 MPa (5000 psi) [1]. The cast-in-place concrete slabs incorporated structural lightweight coarse aggregate and had a specified compressive strength of 27.6 MPa (4000 psi). This two-lane bridge had, for its time, relatively long 36.9 m (121 ft) spans using AASHTO Type 4 sanded structural lightweight concrete girders shown during construction in Figure 2. Continuity was developed by conventional reinforcing steel in the top of the girders, diaphragms and with continuous steel across the deck slab. Concrete specifications called for a maximum fresh density of 1880 kg/m^3 (120 pcf) incorporating a Florida produced rotary kiln expanded clay in combination with a local natural siliceous sand.

Because there was no prior structural lightweight concrete bridge member experience in Florida before use on the Fanning Springs structure, an extensive research and field measurement laboratory program was established to continuously monitor the performance of the completed structure over its first two year history. The suspended car assemblage designed to carry researchers for measurements under the bridge is shown in Figure 3. As a direct result of the 1966-1968 testing program detailed concrete information, deflection, and strain responses of the bridge were available for a wide range of load conditions. The test program in 1992 conscientiously attempted to reproduce the original loads and measurements to provide a direct comparison to determine any change or loss of performance over the 28 year service life of the bridge.

LOAD TEST PLAN AND INSTRUMENTATION

The original HS20 truck configuration used in 1968 is shown in Figure 4 and the schematic of the Florida Department of Transportation truck used in the 1992 test is shown in Figure 5. The trucks are similar in overall weight, but have different axle configurations and spacings. Using the truck's center of gravity as the references, the load points for these tests were matched to the corresponding original loading points. A large number of static load tests were recreated along with numerous combinations of lane spacings as well as positions of longitudinal spacing.

Only a small portion of the accumulated data is reported here and interested readers are referred to the comprehensive report in Reference 2. Instrumentation included electric strain gauges similar to the original 1968 tests. Girder deflections were measured using the offset to taut wire technique. Most of the original positions for the instrumentation were still evident. In addition to the original instrumentation, additional bottom fiber strains were measured at mid-span and LVDT's added to obtain the dynamic deflection profiles created by moving truck loads. Truck lane designations are shown in Figure 6 and location of the truck during static loading is shown in Figure 7.

FIGURE 1. CONCRETE WEIGHING LESS THAN 120 LBS. PER CU. FT. PERMITTED 120 FT. SPANS FOR FLORIDA BRIDGE (ENGINEERING NEWS RECORD, JUNE 4, 1964.)

