

FIELD TESTING OF A BRIDGE SIZE TWO-CELL RC BOX CULVERT

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Out of 1378 bridge size culverts identified for load rating in Kentucky, 1241 (or 90.1%) are cast-in-place reinforced concrete box culverts (RCBCs). Out of these RCBCs 846 (or 68.2%) are two-cell box culverts. Bridge size culverts have spans exceeding 6.1 m (20 ft.). In the U.S., bridges, and bridge size culverts, must be inspected at least once every two years. If deficiencies are identified, the bridges and culverts must be evaluated and load posted to limit the trucks that can traverse them. For bridges, there are well-established methodologies for determining the load carrying capacity. For culverts, the methodologies are very simplistic and, in general, very conservative. This is due to the complexity of soil-structure interaction. Alternatively, detailed finite element analyses can be conducted when accurate geometric and material properties for the different soil layers are determined along with the material properties for the RC box. However, the more accurate method to evaluate the capacity of existing RC box culverts is field testing. The field-testing details are presented for a two-cell reinforced concrete box culvert along with the improved rating factors.

Keywords: Load rating, Diagnostic load evaluation, Strain gauges, Flexure, Deflection.

1 INTRODUCTION

In the United States, culverts that span more than 6.10 m (20.0 ft) fall under the inspection and load rating requirements of bridges. When these structures (many of which were designed decades ago with lighter design vehicles) are rated for the suite of heavier vehicles in use today, they often require weight restrictions. One such structure, 099B00055N, is a cast-in-place reinforced concrete box culvert located in Powell County, Kentucky. The culvert has two cells with 4.27 m (14.0 ft) clear spans, 1.52 m (5.0 ft) cell clear heights, a length of 6.10 m (20.0 ft), and a 279 mm (11.0 in) thick top slab. The corners at the wall to top slab connection do not have haunches, nor do they include supplemental moment resisting reinforcement (i.e., closer to a pinned connection). It has 0.43 m (1.42 ft) of fill above it and an asphalt wearing surface. This box culvert was constructed in 1951 and even though it has been in service for decades, it is in good condition with no major defects. This culvert was load rated as part of a larger project involving load rating and load testing of 18 box culverts across Kentucky (Peiris *et al.* 2024). The low analytic rating factors, based on provisions in the AASHTO LRFD Bridge Design Specifications (2024), were notably at odds with the observed condition and historic performance of this structure. Therefore, it was decided that a diagnostic load test would be conducted to determine the actual in situ performance of this structure with the goal of increasing the load rating.

2 ANALYTIC LOAD RATING

The specialized analysis software, BRASS-CULVERT (WYDOT 2019) was utilized for load rating the box culvert. This 2D frame analysis software package developed by Wyoming Department of Transportation uses plane frame elements and the stiffness method to quickly calculate rating factors for concrete box culverts. The software incorporates the provisions in the AASHTO Specifications including the prescribed attenuated distribution of the rating vehicles' tire loads through the soil. The culvert was load rated according to the Load and Resistance Factor Rating (LRFR) methodology, in accordance with the AASHTO Manual for Bridge Evaluation (2018). Details of the structure's geometry, materials, and reinforcement layout were determined from the bridge plans. The fill height was measured in the field and typical values were used for the unit weights of the soil [18.9 kN/m^3 (120 pcf)], asphalt wearing surface [22.8 kN/m^3 (145 pcf)], and concrete [23.6 kN/m^3 (150 pcf)]. Since the software does not account for soil structure interaction, only the unit weight of the materials needs to be defined to determine the permanent loads. Each culvert member was analyzed for flexure, shear, and axial thrust. The rating for this structure was found to be controlled by positive flexure in the top slab.

