Concrete Box Culvert Earth Pressure Monitoring

tech transfer summary

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RESEARCH PROJECT TITLE
Concrete Box Culvert Earth Pressure Monitoring

SPONSORS
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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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The results of this study to determine the appropriate earth pressure specifications to use for concrete box culverts in Iowa were unexpected and merit further research in the field.

Project Objective

The objective of this project was to determine which load pressure (36/18 lb/ft³ or 60/30 lb/ft³) is more realistic for concrete box culverts given typical Iowa soil conditions and construction methods.

Background and Original Problem Statement

Earth pressure on concrete box culverts is a key component of design and load rating decisions. The accurate determination of these pressures is thereby critical, as soil conditions vary greatly from state to state.

The American Association of State Highway and Transportation Officials (AASHTO) has revised the design guidelines over the years to impose greater design/rating earth pressures for buried structures. This is one of the major reasons that many older culverts that were designed based on allowable stress design (ASD) or load factor design (LFD) guidelines do not pass load and resistance factor design (LRFD) ratings, although the culverts have performed satisfactorily for many years.

Currently, the Iowa Department of Transportation (DOT) Office of Bridges and Structures uses the maximum and minimum lateral earth pressure of 36/18 lb/ft³ specified for the LFD and ASD methods and 60/30 lb/ft³ for the LRFD method.

It would be helpful to understand which load pressure is more realistic for Iowa soil conditions and typical construction methods. This understanding is very important for culvert load ratings to avoid unnecessary load postings of many older culverts, and it was the motivation behind this project.

Northeast end of Crawford County concrete box culvert construction August 4, 2020 (left) and southwest end August 24, 2020 (right)

Research Description

Initially, a brief literature review was conducted to identify additional potential factors related to the vertical and lateral earth pressures on culverts. To gain a better understanding of actual pressures on concrete box culverts in Iowa, two newly constructed culverts were selected for field monitoring.

The first monitored culvert, in Ida County, consisted of multiple 8 ft by 12 ft concrete boxes.

Ida County concrete box culvert construction and earthwork progress July 22, 2016 through November 7, 2016

The monitoring system, which consisted of six strain gauges and five pressure cells, was installed on July 26, 2016.

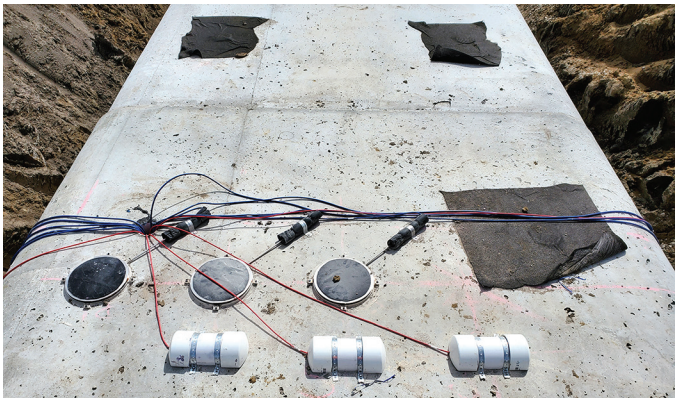
After two full seasonal cycles, and with the amount of accumulated data, the data were collected and analyzed to determine actual earth pressures associated with Iowa soil conditions for use during both the design and load rating of box culverts. The data from that culvert showed that the recorded pressures were actually 2 to 4 times greater than the LRFD and LFD/ASD design values, indicating a potentially concerning situation.

Because of these surprising results on the first monitored culvert, the instrumentation of an additional culvert was proposed to gain a deeper understanding of the pressure data. The second culvert, in Crawford County, was monitored with heavier instrumentation. Three instrumentation sections with different buried depths were identified and instrumented with 11 pressure cells and 10 strain gauges per section. The culvert was monitored for more than a year, from August 3, 2020 until October 7, 2021.

In both phases of this research, the data collection began during construction to collect earth pressures and accompanying fill heights during compaction. The field-collected data were analyzed to find reliable correlations between the earth pressure and other factors (such as construction situation, soil temperature, etc.).

The measured vertical and lateral pressures were compared with specified design loads. Based on the analysis results, the recommended Iowa-specific earth pressures were determined, to be used by bridge designers and load rating engineers when designing or load rating concrete box culverts.

In addition to instrumentation and data analysis efforts, the research team documented the contractors' compaction activity, paying close attention to the equipment and methods used. An emphasis on crack inspections was included throughout the duration of the project, including the culvert condition when it arrived on site, during compaction, and once the culvert was in-service after construction was completed.



Crawford County pressure cells and strain gauges for one of three culvert sections

Ida County Culvert Key Findings

The Ida County field research results indicated that the maximum measured vertical earth pressure 35 ft below the ground was 47 psi. The maximum and minimum lateral pressures measured were about 32/10 psi at 36 ft deep and 61/18 at 40 ft. Compared to the LRFD and LFD/ASD specifications, monitored data were still 2 to 4 times that of the design values.

The researchers found that, as temperature increased, all the pressures tended to increase. This was because the culvert tended to expand when the temperature increased and, hence, increased the pressure between the soil and the culvert exterior surface.

A significant number of cracks were found near the middle span of the top slab within the one-quarter span length on each side.

Crawford County Culvert Key Findings

The Crawford County results indicated that the pressures exceeded the specified design values of 120 lb/ft^3 for vertical pressure and 60/30 lb/ft^3 for lateral pressure. The monitored data measured were 3 to 6 times that of the design values with the LRFD and LFD/ASD methods.

The researchers found that the vertical pressure increased 1 to 2 psi with every additional foot of fill on the top slab, while the lateral pressure increased 0.25 to 0.5 psi with every additional foot of fill.

The inspection results indicated that extensive longitudinal cracking (parallel to the flow) occurred on the bottom of the top slab, as induced by the high vertical soil pressure. The data indicated that, when the temperature reached below freezing, a large variation occurred on the registered pressure data.

Key Finding Conclusions

The monitoring results from both culverts led to the consistent conclusion that the pressure experienced by the culverts is much greater (2 to 6 times more) than the current design values using the LRFD or LFD/ASD method. Due to the pressures, extensive longitudinal cracking (parallel to the flow) was observed at the bottom surface of the top slab on both culverts.

Implementation Readiness and Benefits

Based on the analysis results, the recommended Iowa-specific earth pressures were determined and can be used by bridge designers and load rating engineers when designing or load rating concrete box culverts.

Further research is recommended in the following areas:

- *Determination of a realistic design soil pressure and the relation between the soil weight and culvert vertical/lateral pressure for Iowa design specifications*

  The monitoring results from both culverts led to the consistent conclusion that the pressures experienced by the culverts are much greater (2 to 6 times more) than the current design values; however, it is still not clear what the relation is between the soil weight and the vertical/lateral pressure.

  Further research is recommended to determine a realistic soil pressure design and the relation between the soil weight and the culvert vertical/lateral pressures for Iowa. This would require the instrumentation of additional culverts.

  Although the previous monitoring work provided extensive data on the vertical/lateral pressures experienced by a culvert, both monitored culverts experienced extensive cracks during the early stages of construction, which significantly reduced the structure stiffness. This may induce an effect on the recorded pressure due to the soil arching effect. . Further monitoring work is recommended to record the pressure on a concrete box culvert designed based on the increased earth pressure.

- *Design and construction of a new culvert with updated design for vertical/lateral pressure*

  Once the improved design soil pressure and the relation between the soil weight and the culvert vertical/lateral pressures are identified, a new culvert is recommended to be designed, constructed, and monitored following the updated design for vertical and lateral pressures.