Instrumentation of Deep Corrugated Steel Box Culverts

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The design procedure for predicting the structural performance of deep corrugated box culverts was investigated. Load capacity and deflection measurements were conducted on a fully instrumented, steel box culvert. Response due to the construction sequence was monitored, as was response to static loads of 16, 32, and 42 kips applied with a loaded dump truck.

Several researchers have reported on the design and performance of metal box culverts in the last few years (*1–3*). All of the culverts reported on were made of corrugated aluminum or steel plate. Their moment capacity was increased with transverse reinforcement using angle sections or corrugated sections. There is much controversy as to whether this structural system acts as composite or noncomposite during construction and application of live loads. The dispute can be avoided by utilizing a deep corrugated plate to provide additional moment of inertia without additional stiffening elements.

In this study, a deep corrugated steel culvert was installed on S.R. 554 in Gallia County, Ohio, in May, 1988. This box culvert had a span of 15 ft, a rise of 4 ft 11 in., and a length of 44 ft. The culvert was fully instrumented to monitor the responses due to the construction sequence and live load.

CULVERT DESCRIPTION AND INSTRUMENTATION

The dimensions of the culvert plate, shown in Figure 1, are corrugation width, 15.0 in.; depth, 5.5 in.; and thickness, 0.133 in. This deep corrugated steel culvert is not stiffened by ribs. Because the deep corrugated plates are difficult to bend, haunches are fabricated by welding at the intersections of the formed crown plate and the side plates. This results in a very stiff connection, as shown in Figure 2. The longitudinal supporting edges of the culvert are anchored into reinforced concrete footings. The culvert was placed in position across the creek with reinforced concrete headwalls at both ends.

An instrumentation scheme was planned to determine strains in the culvert structure and the backfill material and deflections at critical sections of the culvert. In this study it is assumed that the stress states of corrugated structural plates were biaxial. Thus the bending moment and thrust were determined using biaxial electrical strain gauge readings. To supplement the electric gauges, vibrating wire strain gauges were also mounted because of their better long-term stability and lesser sensitivity to environmental effects. A total of 52 biaxial gauges and 8 strain gauge rosettes were mounted inside the plate at sections, as shown in Figure 1. Ten vibrating wire gauges were installed at sections 2, 4, 7, 10, and 12, as shown in Figure 2.

Four horizontal rod extensometers were positioned to monitor horizontal movements of the soil near the culvert sides and in the soil cover at the top of the culvert, as shown in Figure 2. Deflection of the culvert was measured at 13 points around the inside culvert periphery at mid-length with respect to two reference points firmly embedded in concrete in the stream bed. Displacement monitoring points were marked by attaching eyebolts to the culvert, and displacements were measured with a tape extensometer. By taking two precise measurements to each eyebolt, the vertical and horizontal movements could be calculated.

Backfilling of the deep corrugated steel culvert was begun on May 16, 1988. Granular backfill material (standard #310 graded sand) was placed in lifts of 4 in. Each lift was compacted to at least 90 percent of the standard Procter maximum density using a hand-operated tamper. The compaction of soil was monitored with a Troxler nuclear density gauge.

A height of 80 in. of fill above the top of the footing was completed by May 19. The next day a 5 in. subbase of crushed limestone was placed, leveled, and compacted. This was followed by three lifts of asphalt paving. Five in. was placed in the first lift on May 23 and 3 in. added after three days. An additional lift of 1.75 in. was placed later.

One week after the completion of the pavement construction, three static live loads consisting of 16, 32, and 42 kips (1 kip equals 1,000 lb) were applied at positions shown in Figure 3. The loads were applied with the rear axle of a gravel-filled dump truck by deflating the tires on the central axle as shown in Figure 4. This was done to simulate 0.5, 1.0, and 1.5 times AASHTO H20-44 loading conditions. A complete load test was conducted by moving the rear axle wheels to five locations on the culvert. The positions of loading were arranged to take advantage of symmetry, since the fill depth was level. Locations at which loads were applied were chosen to simulate static traffic situations.

