Investigation of the Structural Adequacy of *C* 850 Box Culverts

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The structural behavior of American Society for Testing and Materials *C* 850 box culvert sections resulting from live load was investigated using theoretical analyses, field testing, and model testing. The field testing was performed on box culvert sections that were put into service after testing. These box culvert sections were installed on state routes in Ohio using construction crews and normal construction procedures. An overview of these analyses is presented in this paper. The initial purposes were to determine whether shear connector plates are required to transfer the load across a joint between adjacent box culvert sections, and if the recommended maximum spacing of 30 in. was appropriate. Testing at the first site indicated that shear connector plates are not required to transfer the load. The primary purpose of testing at the second site was to verify the results from testing at the first site. For these box culvert sections, there were no provisions for shear connectors, hence the reinforcing steel was not cut because the shear connector attachments were not installed. The results verified those from testing done at the first site. Additionally, it was concluded that *C* 850 box culvert sections are overdesigned structurally. Before testing was undertaken at the third site, a redesign was executed for *C* 850 box culvert sections. The redesigned *C* 850 box culvert section was essentially the same as the *C* 789 design with 4 ft of earth cover and HS 20 loading. Testing at this site demonstrated that the redesigned *C* 850 box culvert section performed satisfactorily. The major conclusions are that shear connectors are not required on American Society for Testing and Materials *C* 850 box culvert sections and that these sections are overdesigned structurally. It was also concluded that the deflection along an edge of the top slab was so low, even with the wheel load applied at that edge, that the American Association of State Highway and Transportation Officials' edge beam requirement need not be enforced.

The design requirements for box culvert sections installed with less than 2 ft of cover and subjected to highway loadings are enumerated in American Society for Testing and Materials (ASTM) Specification *C* 850 (*1*). These requirements generally follow the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges* (*2*). The requirements of interest in this paper (as applied to box culvert sections) are

1. Use of shear connector plates,
2. AASHTO edge-beam requirement, and
3. Applicability of AASHTO distribution width for wheel loads.

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Two separate studies were undertaken to investigate these requirements. These studies included theoretical analyses, model testing in a laboratory, and field testing of prototypes.

THEORETICAL ANALYSES

In the theoretical analyses, the structures were idealized into plane frames with a unit width. The corresponding live load was determined using the AASHTO distribution width for a wheel load. The dead load associated with 2 ft of earth cover and the weight of the box culvert, as well as the lateral earth pressure on the side walls, was also considered. The analyses were performed using classical methods of structural analyses and the finite element method.

A three-dimensional stress analysis was also performed using the finite element method. STRUDL was used for this analysis; prismatic elements with triangular cross sections and six nodes were selected. There were three linear degrees of freedom at each node of the element.

In these analyses, deflections, bending moments, shear, and normal forces were calculated. Reinforced concrete design was performed using the ultimate strength method.

FIELD TESTING

During the field testing of prototype structures, deflections of the top slab were observed and recorded along both edges of a joint that was subjected to load. Additionally, electric resistance strain gages had been mounted at selected locations and strain magnitudes were recorded. Primarily, strain values were recorded for the top slab.

All prototype structures were cast by the same manufacturer, Hyway Concrete Pipe Company in Findlay, Ohio, with tongue-and-groove joints. The cylinder strength of the concrete was a minimum of 5,000 lb/in.^{2} and the minimum yield strength of the welded wire fabric reinforcing was 65,000 lb/in.^{2}. Normal construction techniques were followed except that over-reinforcing was minimized. The theoretical steel areas were matched as closely as practicable.

For the first investigation (*3*), strain gauges were mounted on both the welded wire fabric and the concrete. Also, a few strain gauges were mounted on the shear connector plates. Deflection and strain data were recorded for three load conditions:

1. Wheel load applied directly to the top slabs of *C* 850 box culvert sections without shear connector plates installed,

2. Wheel load applied directly to the top slabs with shear connector plates installed, and
3. Wheel load applied to the asphalt pavement placed over the box culvert sections with shear connector plates installed.

For these conditions, a (simulated) wheel load of 20,800 lb (AASHTO HS 20 16,000-lb wheel load plus 30 percent impact) was applied to a simulated tire print (a 10-in. by 20-in. wooden block). Only one wheel load was applied on the structure at a time. The structure was Ohio DOT bridge number MAR-309-09.42 (located in Marion County) and used six box culvert sections with 12-ft span by 6-ft rise and a total laying length of 36 ft. The primary purposes of this investigation were to determine whether shear connectors were required and whether the 30-in. maximum spacing was appropriate. The geometry of an individual box culvert is presented in Figure 1; the overall configuration of the structure is shown in Figure 2. Because this structure was to be placed in highway service after testing, it was decided to limit the magnitude of the loading to 20,800 lb.