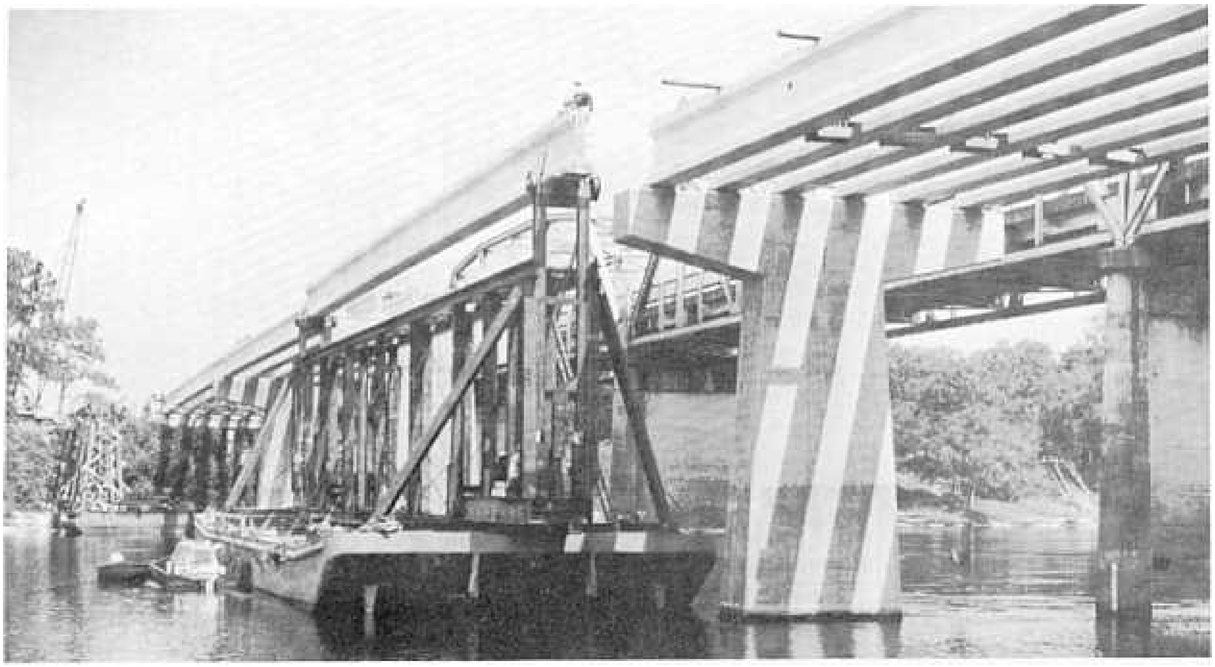


FIGURE 2. BARGE-MOUNTED FRAME PLACED BEAMS. TO THE RIGHT IS OLD TRUSS BRIDGE. BOTH WILL CARRY U.S. 19 TRAFFIC. (ENGINEERING NEWS RECORD, JUNE 4, 1964.)

FIGURE 3. SUSPENDED CAR WILL CARRY RESEARCHERS UNDER ONE BRIDGE SPAN. (ENGINEERING NEWS RECORD, JUNE 4, 1964.)

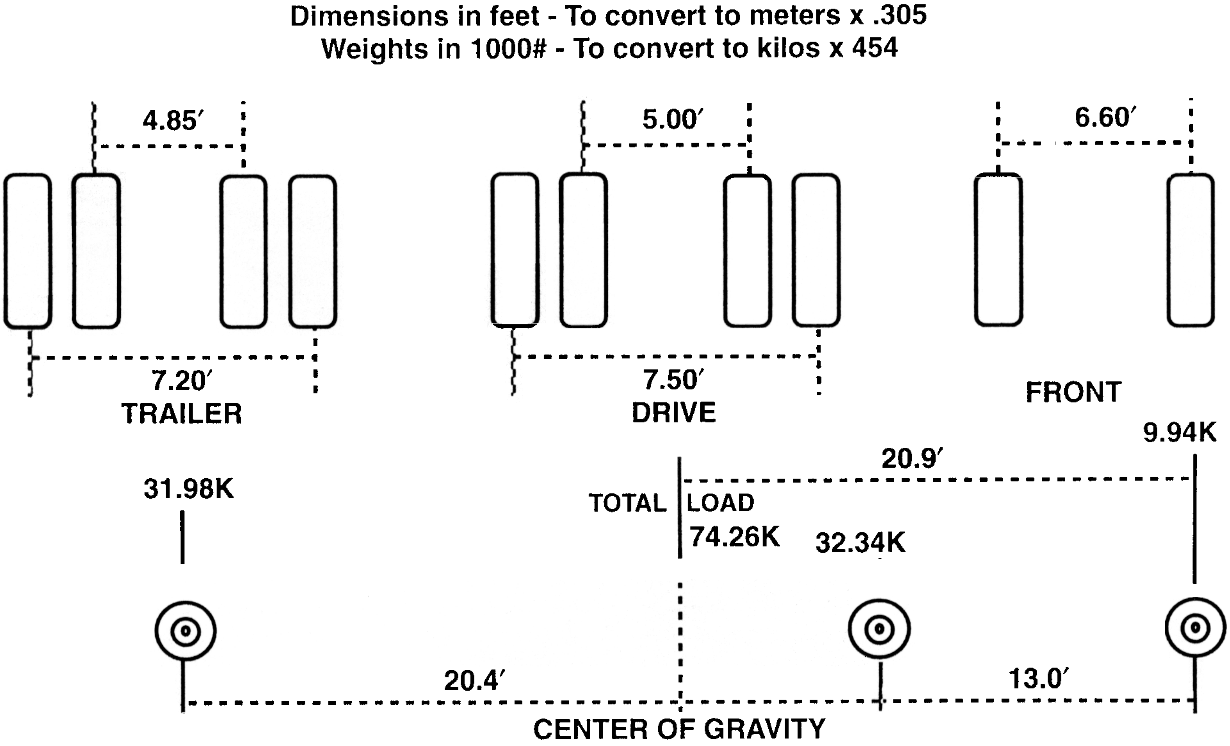


FIGURE 4. AXLE SPACING 1968.

