TECHSUMMARY July 2018

State Project No. DOTLT1000108 / LTRC Project No. 16-3ST

# Live Load Rating of Cast-in-Place Concrete Box Culverts

## INTRODUCTION

Eight culverts were selected by the DOTD Bridge Design Section to assess their load carrying capacity. The culverts were selected to have low fill height (FH) (6 culverts with FH ≤ 2.24 ft., 1 culvert with FH = 4.14 ft., and 1 culvert with FH = 7.00 ft.) and were all cast-in-place concrete box culverts designed using old standard details. These details did not call for reinforcement at corner joints, which are necessary for establishing full continuity between the slabs and the outer wall. Therefore, engineers typically assume a hinge at these locations when performing load rating calculations. Furthermore, AASHTO formulas for wheel load distribution (developed based on critical shear cases and known to overestimate the wheel load pressure on the culvert's top slab) add to the conservatism. Consequently, this assumption often results in rating factors less than 1.00 from these traditional procedures, requiring action from DOTD. Nevertheless, the performance of these culverts is typically acceptable, and they rarely show signs of distress.

The research team adopted a two-phase approach to address the question. In the first phase of this research, field live load testing of the culverts was conducted after instrumenting each culvert with a structural health monitoring (SHM) system consisting of a total of 48 sensors including displacement, strain, and tiltmeter sensors. In the second phase of the research, refined three-dimensional (3D) finite element (FE) models were built for each tested culvert and were calibrated using measured field data. AASHTO's Manual for Bridge Evaluation (MBE) rating methodology was followed in this research to distribute the live loads through the soil fill, and project drawings were used to develop connection details in FE models. AASHTO's design truck, HL-93, and legal trucks were passed on the calibrated culvert models, and the resulting straining actions were used to estimate load rating factors.

## OBJECTIVE

The main objective of this study was to assess live load effects on eight cast-in-place (CIP) reinforced concrete (RC) box culverts by conducting field load tests. Understanding the actual response of the culverts will provide insight as to how the live loads are actually distributed as well as the actual rigidity of the box corner connections. More precisely, the research effort goals were to: (1) study the current standard DOTD culvert drawings and the inspection reports for the eight selected culverts, (2) define critical sections and produce culvert specific instrumentation plans, (3) instrument the culvert by installing the sensors at specified locations and evaluate the current condition, (4) conduct the live load test and collect sensor data, (5) build FE models for each culvert and calibrate them using collected sensor data, (6) load rate the selected culverts for design and legal trucks, and (7) provide the rating details and recommendations to assist rating of CIP-RC box culverts.


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**FUNDING:**
SPR: TT-Fed/TT-Reg

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## SCOPE

This study focused on live load rating of eight cast-in-place (CIP) reinforced concrete box culverts from DOTD's inventory. The fill heights over the selected culverts varied but were chosen to be mostly with low soil fill since this condition is known to pose rating challenges. Refined live load rating factors considering HL-93 design truck and 10 different legal trucks were determined for each of the eight culverts.

## METHODOLOGY

Each of the selected culverts was load tested using a loaded truck with known axle loads. The structural response was measured using a 48-channel structural health monitoring (SHM) system for three different loads paths. The SHM system comprised of surface mounted sensors that measured strains, rotations, and deflections. Refined three-dimensional (3D) FE models were developed based on the provided and measured properties of the culverts, which were then calibrated using field load test response measurements to minimize the overall response error between measured and predicted values. The calibrated models were used for determining the straining actions caused by design and legal trucks, which were then used to determine the rating factors.

## CONCLUSIONS

Based on the results of this study, the following conclusions may be drawn.

***Specific Results for Tested Culverts***

1. None of the eight culverts had a rating factor less than 1.0. Three culverts had an acceptable inventory level rating factor between 1.0 and 1.5, while the rest of the culverts had inventory level rating factors above 1.5.
2. Three of the culverts' rating factors were calculated to be between 1.4 and 2.0 at the operating level, while the others had higher rating factors.
3. The rating factors for all legal trucks were all above 1.0, with the lowest rating factor being 1.60.

***General Observations based on Performance of Tested Culverts***

1. In general, there were not any major structural cracks in the selected culverts (i.e., caused by flexural moments due to gravity loads) observed in sections that the research team inspected.
2. Low fill height culverts and larger spans are more susceptible to lower load rating factors.
3. The controlling section that produces the minimum rating factor is typically the midspan (moments) in exterior cell slabs.
4. AASHTO LRFD live load distribution for flexible pavements can be conservatively used capture real load effects on 3D FE models. Concrete pavements provide additional distribution of wheel loads. With more advanced modeling features (e.g., stiff plate on soil fill), it may be possible to take advantage of this additional load distributing element.
5. Backfill soil springs reduce the exterior span forces and displacements due to live load effects. Thus, neglecting the backfill provides conservative load rating factor for the critical sections located in exterior span.
6. Soil-structure interaction in CIP culverts does not appear to provide a major change in rating factor for the tested culverts. This may not be a general conclusion as the dimensions of the tested culverts are considered to be on the low end. Larger culverts may exhibit a different behavior.

## RECOMMENDATIONS

Based on the results from studying the load rating of eight CIP-RC culverts, it can be said that many culverts with rating challenges can still have acceptable rating factors as demonstrated by the field tests and refined 3D FE models. Refined models should only be used after exhausting the use of the simpler 2D models if they do not result in acceptable rating factors. A procedure giving the details and procedure for load rating CIP-RC box culverts is provided in the "Implementation Statement" section of the project's final report. Furthermore, simple adjustments to conventional 2D modeling are proposed for cases where the software on hand does not allow incorporating advanced features such as rigid connections.

Given that refined models (3D FE) are expensive and not practical for implementation in load rating all culverts in the inventory, and that producing 2-dimensional (2D) models that take advantage of all load distribution sources (i.e., soil and structural) was not part of the scope of this study, it is recommended that a follow up study should be focused on calibrating 2D models to produce better results than what current AASHTO equations deliver. Such a study should also attempt to produce rating tables for categories of CIP-RC box culverts for a wide range of box dimensions, earth fill height, and concrete strength.