For the second investigation (*4*), strain gages were mounted on the concrete only. Two prototype structures were field tested in this investigation: PUT-109-02.67 and CRA-19-17.10. Deflection and strain data were recorded at each site. Based on the results of testing at the Marion County site, it was decided to load these box culvert sections until a hairline crack developed.

At Ohio Department of Transportation (DOT) bridge No. PUT-109-02.67 (located in Putnam County), the primary purpose was to verify the conclusions from MAR-309-09.42 on box culvert sections that did not have the reinforcing steel cut as is necessary when installing the shear connector attachments. This structure consisted of 17 box culvert sections with 12-ft span by 4-ft rise. These sections conformed to ASTM *C* 789 (*5*) for 3 ft of cover; the geometry of an individual box culvert is presented in Figure 3. However, they were subjected to live loading as though they were *C* 850 box culvert sections. After the sides had been backfilled to the elevation of the top slabs, the box culvert sections were loaded directly on the top slabs with a load of at least 20,800 lb before any earth cover

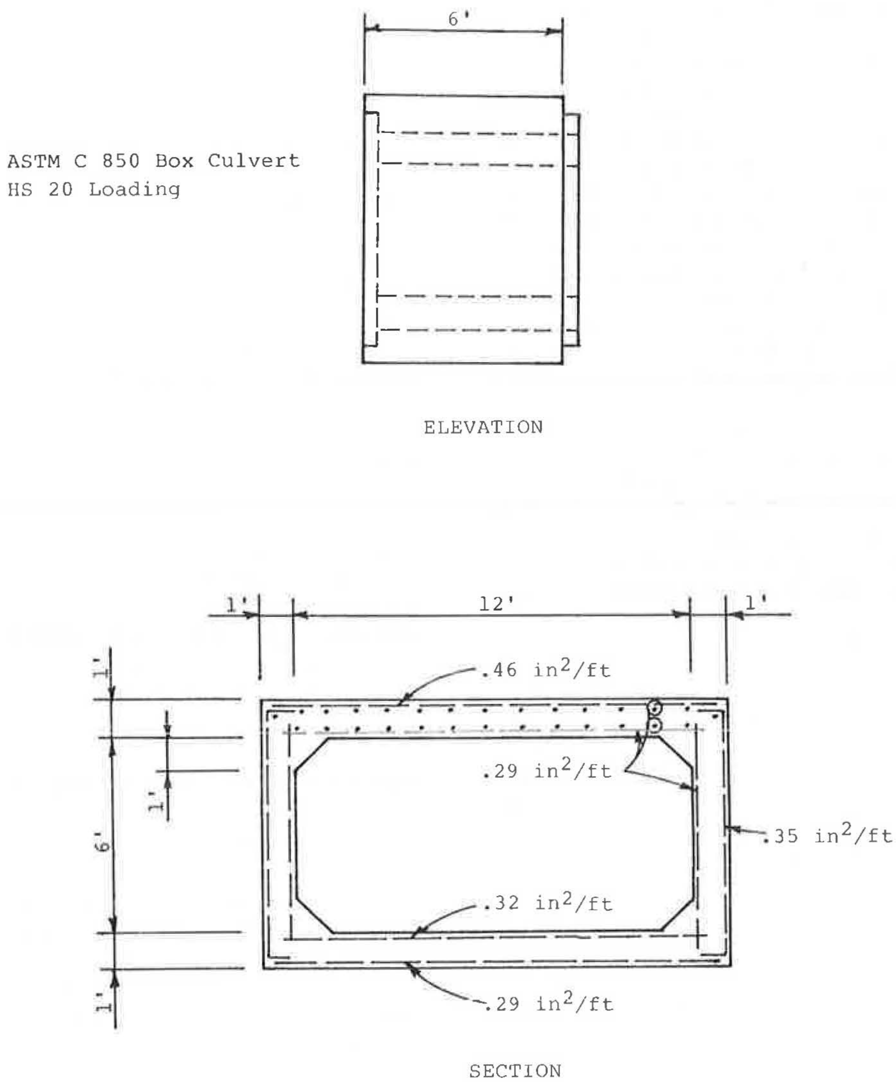

FIGURE 1 Details of 12-ft by 6-ft box culvert (Ohio DOT bridge MAR-309-09.42).