Recordings of strain gauge readings were taken with a Model HP 3497A data acquisition system in conjunction with an HP personal computer. An initial set of all gauge readings was recorded prior to backfilling. The electric strain gauge (uniaxials, biaxials, and rosettes) were read at the completion of each lift. The reading used for purposes of analysis was the average of five individual readings, which were recorded on

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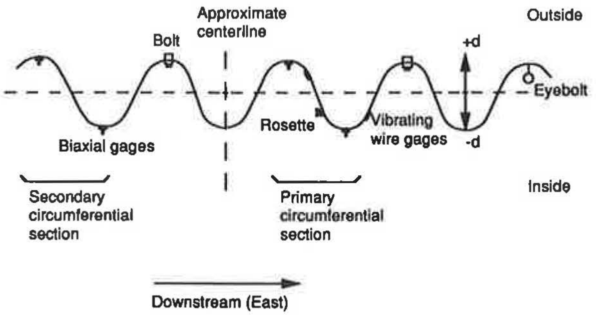

FIGURE 1 Typical section of deep corrugated steel (*d* is the distance to the neutral axis).

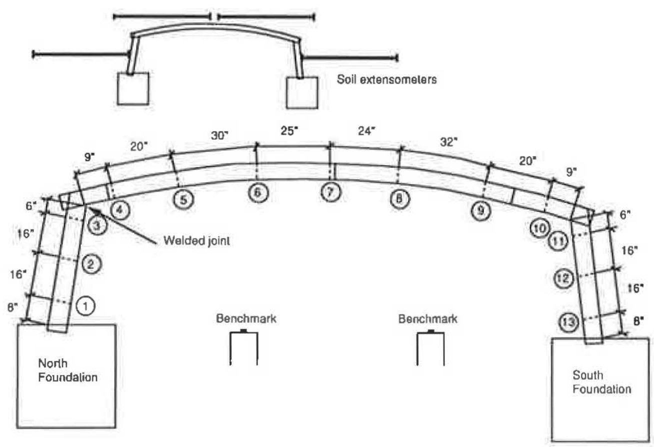

FIGURE 2 Cross section of test culvert showing 13 instrument locations and 4 soil extensometer locations.

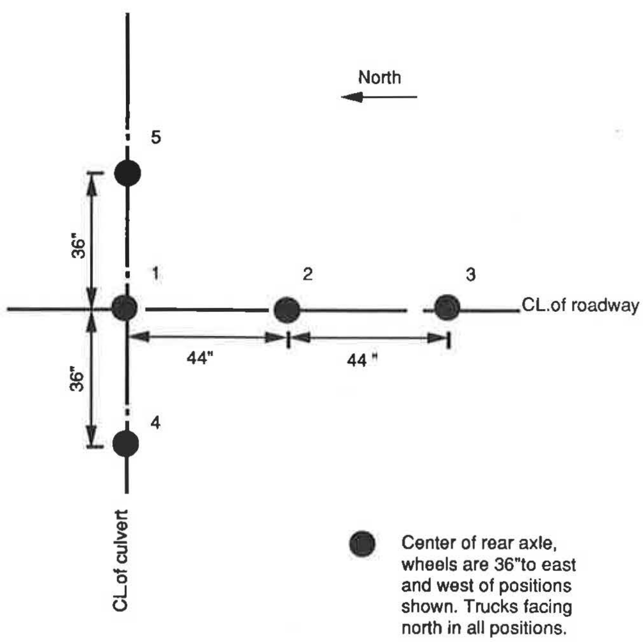

FIGURE 3 Live load application points (center of rear axle; wheels are 36 in. east and west of positions shown; truck facing north in all locations).

FIGURE 4 Application of live load (note flat tires on central axle to shift weight to rear axle).

a diskette and printed out on paper. This average was used in subsequent calculations as one reading. The average scanning time per gauge was 1.2 seconds in order to eliminate any undesirable noise in the readings. The vibrating wire gauges and the rod extensometers were also read at the end of each lift. Deflection measurements, on the other hand, were recorded every second lift, because construction had to be halted each time deflection readings were made. A hose level was used to monitor movement of the internal reference points as well as the culvert foundations. The hose level consists of a long plastic hose filled with colored water connected to a measuring scale on a rigid rod. One end of the level was fixed to a bench mark located outside the culvert on firm ground. This simple apparatus had an accuracy of $\frac{1}{16}$ in. and permitted measurements to be made quickly and easily.

Since the thickness of the culvert plate with respect to the corrugation depth was small, a dial gauge was mounted to monitor the change in corrugation depth, as shown in Figure 5. The highest point in the culvert center was selected for monitoring, as it was expected to give the largest distortion. The maximum change in corrugation depth recorded was 0.014 in.

