Diagnostic Load Testing and Refined Analysis of Concrete Box Culverts

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ACI Concrete Convention – Boston, MA

Fall 2023

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Overview

- Introduction
- Methodology
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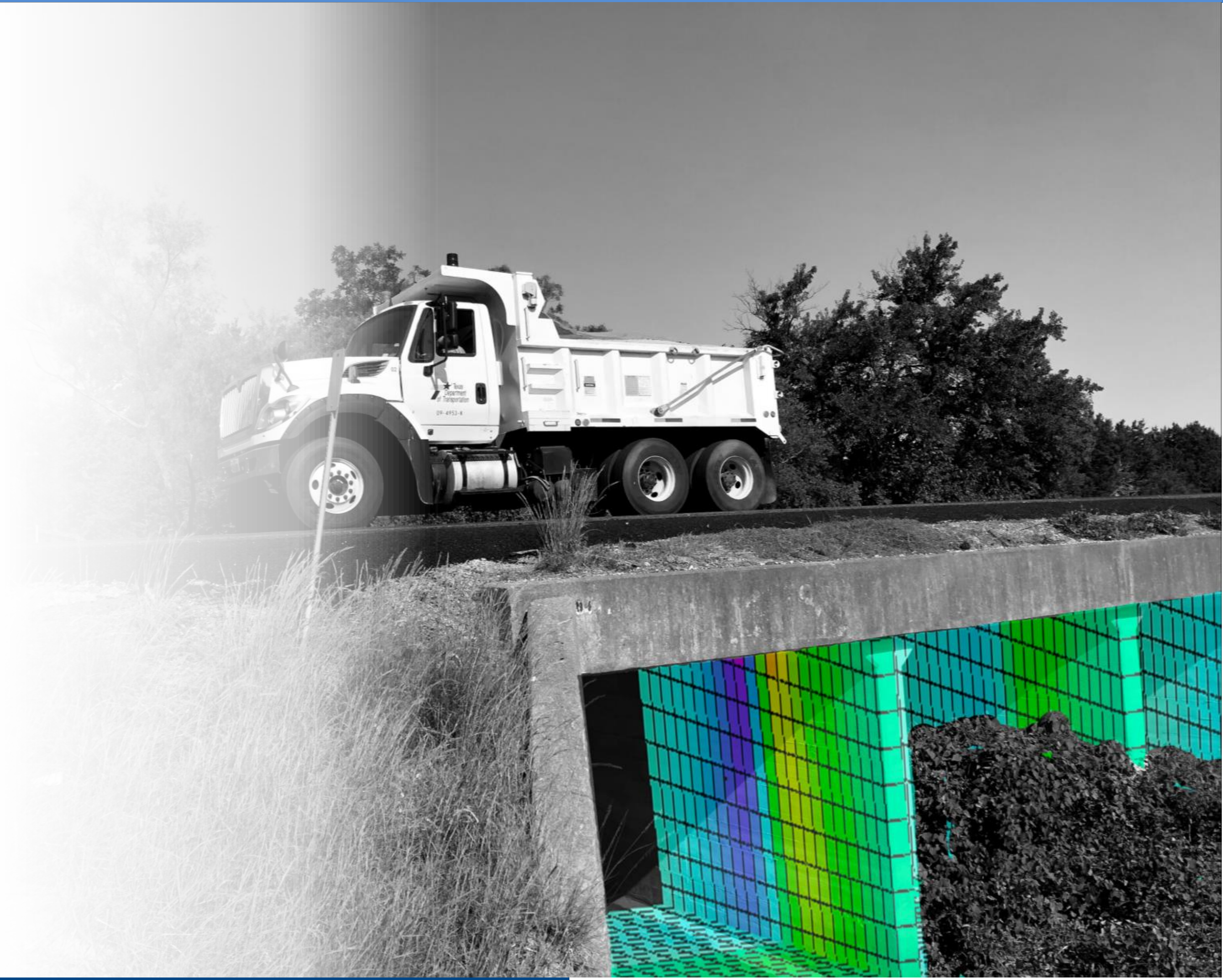
- Computational Modeling
- Refined Load Ratings
- Summary / Conclusions



Introduction

- TxDOT has over 19,000 bridge-class culverts in their inventory.
- Bridge-class culverts:
  - Single or multi-cell box culverts that carry traffic.
  - Have total clear opening greater than 20ft along the roadway CL.
- They are part of the NBIS and receive routine inspections.
- Texas previously used <u>assigned load ratings</u> for these culverts.
- The assigned load rating applies when:
  - Plans are available for a culvert with an indicated design load.
  - An inspector determines that no new load rating calculation is required.
  - None of the principal structural elements have a condition rating below 5, or “moderate deterioration”.
- Per FHWA requirements, ratings may only be assigned to in-service structures that are designed or checked using either <u>AASHTO LRFD or LFD</u> (HL-93 or HS-20 loads).
- TxDOT used Allowable Stress Design (ASD) until 1990’s.