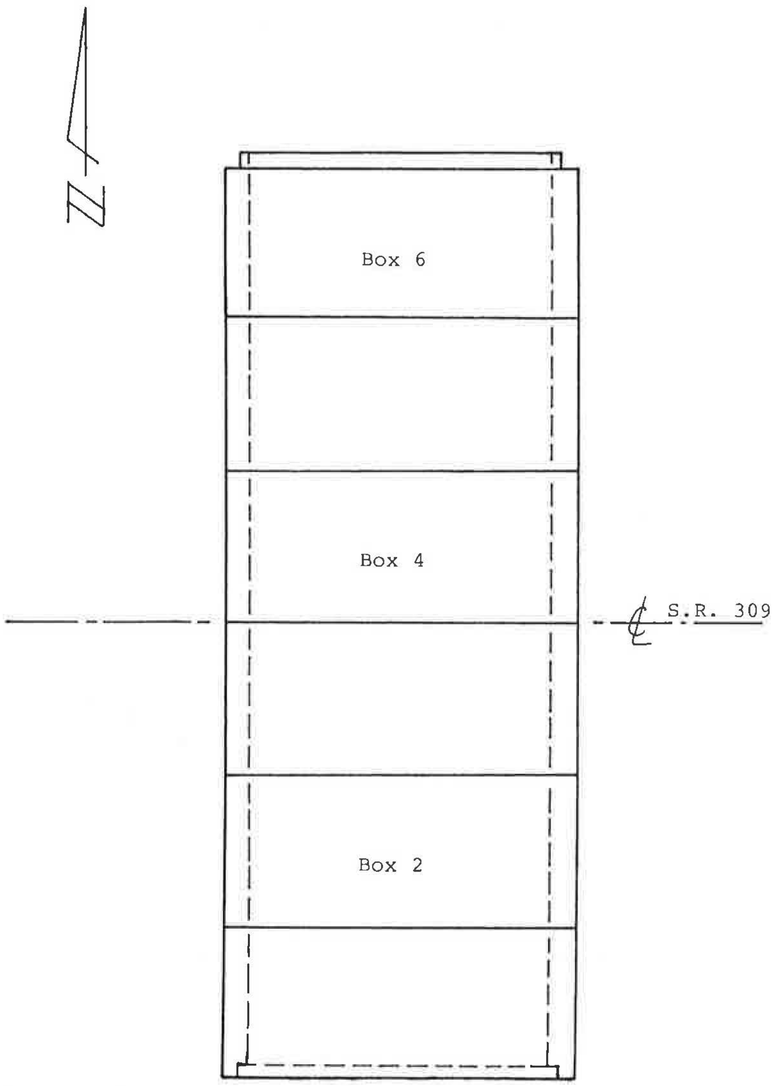

FIGURE 2 Arrangement of box culvert sections (Ohio DOT bridge MAR-309-09.42).

was placed. Four of the box culvert sections in this structure, as indicated in Figure 4, were subjected to single (simulated) wheel loads to produce a hairline flexural crack in the bottom sides of the top slabs.

At Ohio DOT bridge No. CRA-19-17.10 (located in Crawford County), the primary purpose was to verify a redesigned box culvert section that would be subjected to AASHTO HS 20 loading with asphalt pavement placed directly on the top slab. This structure consisted of 10 box culvert sections with 10-ft span by 6-ft rise. All walls of these sections were maintained at thicknesses of 10 in. so that conventional forms could be used in their manufacture. However, the reinforcing steel areas were less than those specified in ASTM C 850. The details of the redesigned box culvert are presented in Figure 5; the overall structure is shown in Figure 6.

MODEL TESTING

Model testing (*6*) was performed in a laboratory on ⅙ size scale models of each of the prototypes that were field tested. These models were cast in plywood forms using portland cement concrete and hardware cloth for the reinforcing steel. The concrete was proportioned to provide a 28-day compressive strength of 4,000 lb/in.^{2}. The aggregate used had a maximum particle size of ¼ in. The wires in the hardware cloth were spaced at ⅜ in. in both directions. To achieve the required areas of reinforcing steel, ⅛-in. diameter steel rods were wired to the hardware cloth as necessary. No attempt was made to match the distribution reinforcing or the shrinkage and temperature reinforcing. Each model was subjected to a scaled wheel load. The models were not subjected to lateral earth pressure or dead load (other than the weight of the model).