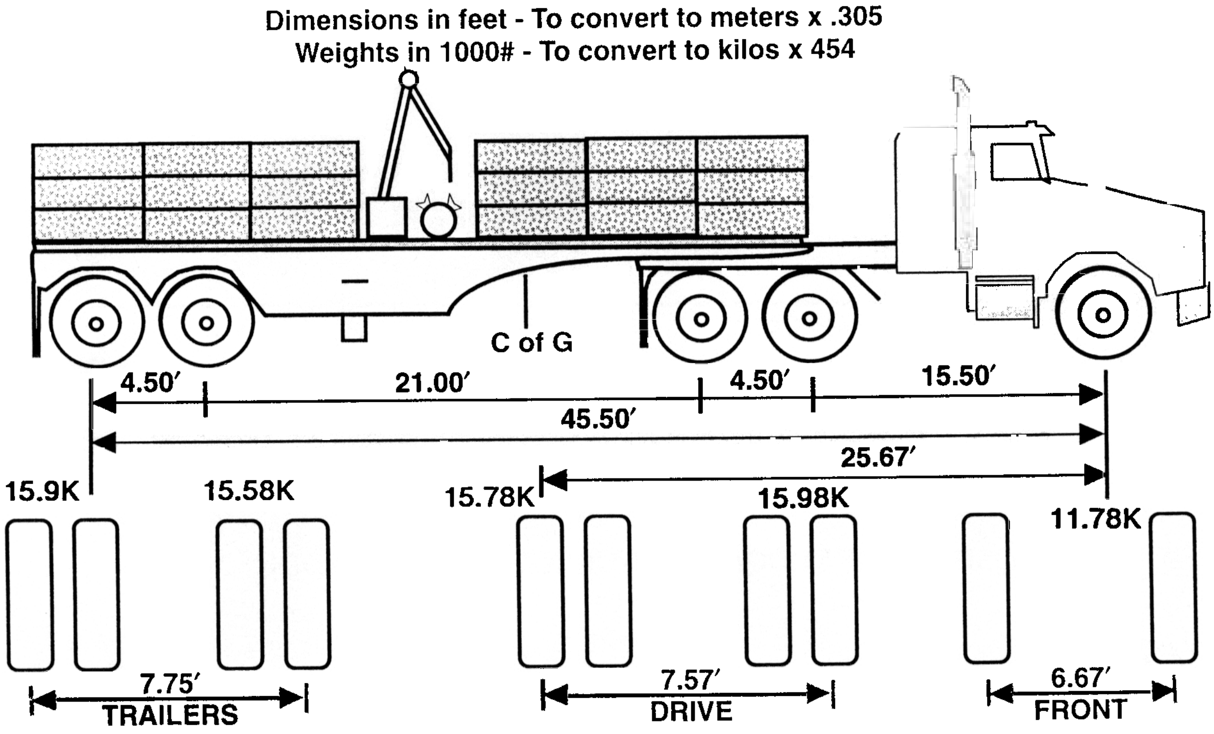


FIGURE 5. AXLE SPACING 1992

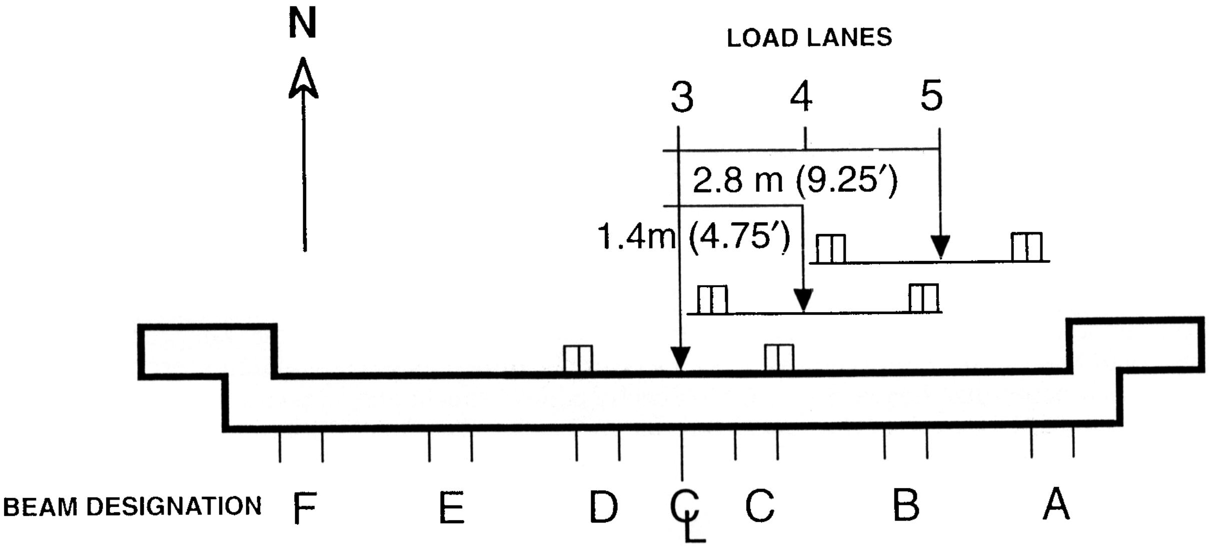


FIGURE 6. LANES TRUCK TRAVERSED BRIDGE

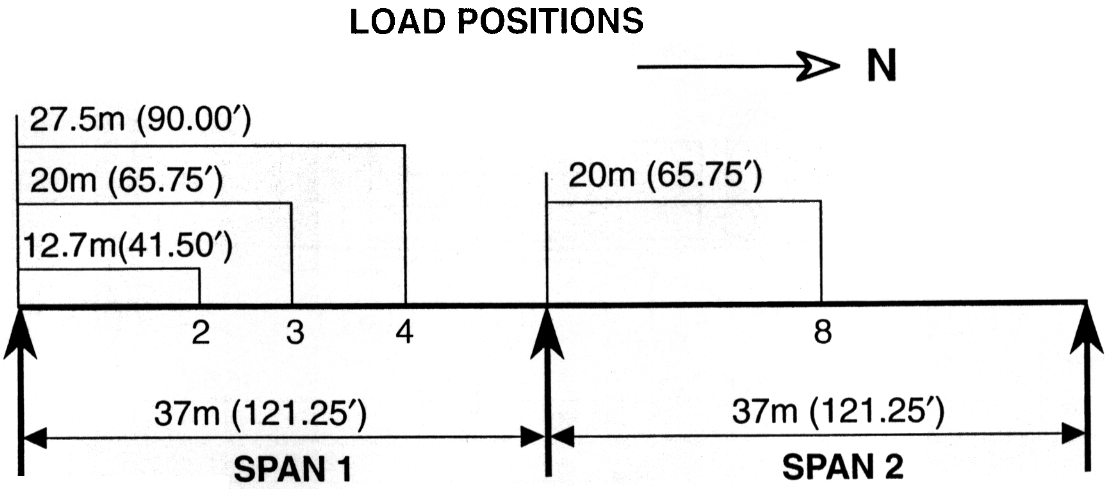


FIGURE 7. POSITION OF TRUCK (CG) DURING STATIC LOADING.

LOAD TEST RESULTS

The original loadings and measurements were duplicated with typical calculated and measured deflection curves shown graphically in Figure 8. Maximum deflection for one particular beam due to a mid-point load was 7.1 mm (.28 inches), measured at 18.4 m (60.5 feet) from the unrestrained end of the span. This compares very well with the original deflection which was recorded to be 6.6 mm (.26 inches) measured at 15.4 m (50.5 feet). Rolling load deflections shown in Figure 9 were comparable, but slightly less in magnitude than the static loads. Comparison of predicted with measured deflections for the bridge profile of several beams are shown in Figure 10.