The primary vehicle used in the load rating was the AASHTO HL-93 vehicle. This is the design vehicle in the current AASHTO specifications and is taken as the maximum of either the design truck or the design tandem. The design truck consists of 3 axles weighing 35.6 kN (8.0 kip), 142.3 kN (32.0 kip), and 142.3 kN (32.0 kip). The first and second axles are spaced 4.26 m (14.0 ft) longitudinally, the second and third axles' spacing varies from 4.26 m (14.0 ft) to 9.14 m (30.0 ft). The design tandem consists of a pair of 111.2 kN (25.0 kip) axles spaced 1.22 m (4.0 ft) from each other longitudinally. The transverse spacing of the tires is 1.83 m (6.0 ft) for both the design truck and design tandem. The design vehicle also typically includes a 9.34 kN/m (640 plf) uniform lane load; however, the uniform lane load is not applied to buried culverts and is therefore ignored in box culvert load ratings. The AASHTO MBE (2018) requires rating the HL-93 vehicle at two levels: Inventory and Operating. Inventory rating indicates the structures' ability to carry routine traffic for an indefinite period. Operating rating indicates the structure's ability to carry the maximum live load which the structure may be subjected to for shorter durations.

While the force effects from the self-weight of the slab and the soil mass can be easily determined, the force effect due to the attenuated live load is more complicated. For fill heights less than 0.61 m (2 ft), the AASHTO specifications assume the soil cannot adequately distribute the tire pressure and instead uses an equivalent strip method, like slab type bridges, for determining the force effects in the culvert top slab. For fill heights greater than 0.61 m (2 ft), a trapezoidal tire pressure distribution is used with a slope of 1.15:1 in both directions to determine a live load pressure on the culvert top slab. The pressures from the tires of the design vehicle get distributed both longitudinally and transversely, and the individual tire distributions overlap at larger fill heights. Using this type of load distribution has been shown to be simplistic and overly conservative when compared to field measurements (Peiris *et al.* 2024). Additionally, typical design and load rating analyses use 2D frame analysis which is unable to account for the many uncertainties which lend to the over conservatism in the current design specifications (i.e. two-way action in the top slab, unintended fixity over the walls, stiffening effect of large parapet barriers, soil structure interaction, etc.). While a 3D finite element model would potentially be able to consider some or all these factors, it requires specific material and geometric properties of the soil, wearing surface, and culvert that are often unavailable for older in-service box culverts. In these cases, a diagnostic load test is a readily available methodology to accurately evaluate the field performance of these structures even when lacking such detailed information.

3 FIELD LOAD TESTING

Reusable strain gauges were attached to the soffit of the culvert top slab and the vertical face of the side walls and interior wall. The cells were designated primary and secondary depending on the number of gauges applied in each cell, with the primary cell having most gauges while the secondary cell had fewer gauges. The primary cell had 15 gauges applied to the slab soffit, and the secondary cell had 5 gauges applied. The secondary cell was more lightly instrumented due to the number of gauges available and was mainly used to verify symmetry and provide redundancy to the load test results. The gauges were laid out in a cruciform pattern centered on the slab and all gauges were aligned with the direction of the main reinforcement, perpendicular to the sidewalls, as shown in Fig. 1. Although it was impractical to place gauges on the top face of the slab over the interior walls to directly measure negative live load strains, negative bending strains could still be estimated since gauges were placed 152.4 mm (6 in) from either face of the interior wall. Strain gauges were in conjunction with the truck positions for each load case so that a gauge was always either directly below the truck tire or centered between the tires of a given truck's axle.