RESULTS AND CONCLUSIONS

The primary observations (at a wheel load of 20,800 lb) from the investigations of MAR-309-09.42 were as follows:

1. The maximum compressive strain in the concrete in top slabs is very low—of the order of 120 microin./in.

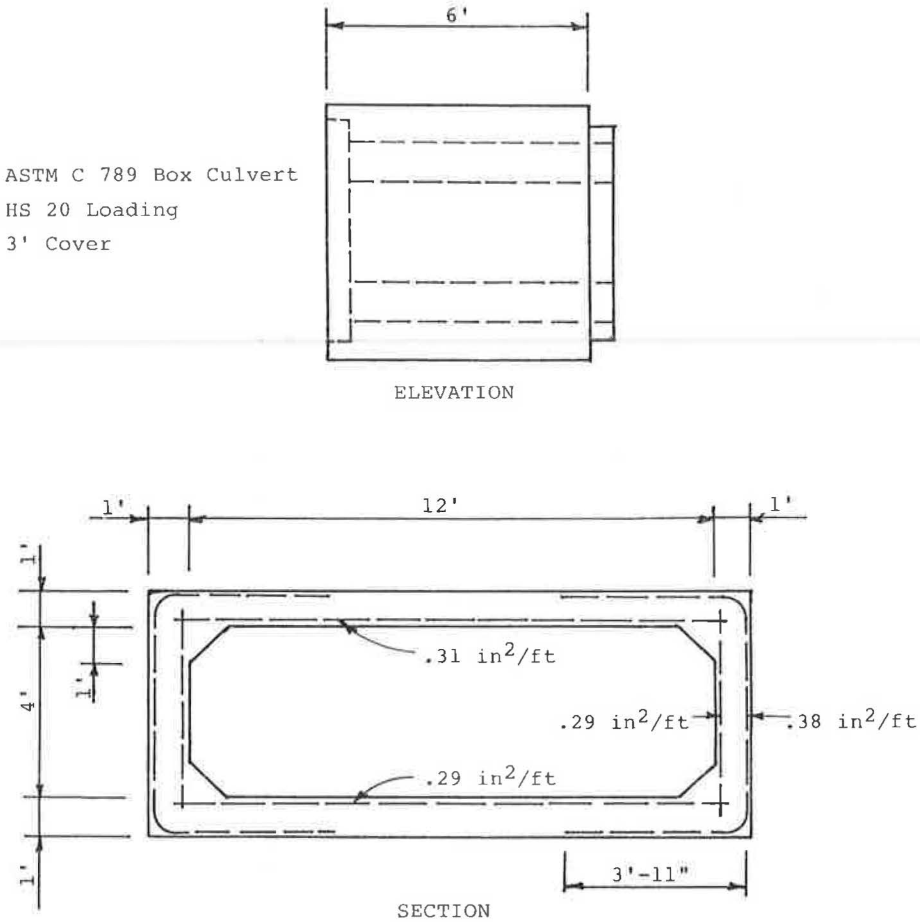

FIGURE 3 Details of 12-ft by 4-ft box culvert (Ohio DOT PUT-109-02.67).

2. The maximum tensile strain in the reinforcing steel is very low—of the order of 120 microin./in. (This is so low that the concrete did not develop tensile flexural cracks.)
3. The maximum deflection along a joint between adjacent box culvert sections was 0.027 in. without shear plates in place.
4. The average values of the deflections without shear plates for the loaded edge and relative deflection across the joint were 0.018 in. and 0.012 in., respectively.
5. The average values of the deflections were 0.014 in. and 0.006 in., respectively, with shear plates and without pavement.
6. The average values remained virtually the same after the pavement was in place.
7. The strain in the shear plates was very low—on the order of 120 microin./in.

Hence, because the deflections and strains were very low, it was concluded that shear connectors are not required to transfer load across a joint. Further, it was concluded that the AASHTO edge-beam requirement does not need to be enforced for box culverts. Note that it was necessary to cut the reinforcing steel to install the anchorages for shear connectors. Often this required cutting the reinforcing steel in locations of greatest bending moments. This did not appear to adversely affect the structural behavior of the box culvert sections. All of the above observations led to the conclusion that ASTM *C* 850 box culvert sections are overdesigned structurally.

The primary observations from the investigations of PUT-109-02.67 were

1. The maximum strain in the concrete was very low at design load plus impact.
2. The average deflection along a joint was very low at design load plus impact—of the order of 0.020 in. The average relative deflection was 0.012 in.
3. The average load required to produce a hairline flexural crack was twice the design wheel load plus impact.