Introduction

- Approximately 1,600 bridge-class culverts, designed and constructed prior to 1999, were rated by TxDOT.
  - Rating analysis was performed using an in-house proprietary software (i.e., CULVLR).
  - Load rating results indicated the need for posting on some culverts (RF <1.0).
  - Culverts have had unrestricted traffic through their service life, and exhibit no major signs of distress.
  - Some of the ratings indicate that the culverts are "failing" under dead load only.
- It seemed evident that the ratings are conservative and not reflective of the in-service performance.
  - Assumptions were made based on the guidelines set forth in AASHTO Specifications.
  - Distribution behavior in culverts is based only on the fill height (2 ft is the critical depth).
  - Use of AASHTO equations could lead to conservative estimation of the loads on the culverts.
- **Methodology:** Multi-step process to refine the ratings of a select class of culvert (40+).
  - **Diagnostic load testing** (10 select culverts)
  - **Refined Analysis** (40+ culverts)

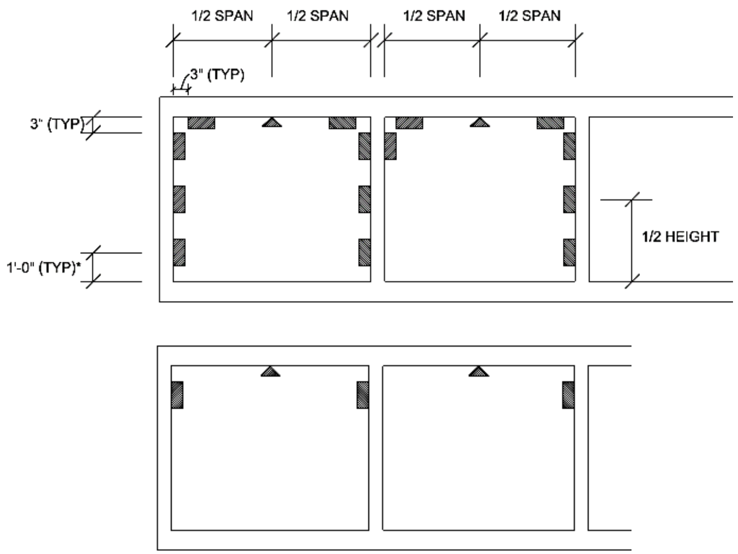
Diagnostic Load Testing

- Goal: understand the structural response, load distribution behavior
- Culvert Selection
  - Attributes with potential impact on performance (e.g., fill depth, culvert height, location, design standard)
  - Previous load rating results (e.g., controlling rating, failure mechanism, controlling section)
  - Most culverts selected were recommended for load posting per previous load rating analysis.

No.	No. of Cells	Cell Span ft (m)	Cell Height ft (m)	Fill Height ft (m)
1	3	9.0 (2.74)	9.0 (2.74)	2.0 (0.61)
2	4	10.0 (3.05)	14.0 (4.27)	9.0 (2.74)
3	6	8.0 (2.44)	8.0 (2.44)	0.0 (0.00)
4	3	10.0 (3.05)	12.0 (3.66)	7.0 (2.13)
5	3	10.0 (3.05)	10.0 (3.05)	7.0 (2.13)
6	3	10.0 (3.05)	5.0 (1.52)	5.0 (1.52)
7	3	10.0 (3.05)	10.0 (3.05)	0.0 (0.00)
8	2	10.0 (3.05)	10.0 (3.05)	0.0 (0.00)
9	4	8.0 (2.44)	7.0 (2.13)	1.0 (0.30)
10	2	10.0 (3.05)	7.0 (2.13)	1.0 (0.30)

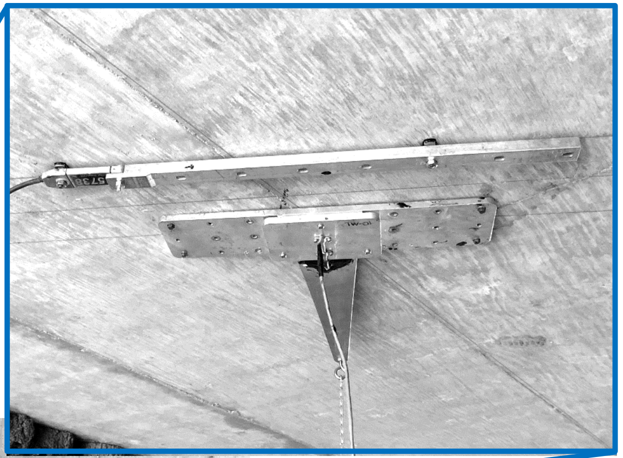
Diagnostic Load Testing (cont.)