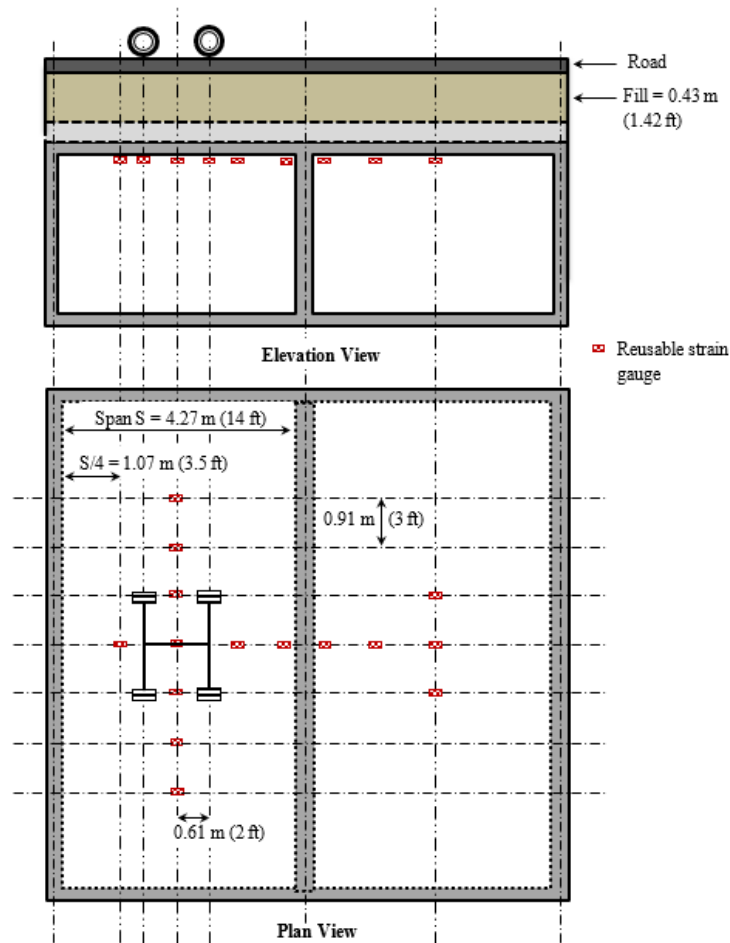


Fig. 1. Strain gauge layout and controlling load case for tandem rear axle test truck.

Two scale measured, loaded dump trucks, with known axle configurations, were used for the field load test: one tandem rear axle truck and one single rear axle truck. A total of 21 static truck

positions were used for the field test to identify and record the worst-case strain values. The tire locations for each load case were marked on the roadway to accurately position the test trucks. The static load tests involved driving the test truck onto the culvert to the marked location and stopping for approximately ten seconds before driving off the culvert. Load cases included running each truck in both directions to evaluate the effects of the front axle. The first eight load cases utilized just the tandem rear axle truck (gross vehicle weight of 30.32 tons). The next eight load cases utilized just the single rear axle truck (gross vehicle weight of 18.05 tons). The first 16 load cases were intended to maximize positive bending in either cell of the top slab. The last 5 load cases had both trucks on the culvert simultaneously to maximize negative bending over the interior wall as well as to investigate the effects of multiple adjacent vehicles. Each load case also included variants where the trucks were offset from the centerline of roadway 0.46 m (1.5 ft) left and right. For cases with two trucks, the heavier truck was always placed on the primary cell. A data collection sampling rate of 10 Hz was used for the strain gauges during the static load tests.

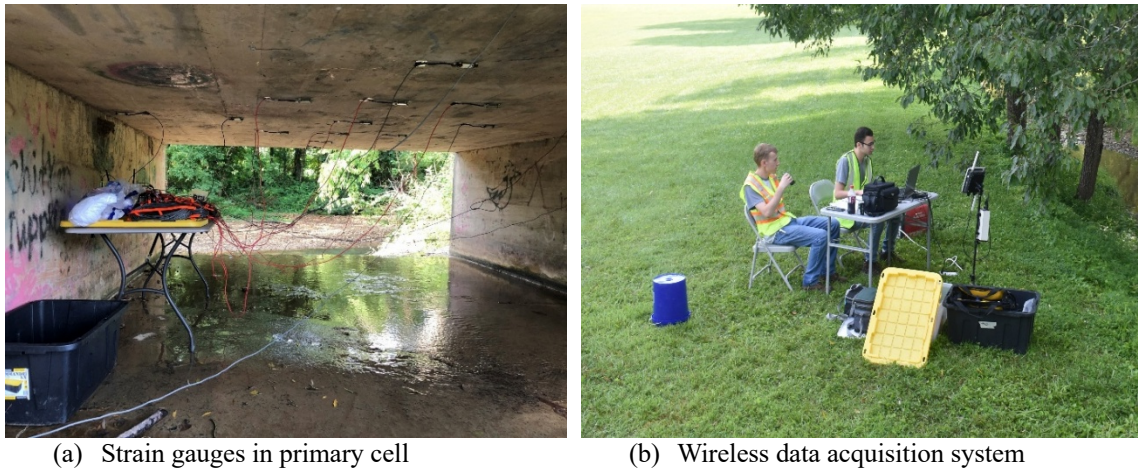


Fig. 2. Instrumentation used for load testing.