The results of this testing confirmed the results from testing of MAR-309-09.42. It is emphasized that box culvert sections conforming to ASTM *C* 789 for 3 ft of earth cover were tested using *C* 850 live load conditions. Because none of the four box culvert sections subjected to load exhibited a hairline flexural crack at 20,800 lb, it is concluded that a *C* 789 design without shear plates is adequate for *C* 850 live-load conditions. The hairline cracks that developed at twice the design load plus impact virtually closed after the load was removed. This indicated that the reinforcing steel had not yielded. Note that

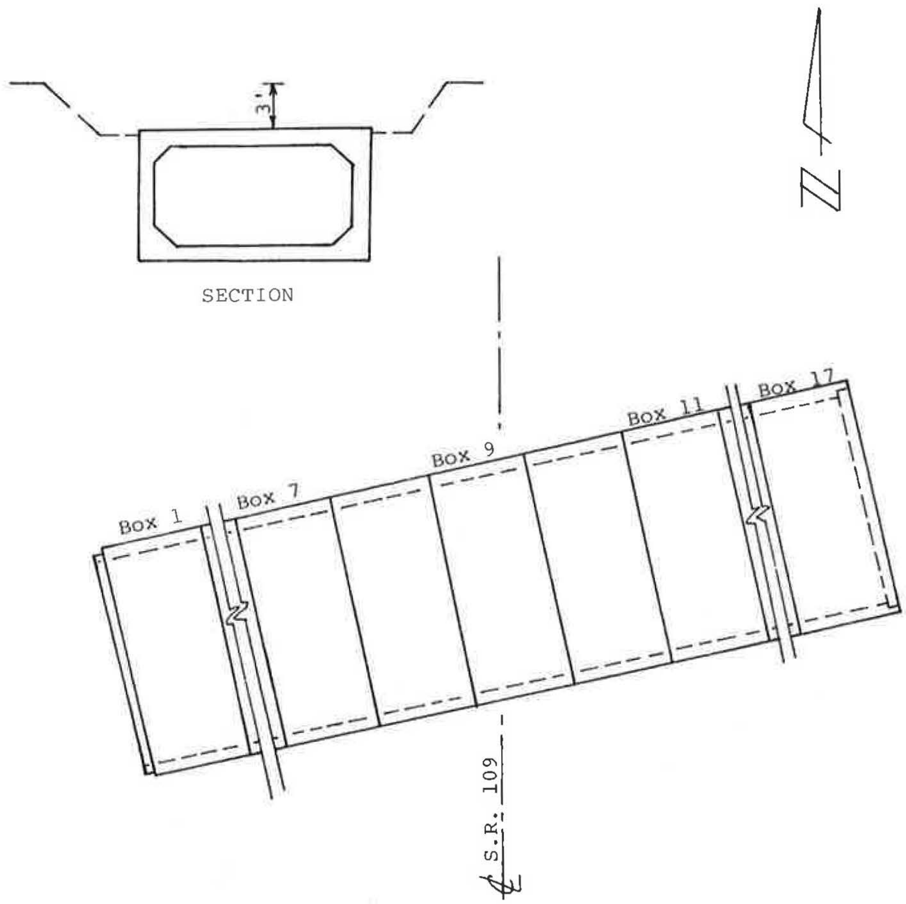

FIGURE 4 Arrangement of box culvert sections (Ohio DOT bridge PUT-109-02.67).

the average cracking load of 41,600 lb is almost equal to the ultimate design load of 45,140 lb (calculated using AASHTO load factors).

The deflection data from both MAR-309-09.42 and PUT-109-02.67 indicated that on the average a moderate amount of load is transferred across a joint between adjacent box culvert sections even when shear connectors are not used. A butyl rubber (ribbon) gasket was installed in each joint. It is believed that this transfer is due primarily to friction in the joint and the presence of the butyl rubber gasket. In many instances the unloaded side of the joint deflected as much as 50 percent of the loaded side. This load transfer appeared to be largely independent of whether the tongue end or the groove end was the loaded side of the joint. As might be suspected, the transfer resulting from friction was sensitive to how tightly the joint was made.

The primary observations (at a wheel load of 20,800 lb) from the investigations of CRA-19-17.10 were

1. The maximum strain in the concrete was very low both with and without the asphalt pavement in place.
2. The average deflection along a joint was very low without the pavement in place—of the order of 0.009 in. The average relative deflection was 0.003 in.
3. The average deflection along a joint was very low with the pavement in place—of the order of 0.013 in. The average relative deflection was 0.006 in.