- Instrumentation
  - A combination of strain and displacement sensors were used.
  - Extension bracket used to increase the gauge length on concrete surface.
    - *Non-homogenous composition of concrete*
    - *Surface cracks, large aggregates*
  - Similar instrumentation on all tested culverts



Section A

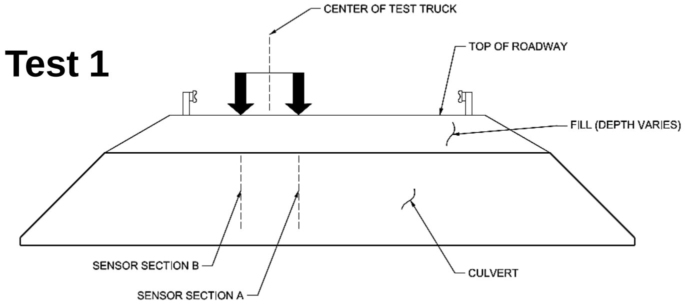
Section B
(6ft apart)



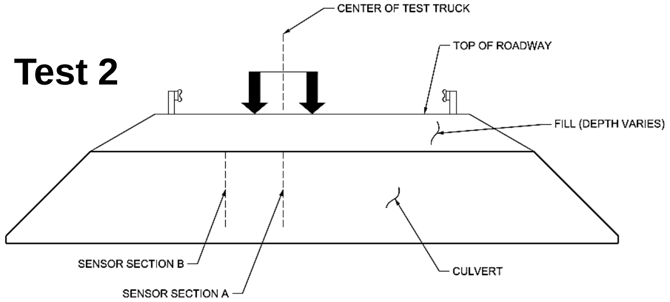
Diagnostic Load Testing (cont.)

- Testing procedure
  - Similar procedure for all tested culverts
  - Five test configurations, each repeated 3 times
    - *Test 1: Rear wheel lines aligned with instrumented sections*
    - *Test 2: center of test truck aligned with instrumentation Section A*
    - *Test 3: left rear wheel path aligned with instrumentation Section A*
    - *Test 4: left rear wheel path 3'-0" right of instrumentation Section A*
    - *Test 5: trucks 4 feet apart, centered over*
    - *instrumentation Section A*