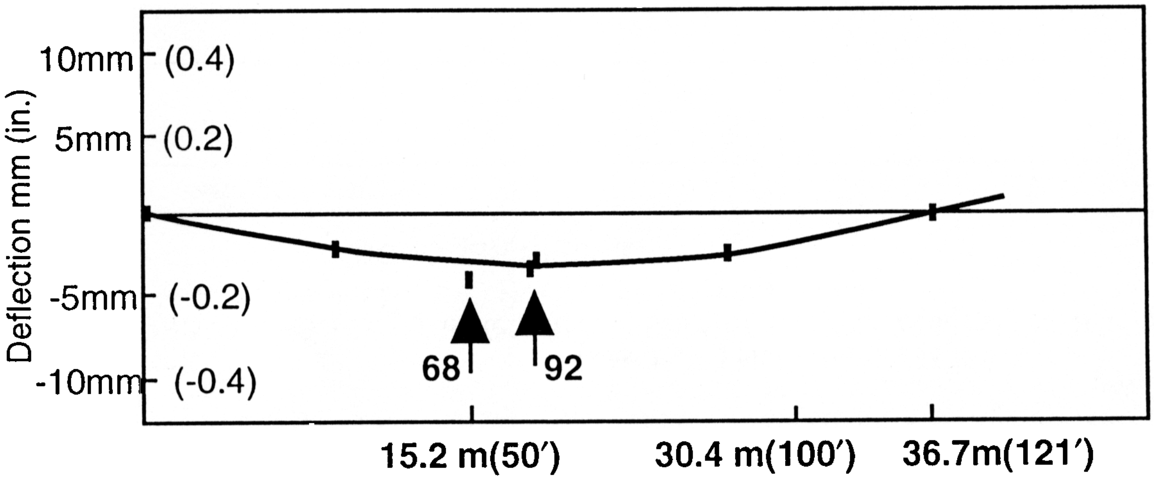
Strain measurements across the bridge profile were also duplicated and are shown for one particular loading in Figure 11. Again, the strain measurements compare very closely for most locations located in areas of significant strain. Highest strains of 85 and 72 microstrains were recorded for the exterior beam at 15.4 m and 18.4 m (50.6 and 60.5 feet) when loaded with a truck in the appropriate lane. Again, comparison of 1994 and the 1968 data shows bridge behavior to be essentially similar with the profiles closely matched.

FATIGUE

It appears that the dynamic testing determination of the flexural characteristics of the 31 year old long-span structural lightweight concrete bridge (Realcrete) corroborate the conclusions of fatigue investigations conducted on small (Labcrete) specimens tested under controlled conditions in numerous laboratories [3], [4], [5]. In these investigations, it was generally observed that the structural lightweight concretes performed as well as, and in most cases, somewhat better than companion normal density control specimens. Several investigators have suggested that improved performance was due to the elastic compatibility of the lightweight aggregate particles to that of the surrounding cementitious matrix. In structural lightweight concrete, the elastic modulus of the constituent phases (coarse aggregate and the enveloping mortar phase) are relatively similar while with normal density concretes the elastic modulus of most ordinary aggregates may be as much as 3 to 5 times greater than their enveloping matrix [6]. With structural lightweight concretes, elastic similarity of the two phases of a composite system results in a profound reduction of stress concentrations and a leveling out of the average stress over the cross section of the loaded member. Normal density concretes having a significant elastic mismatch will inevitably develop stress concentrations that result in extensive microcracking in the concrete composite.

Additionally, it is well known that because of the pozzolanic reactivity of the surface of the lightweight aggregate [7], the quality and integrity of the contact zone of structural lightweight concrete is considerably improved. As the onset of microcracking is most often initiated at the weak link interface between the dense aggregate and the enveloping matrix, it follows that structural lightweight concrete will develop a lower incidence of microcracking [8].