Additionally, no hairline cracking was observed in the box culvert section subjected to a load of 30,350 lb without the pavement in place.

The results of this testing confirmed the results from testing of MAR-309-09.42 and PUT-109-02.67. It is emphasized that the box culvert sections for CRA-19-17.10 were redesigned box culverts. The redesigned box culverts used for *C* 850 live load conditions were very close to the *C* 789 design for 4 ft of earth cover. Hence, for CRA-19-17.10, the ASTM *C* 789 design for 4 ft of earth cover was used for a redesigned *C* 850 box culvert. It should also be noted that the box culvert sections for CRA-19-17.10 had a 10-ft span by 6-ft rise with wall thicknesses of 10 in.

A visual inspection of the box culvert sections for CRA-19-17.10 performed 21 months after they were installed revealed no signs of distress. Hence, the redesigned box culvert sections appear to be performing satisfactorily.

For the three box culvert sizes indicated, ⅙ size scale models were constructed and tested in a laboratory. These tests were performed on individual sections with the load applied along an edge. The measured strains on the concrete and deflections along the loaded edge agreed well with those quantities measured in the field. The strain values resulting from the application of the design wheel load plus impact on a scale model of the 12-ft by 6-ft box culvert are shown in Figure 7. The models exhibited a hairline flexural crack in the upper slab at approximately 2½ times the scaled design wheel load plus impact.