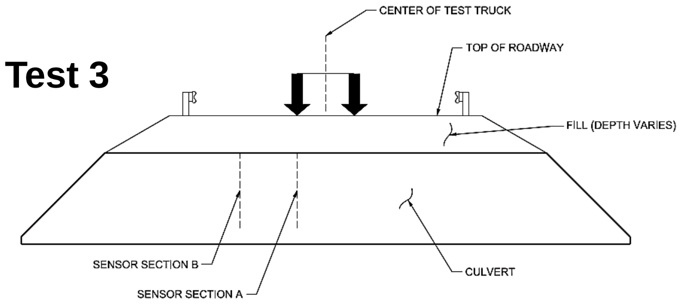
Test 1



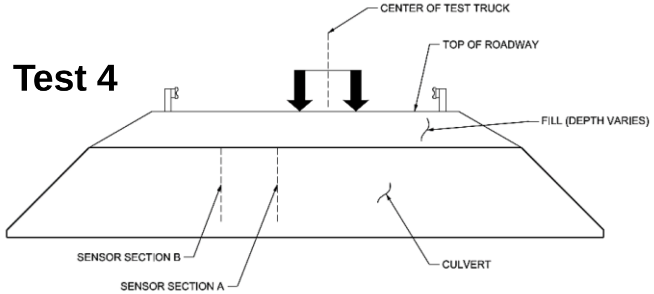
Test 2



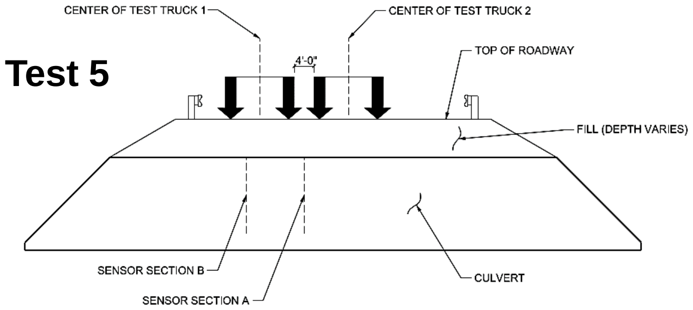
Test 3



Test 4

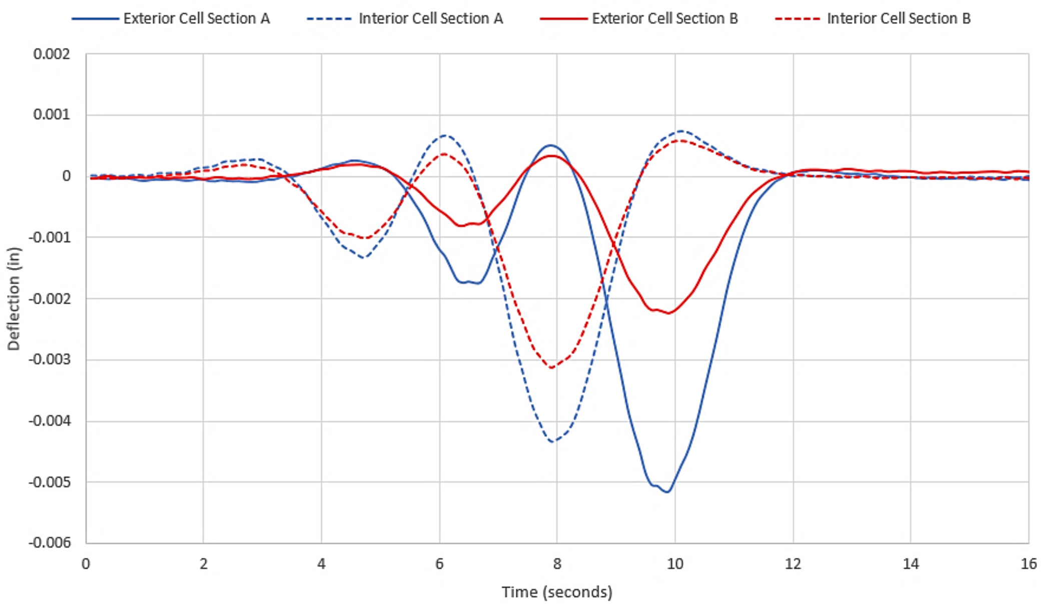


Test 5

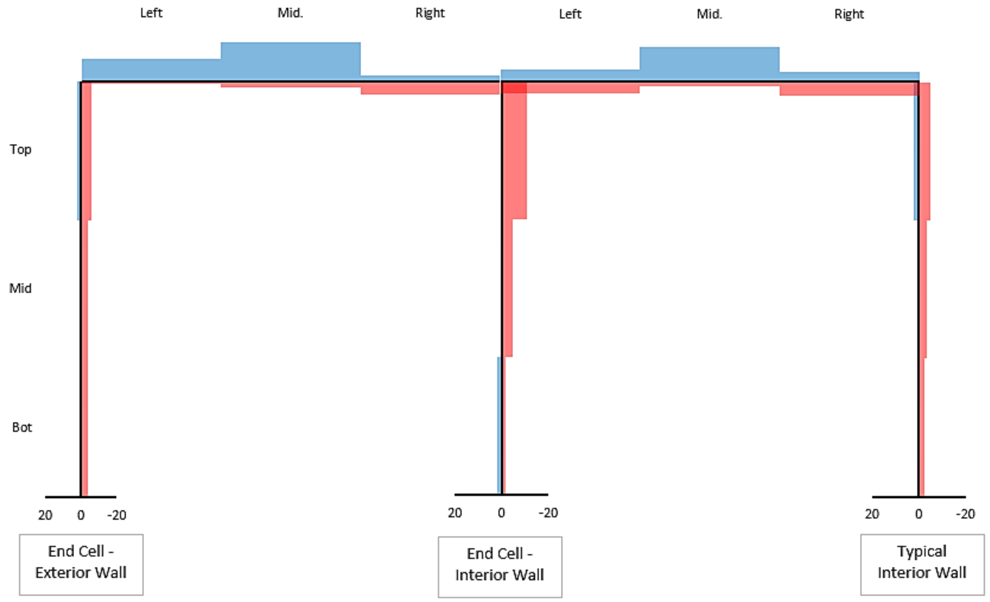


Diagnostic Load Testing (cont.)