BEAM C LOAD CASE 7



BEAM C LOAD CASE 2

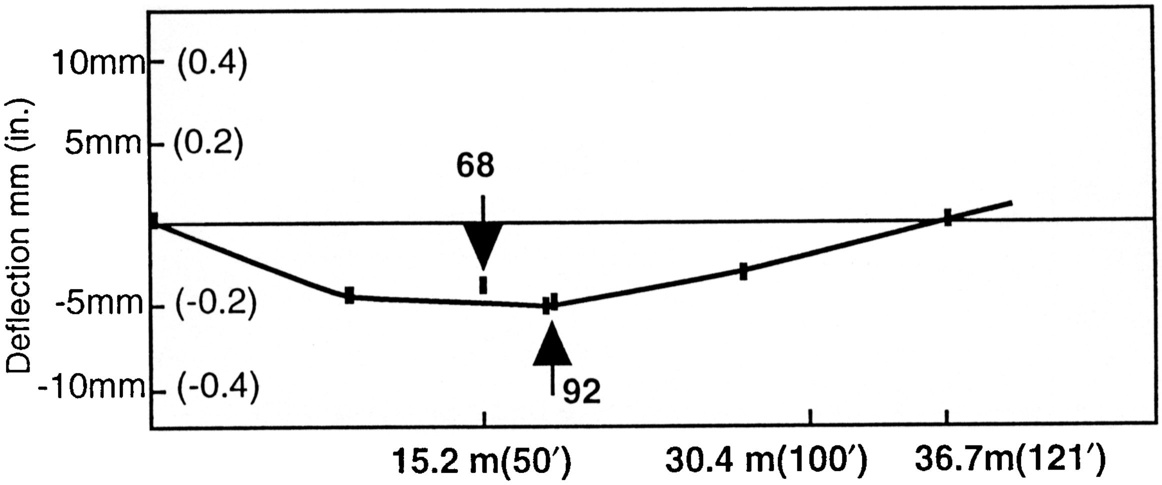


FIGURE 8. FLORIDA DOT PREDICTED DEFLECTIONS COMPARED WITH 1968 AND 1992 MEASUREMENTS

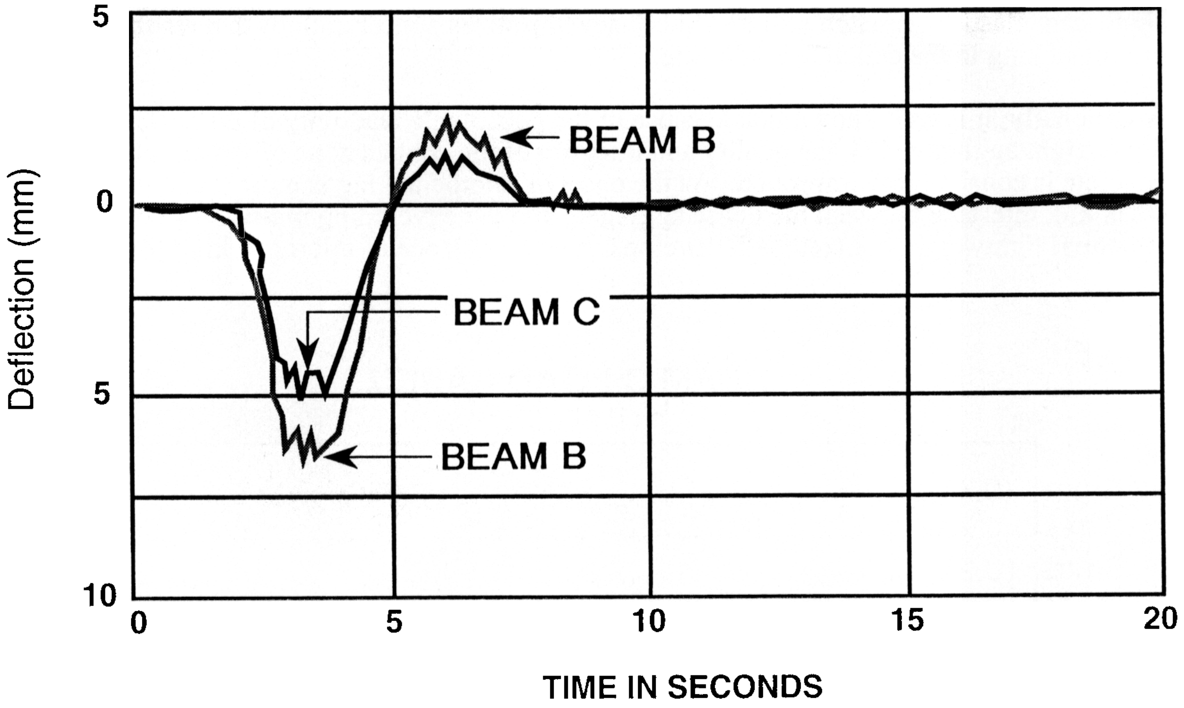


FIGURE 9. DEFLECTION OF BEAMS B AND C DUE TO TRUCK TRAVELING AT 48 KM/H (30 MPH) IN LANE 4.