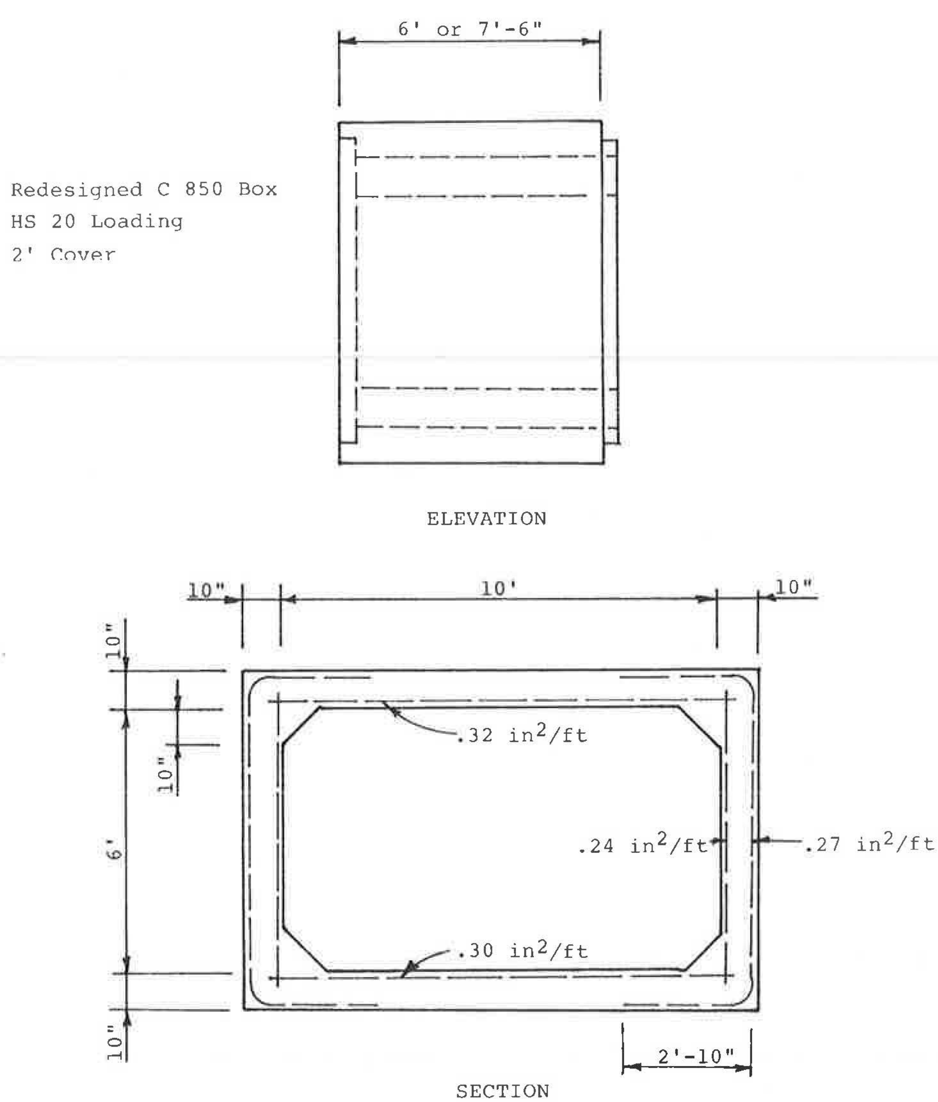

FIGURE 5 Details of redesigned 10-ft by 6-ft box culvert (Ohio DOT bridge CRA-19-17.10).

CLOSURE

Based on the findings described in this paper, the Ohio DOT no longer requires the use of shear connectors on box culvert sections conforming to ASTM *C* 850. The Ohio DOT does not enforce the AASHTO edge-beam requirement for slabs with main reinforcing parallel to traffic in box culverts, even though shear connectors are not used.

Based on the performance of box culvert sections at CRA-19-17.10, it appears that the structural design of ASTM *C* 850 box culvert sections can be economized. In this study only the steel reinforcement areas were changed. However, it is also possible to reduce the wall thicknesses. This may be undesirable because box culvert manufacturers would be required to modify existing forms or to purchase new forms.

It is further concluded that the ASTM *C* 850 specification, as well as the *C* 789 designs for less than 4 ft of cover, can be eliminated. The *C* 789 design for 4 ft of cover is recommended for these cases. For cover depths greater than 4 ft, the *C* 789 designs should be reevaluated.

In the redesigned box culvert section for *C* 850 live load conditions used in this study, the AASHTO distribution width for a wheel load was not used. Accounting for the transfer of load to adjacent sections by friction at a joint, a distribution width somewhat larger than the AASHTO recommendation, was used. Additional research should be undertaken to define a more appropriate expression for distribution width for a wheel load. In this redesign, a distribution width of 7.5 ft was used. This width corresponded to the largest laying length for these box culvert sections.

Note that the results and conclusions relative to MAR-309-09.42 are in agreement with those of James (*7*), who concurrently and independently investigated *C* 850 box culverts. Additionally, at least in Ohio, the authors' recommendation