- Representative test results



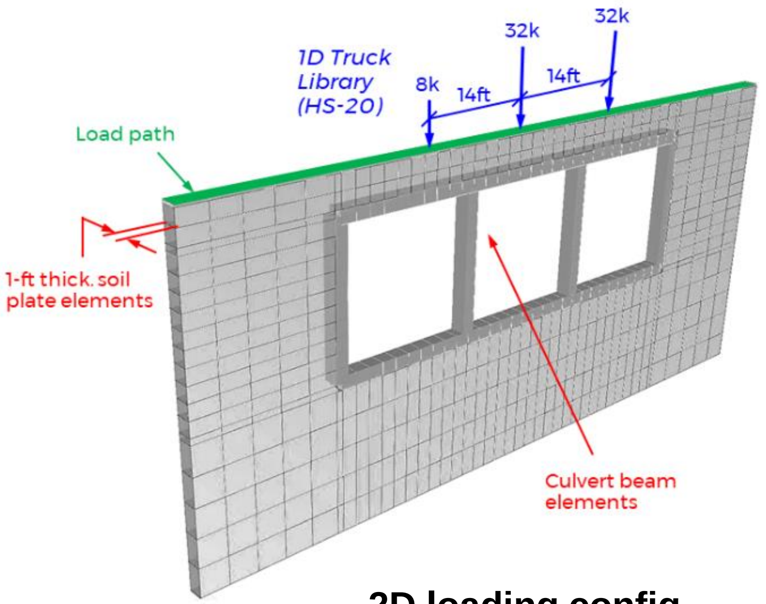
Top slab deflection response



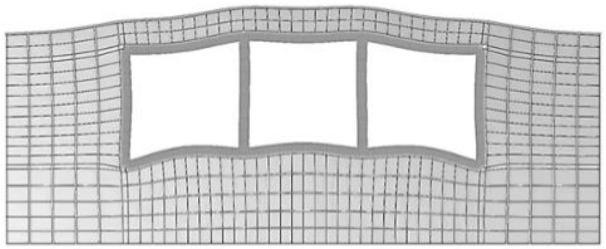
Strain distribution between slab/walls

Computational Modeling

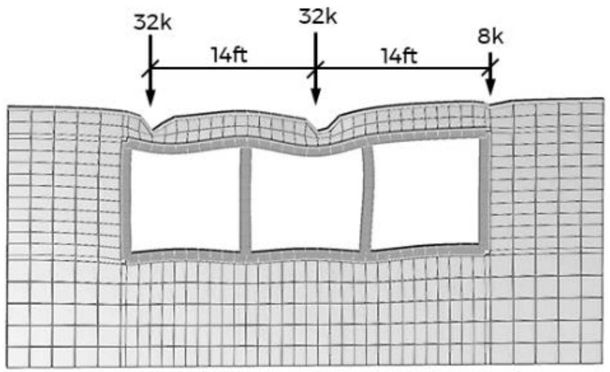
- 2D modeling and analysis
  - 1ft strip of culvert controlling segment, including soil-structure interaction
  - Mesh sensitivity analysis was performed
  - Initial attributes assumed per plans/previous ratings
  - Analyzed under DL and moving LL



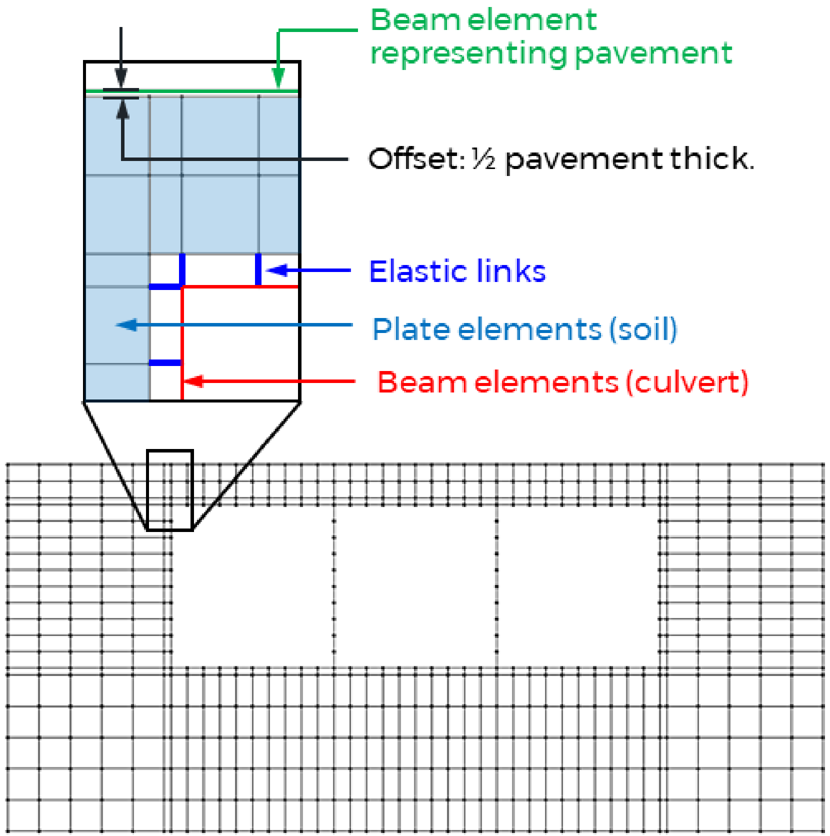
2D loading config.



DL defl.