RESULTS

The change of the culvert shape during the construction sequence is shown in Figure 6. Examination shows a slight

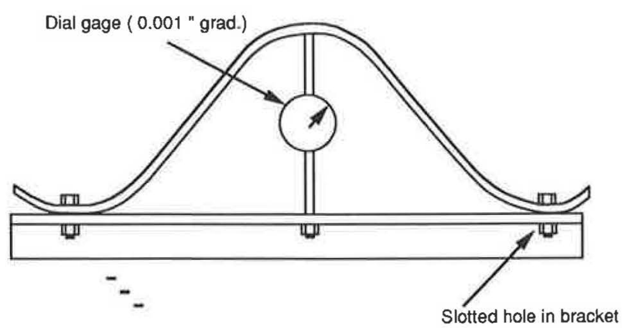

FIGURE 5 Attachment to measure change in corrugation depth.

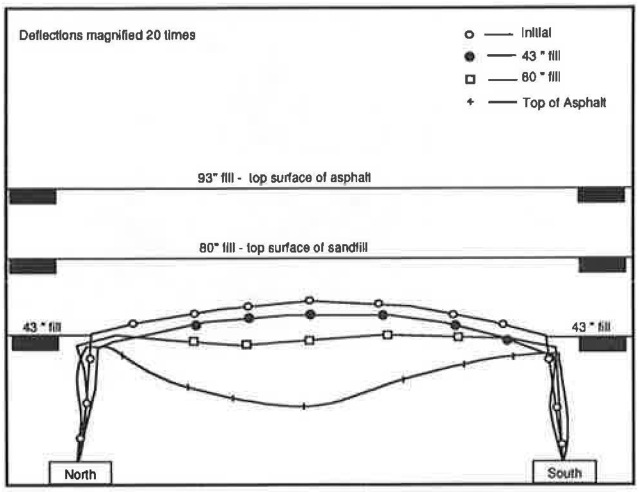

FIGURE 6 Changes in culvert shape during construction sequence (deflections magnified 20 times).

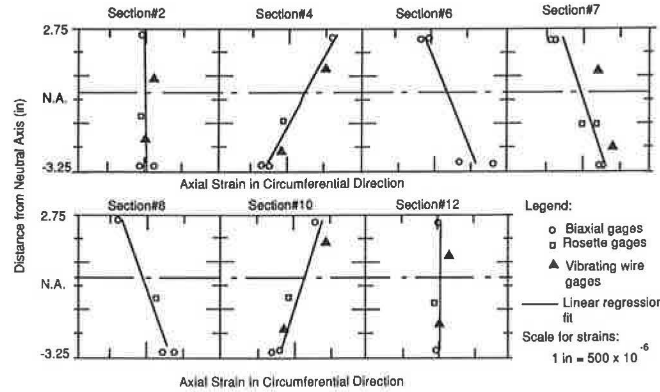

FIGURE 8 Strain measurements compared to beam response for 78 in. of backfill.

shift of the culvert during backfill. This shift might be due to the sequence of placing and compacting fill. Such deflection illustrates the importance of proper backfill and compaction procedures.

The results of the crown deflections are shown in Figure 7. During the first few lifts the culvert did not move significantly. This result contrasts with previously reported investigations (*1,2*), where the crown deflected upward. This culvert was initially composite, whereas the other culverts reported on were initially noncomposite. Most of the large downward vertical movement was recorded during the placement of asphalt and subsequent roller compaction. The maximum deflection under a 42 kip live load was 0.21 in.

Electric strain rosettes were mounted between the centroid and the peaks and valleys of the plate corrugations to determine if this structure can be modelled as a beam or a folded plate. Figures 8 and 9 confirm a beam response as indicated by the linearity of strains with respect to depth. During the analysis it was noticed that strain readings obtained with the vibrating wire gauges and the electric strain gauges gave almost identical results.

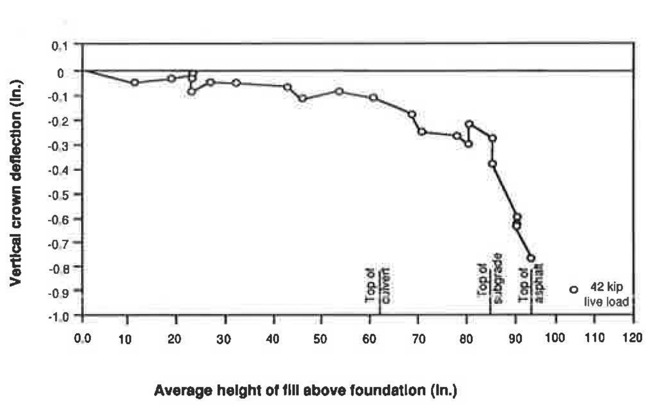

FIGURE 7 Crown deflection of culvert during construction sequence and under 42 kip static live load.