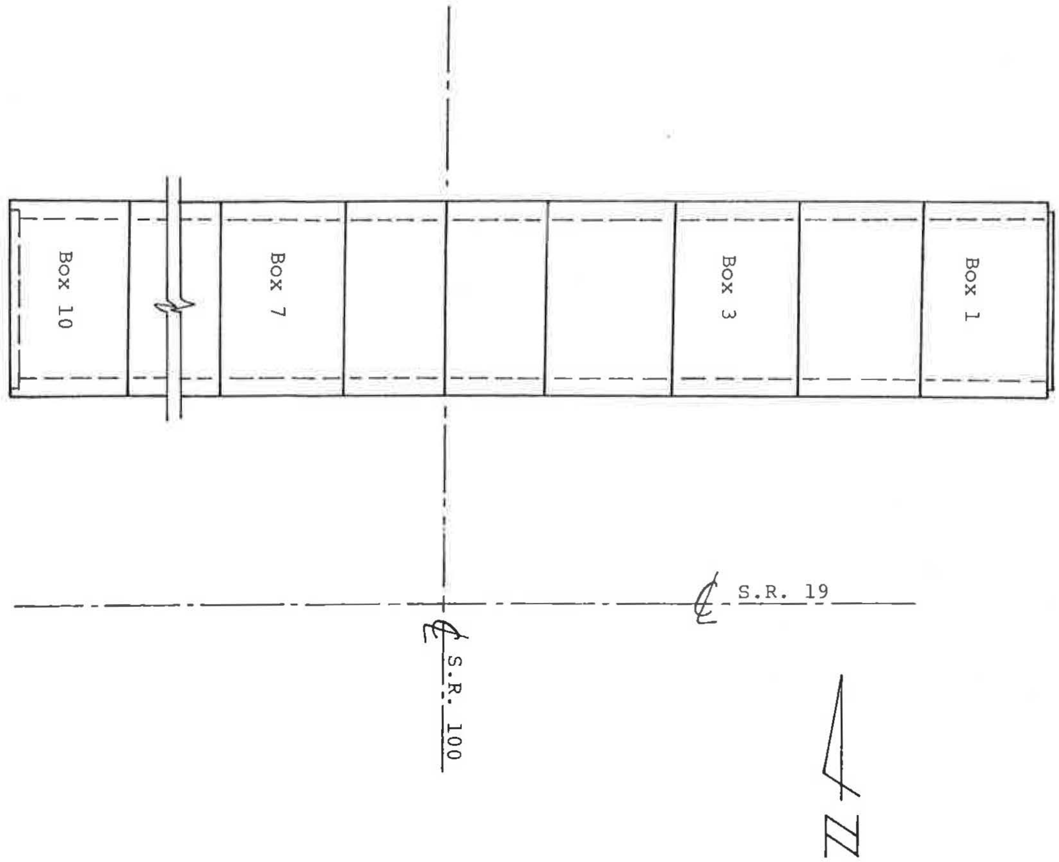

FIGURE 6 Arrangement of box culvert sections (Ohio DOT bridge CRA-19-17.10).

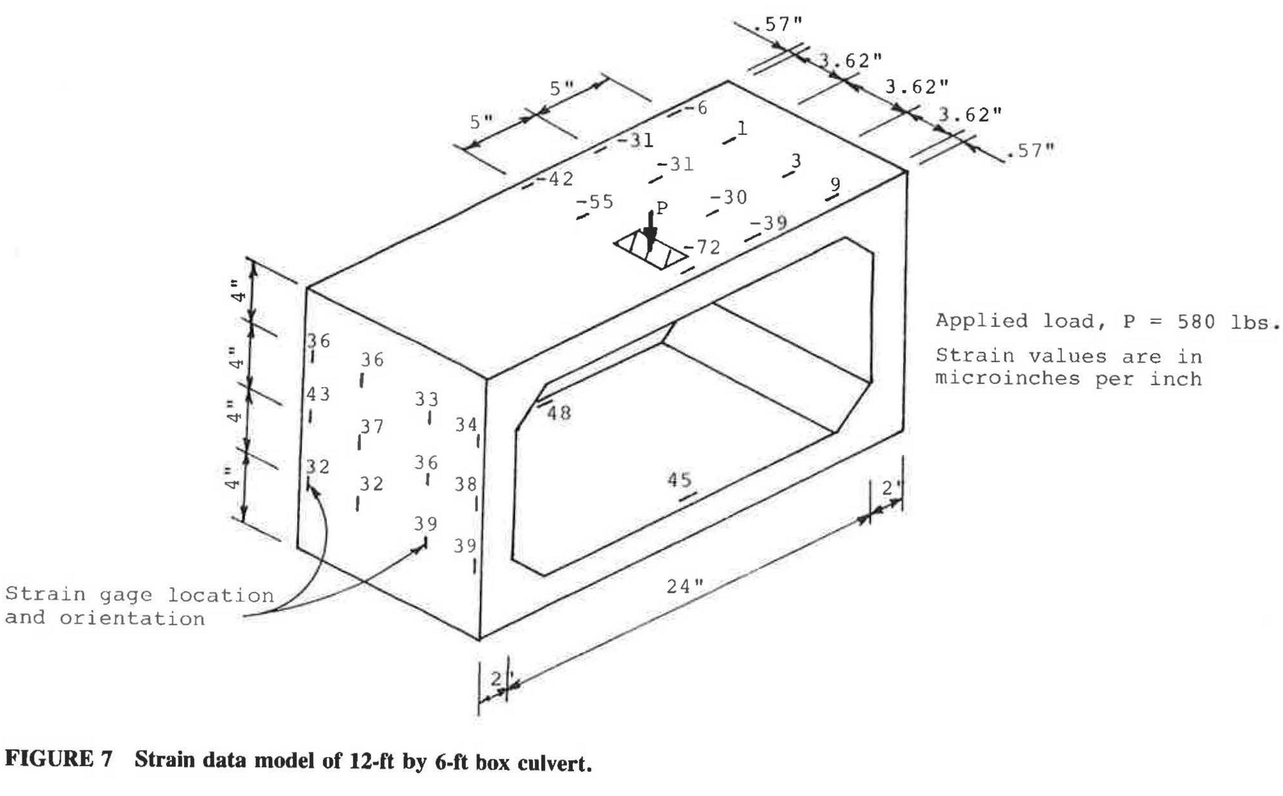

FIGURE 7 Strain data model of 12-ft by 6-ft box culvert.

(as well as that of James) regarding elimination of shear connectors has been implemented. Furthermore, our investigations at all three sites satisfy his second recommendation of field tests of box culverts installed without shear connectors.

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