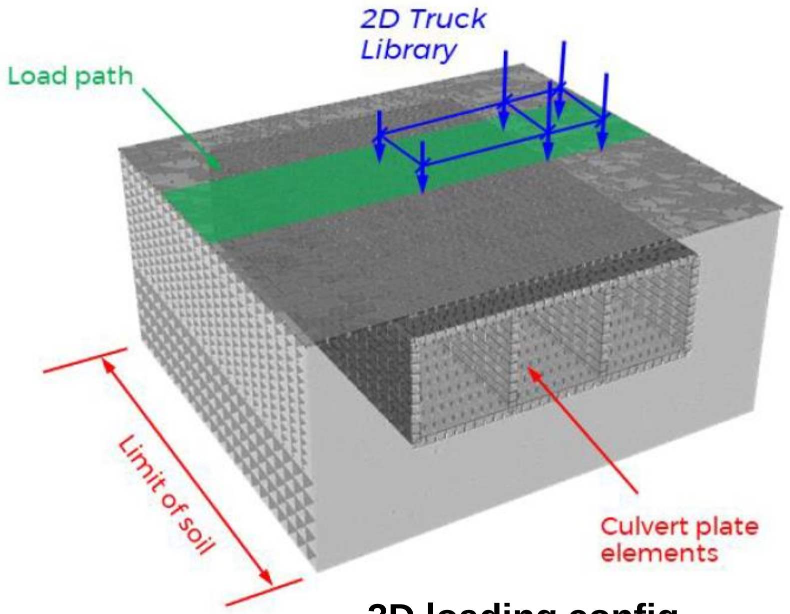
LL defl.



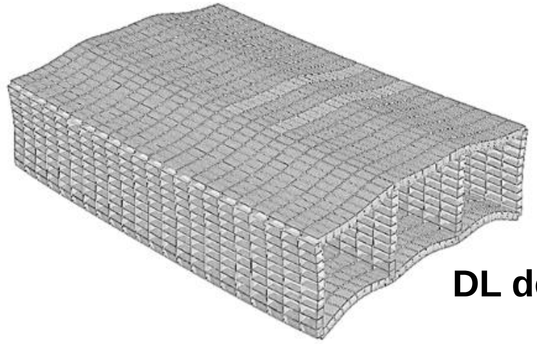
2D model mesh layout

Computational Modeling

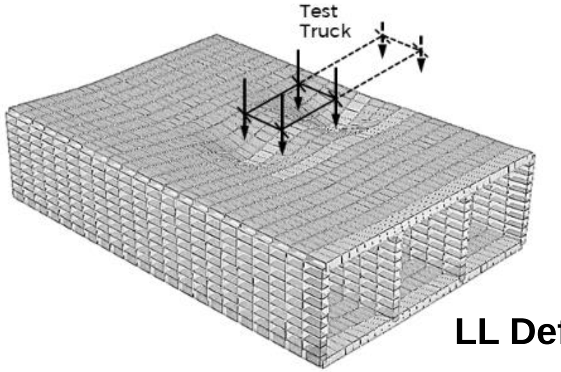
- 3D modeling and analysis
  - Full 3D representation, including soil-structure interaction
  - Optimized 2D mesh layout was utilized
  - Attributes calibrated based on test results
  - Analyzed under DL and moving LL



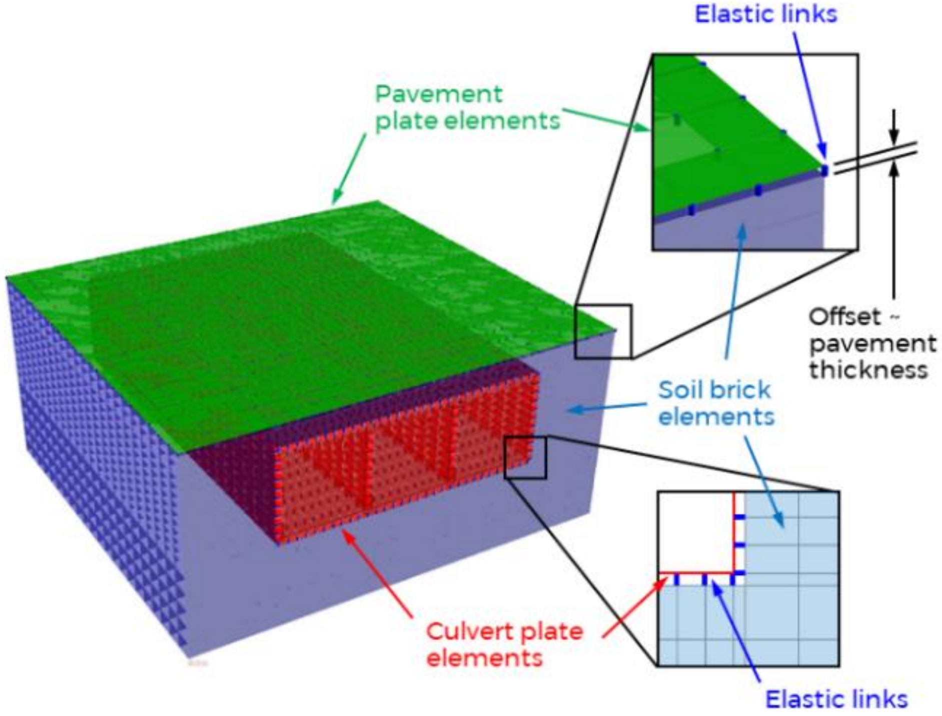
3D loading config.