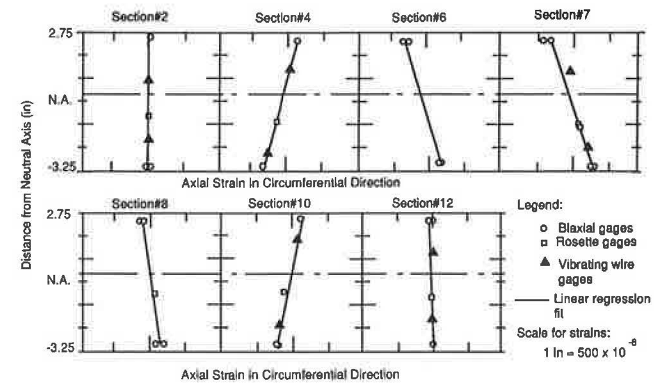

FIGURE 9 Strain measurements compared to beam response for 32 kip static live load at Position 1.

Settlement of the foundations, as observed with the hose level, was monitored independent of the interior bench marks. The reference points in the stream bed did not move appreciably in the vertical direction and moved only slightly in the horizontal direction. Accuracy of settlement was 0.02 in. Deflection measurements recorded for the culvert were taken to be the vector difference of foundation settlement and culvert deflections.

Moment and thrust due to the live load are shown in Figure 10, where they are plotted with respect to position of loading. Positions 1, 2, and 3 were centered over the culvert, midway between eyebolts and strain gauge section. Positions 4 and 5 were such that one wheel is located directly over the center of the culvert.

For live loads, the two instrumented cross sections behaved differently. As expected, maximum moment occurred at the section most directly under the wheels. This occurred in the primary section when loaded at positions 4 and 5, and in the secondary section (Figure 1) when loaded at position 1. Thrust also responded differently at the two sections due to the same

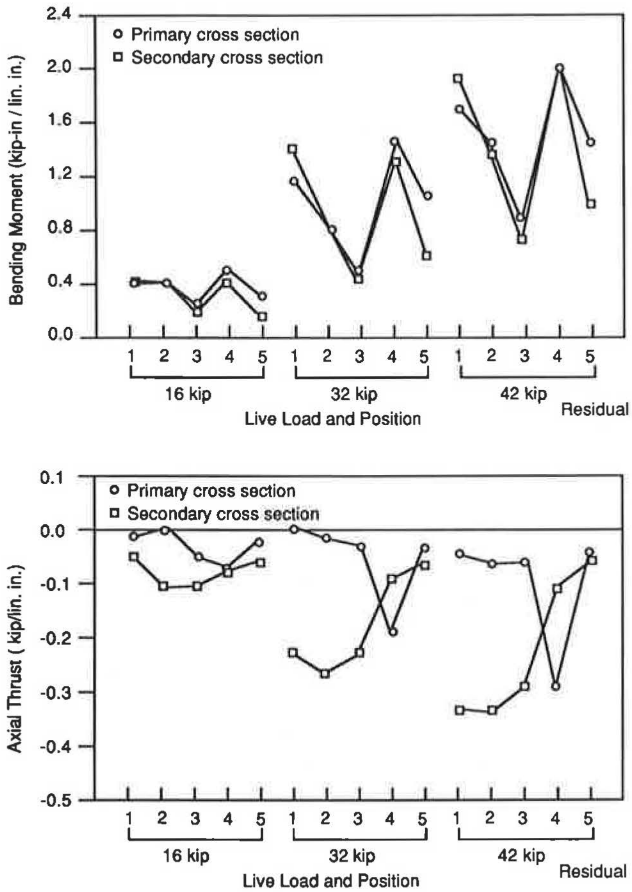

FIGURE 10 Bending moment (top) and axial thrust (bottom) due to varying static live load at five positions.

effect. The maximum moment and thrust recorded were 24 kip-in. and −3.5 kip per linear foot.

CONCLUSIONS

Based on the field instrumentation results, the deep corrugated culvert behaves as a beam. Furthermore, there is no major distortion of corrugation geometry during construction sequence or live load application, and the moment of inertia can be kept constant. This type of structure does not deflect upwards at the crown in early construction; most vertical deflection occurs as pavement is placed. The foundation movement was significant, however, and must not be ignored. The true deflection must take into account the foundation movement, otherwise results will be conservative.

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