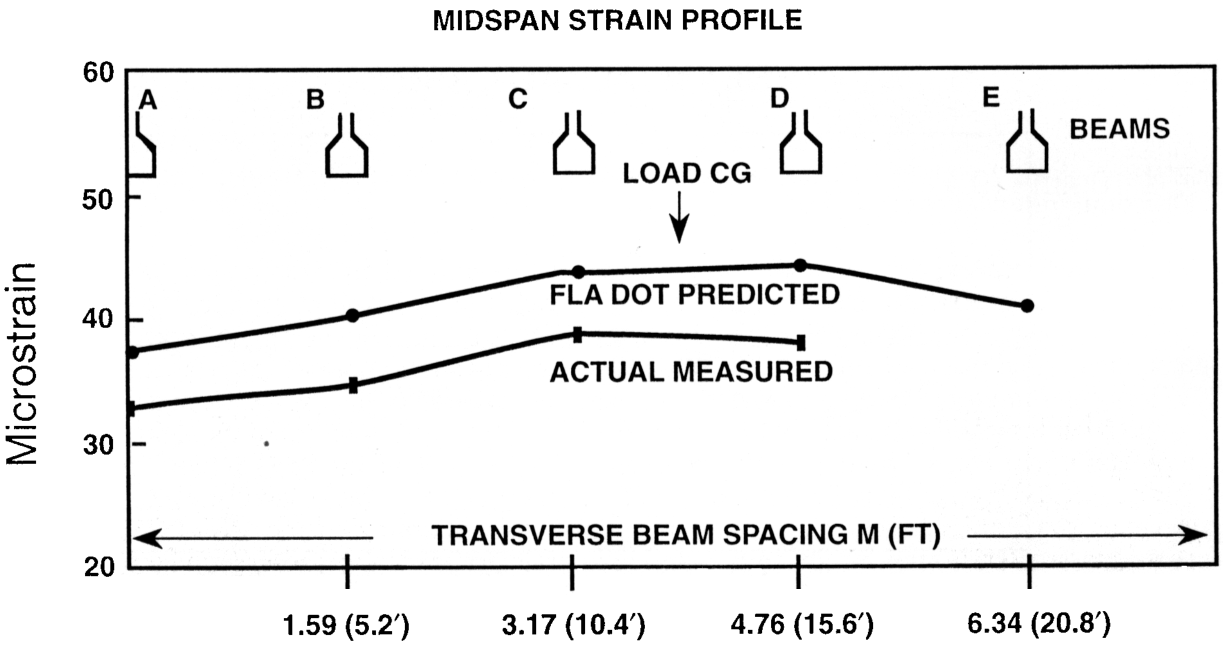


FIGURE 10. PREDICTED AND MEASURED TRANSVERSE STRAIN PROFILE.