DL defl.



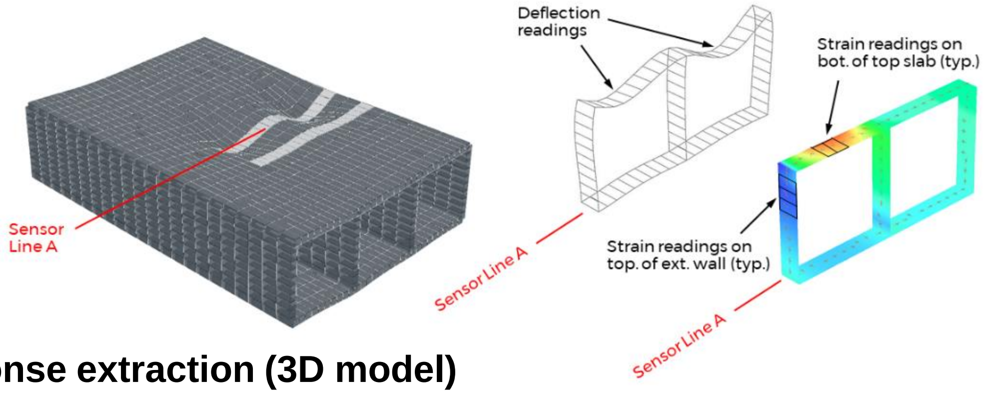
LL Defl.



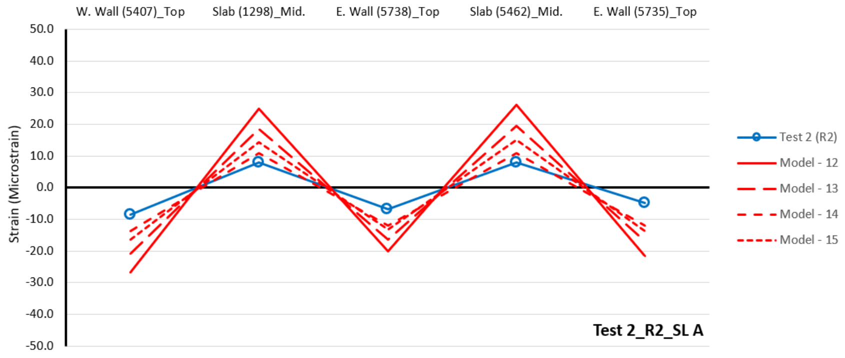
3D Model Mesh Layout

Computational Modeling (cont.)

- 3D Model calibration
  - Modification of material attributes (iterative)

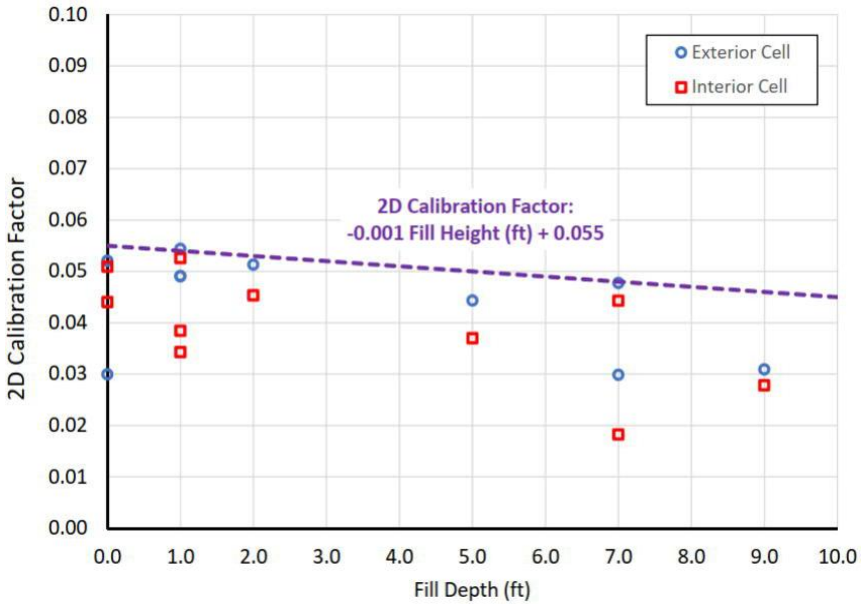


Response extraction (3D model)



Iterative calibration process

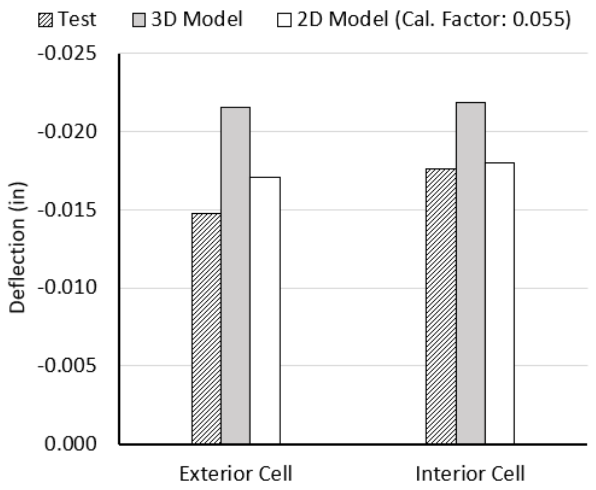
- 2D Model calibration
  - Ratio between test results and 2D model response