Fig. 2 shows the strain gauge application in the primary cell, and the wireless data acquisition system used to transmit the live data to the computer during the field testing. The maximum positive live load strain from just the tandem rear axle truck (35.95×10^{-6}) was recorded near midspan directly under one of the tandem rear wheels when the truck had its rear axle centered at midspan of the primary cell. The maximum positive live load strain from just the single rear axle truck (28.60×10^{-6}) was recorded at midspan directly under the truck tire and occurred when the truck had its rear axle at midspan of the primary cell. The maximum negative live load strain (-18.72×10^{-6}) was recorded next to the interior wall when both trucks were backed up to each other with their rear axles centered at midspan of the two cells (as seen in Fig. 3a).



Fig. 3. Typical load cases utilizing both test trucks.

4 LOAD RATING BASED ON FIELD TESTING

The analytic rating factors from BRASS-Culvert are listed in Table 1 for the design HL-93 vehicle. A rating factor less than unity denotes that the member does not have enough capacity to handle the given live load demand and therefore weight restrictions may be required to be placed on the structure. A rating factor greater than or equal to unity denotes the member has sufficient capacity for the given live load demands. The analytic rating factors from BRASS were increased by a field test adjustment factor, K , per the AASHTO MBE (2018) to arrive at the final rating factor based on the field load test. This adjustment factor considers the weight of the field test vehicle compared to the weight of the rating vehicle, whether the measured test behavior can be reliably extrapolated to heavier loads, as well as comparison of the measured test behavior with the analytical model. The field test rating factors based on the field testing showed significant improvements over the analytic rating factors.

Table 1. Analytic versus field test rating factors.

Rating Vehicle	Rating Level	Analytic Rating Factor	Field Test Rating Factor
HL-93	Inventory	0.62	3.26
HL-93	Operating	0.81	4.26

5 CONCLUSIONS

A diagnostic load test was carried out for a box culvert in Kentucky with poor analytic rating factors. The analytic rating factors based on the AASHTO LRFD specifications are simplistic and overconservative. Load testing was carried out using multiple scale measured fully loaded trucks and reusable strain gauges. Field load testing showed that the structure does not behave as analytically predicted, and that it has more reserve capacity than typical 2D frame analyses would indicate. The rating factors for the box culvert were increased substantially, in accordance with the AASHTO MBE, to the point where the structure was cleared to carry all legal loads in the state of Kentucky without restriction. Field load testing can account for the inherent extra capacity that most structures possess and that typical simplified analysis methods may not be able to capture. This can be a powerful tool for bridge owners who have posted weight restrictions on structures in

their inventory that are based on conservative load rating methodologies. Load testing can be an especially appealing choice for bridge owners when faced with alternatives such as replacement or repair of the existing structure, as testing can often be a much cheaper and more expedient solution.

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References

- American Association of State Highway and Transportation Officials (AASHTO), *Manual for Bridge Evaluation*, 3rd ed., Washington, D.C., 2018.
- American Association of State Highway and Transportation Officials (AASHTO), *LRFD Bridge Design Specifications*, 10th ed., Washington, D.C., 2024.
- Peiris, A., Cole, A., Russel, E., Hutchinson, C., and Harik, I., *Effect of Live Loads on Top Slab of Cast-in-Place Reinforced Concrete Box Culverts*, Engineering Structures, Elsevier, 318, 118709, November 2024.
- WYDOT, *Analysis, Design, and Rating of Reinforced Concrete Box Culverts*, BRASS-CULVERT™, Version 3.5 SP 1, Wyoming Department of Transportation, September 2019.