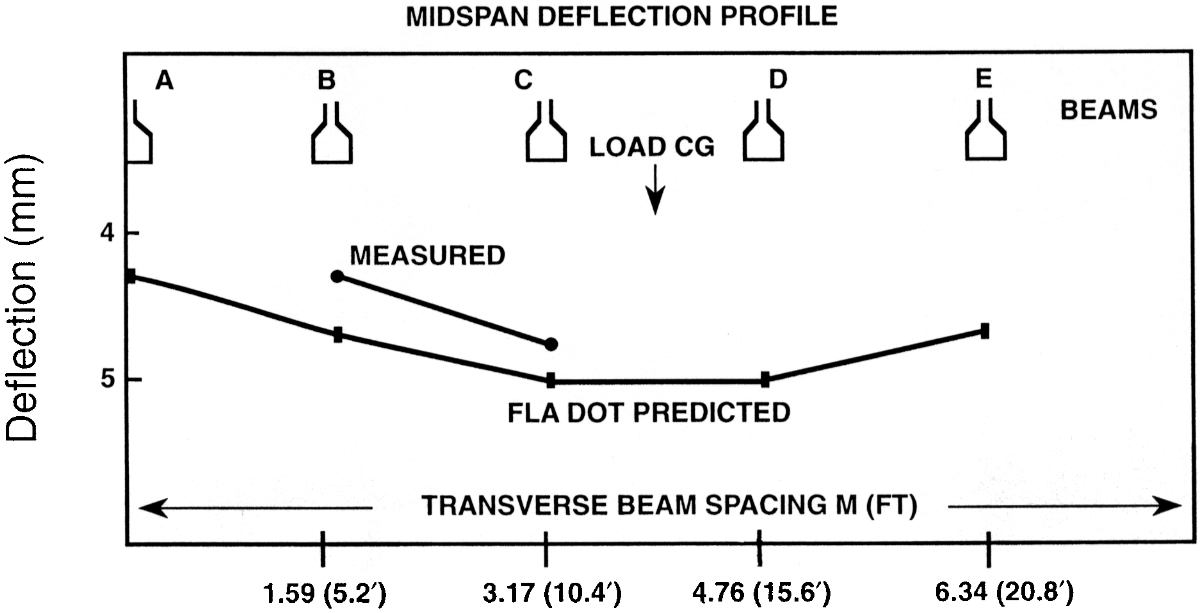


FIGURE 11. PREDICTED AND MEASURED TRANSVERSE DEFLECTION PROFILE

SEBASTIAN INLET BRIDGE

Also in 1964, the Florida Department of Transportation utilized a structural framing design developed by the consulting engineering firm of Howard Needles Tammen & Bergendorf in the construction of a drop-in, long-span structural lightweight concrete girder system at the Sebastian Inlet where the Indian River flows rapidly into the Atlantic Ocean. The 22.3 m (73 ft) approach spans were constructed of Type 3 normal density concrete. At the center are three main spans of 30.5, 54.9, and 30.5 m (100, 180, and 100 ft) long (Figure 12). The cantilever arms from each side support 36.6 m (120 ft) long drop-in girders which, thus, complete the required 54.9 m(180 ft) span over the main channel. This cantilever concept directed the designers to lightweight concrete since it was obviously highly desirable to keep the weight of the drop-in section to a minimum. The 1.83 m (6 ft) deep, 36.6 m (120 ft) long precast, prestress girders and the cast-in-place deck slab, curb and parapets for the drop-in portion are of structural lightweight concrete.

The surface wearing characteristics of this bridge were observed after more than 30 years of exposure. Close examination of Figure 13 indicates that the wear of the structural lightweight slab concrete surface on the left of the expansion joint is essentially the same if not slightly less than the normal density concrete. This "Realcrete" demonstration of wearing characteristics is of particular importance in order to determine the contribution of the coarse aggregate toughness to the overall wearing characteristics of the concrete. Degradation losses of the lightweight aggregate, when tested by the C Grading of ASTM C131, "Standard Test Method for Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine", are generally less than the maximums permitted under ASTM C33 requirements for normal weight aggregates. Laboratory abrasion test losses are however, in general, greater for lightweight aggregates than most ordinary aggregates. The entirely satisfactory long-term wearing surface performance of the structural lightweight concrete on this bridge, was essentially the same as that of the normal weight concrete. This merely demonstrates yet another instance when primary emphasis should be given to the "Realcrete" performance as opposed to accelerated, short-term, artificially contrived "Labcrete" test results that are presumed to correlate with natural wearing and durability considerations.

FIGURE 12. SEBASTIAN INLET BRIDGE OVER INDIAN RIVER, FLORIDA.

FIGURE 13. EXPOSED WEARING SURFACE, LIGHTWEIGHT CONCRETE BELOW THE JOINT AND NORMAL WEIGHT CONCRETE ABOVE THE JOINT, SEBASTIAN INLET BRIDGE, FLORIDA.

CONCLUSIONS

Comparison of the 1992 measurements with those recorded in 1968, as well as a detailed inspection of the Fanning Springs Bridge, confirm that the bridge has lived up to the designers expectations after 31 years of service. Deflection and strain data, when taken as a whole, indicates no increase in flexibility over time. When measurement uncertainty is included, most of the individual measurements may be considered as essentially the same. The structural lightweight aggregate concrete used in the decks and girder of this experimental bridge have met expectations and performed satisfactorily in this unique design. This investigation also successfully demonstrated that the Florida Department of Transportation bridge rating system program may be used to verify bridge performance and the model used provided data that correlated well with the service load response.

Wearing characteristics of exposed lightweight concrete slab surfaces of the Sebastian Inlet Bridge were observed to be essentially the same as adjacent ordinary concrete slab surfaces after more than 30 years of exposure.

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