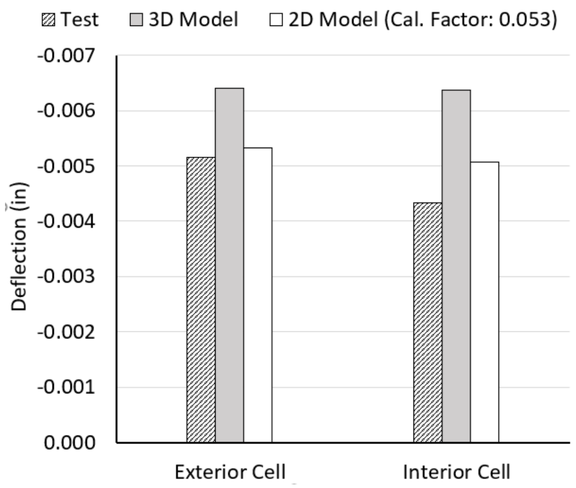
2D Calibration Factors

Computational Modeling (cont.)

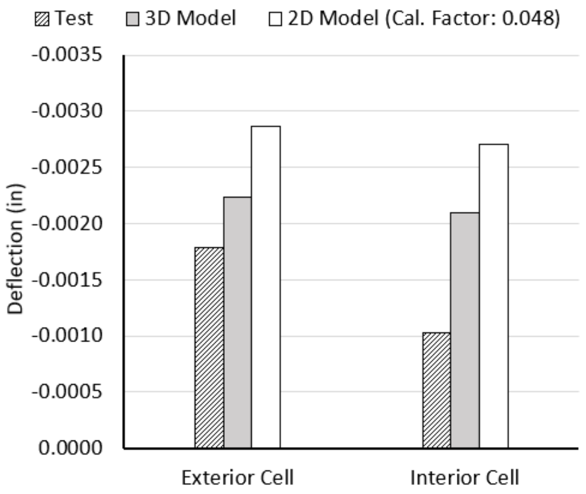
- 2D/3D correlation study
  - Adoption of the calibrated material attributes and obtained 2D calibration factors
  - To ensure that the idealized (simplified) 2D models can accurately imitate 3D structural behavior
  - Goal: to achieve reasonable agreement between deflection response (test, 2D and 3D models)
  - Correlation study performed on three representative culverts (various fill heights)



0ft fill



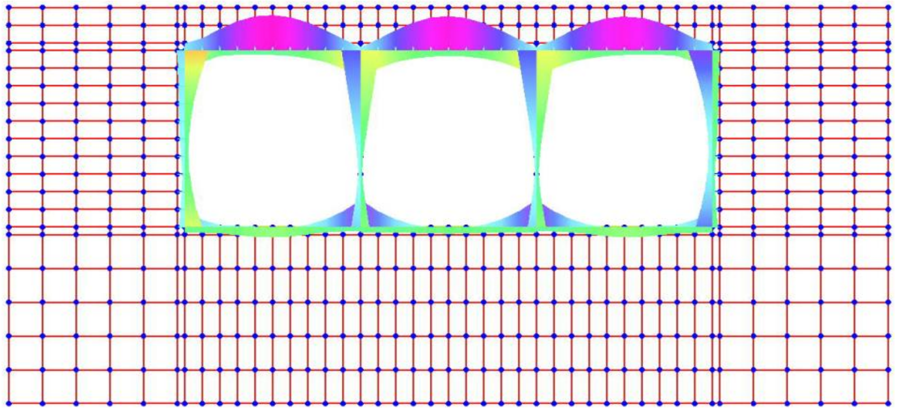
2ft fill



7ft fill

Refined Load Ratings

- Load demands from calibrated 2D models
- Capacity calculations and load rating using LFR
- Factors (load, IM, MPF) according to AASHTO MBE
- Multi-step linear elastic analysis (progressive hinging)
  - Stage 1: initial load rating performed assuming full flexural fixities between walls/slabs
  - Stage 2: placing plastic hinges (i.e., moment release) where there was no reinforcement per plans
  - Stage 3: Placing additional hinges where RF OPR < 1.0 for design (HS-20) and legal trucks (SHVs & EVs).
    - *Flexural overload would not induce a failure*
    - *No hinges applied in the middle of slabs and/or walls*
    - *Hinge placement cautiously conducted to avoid compromising the overall stability*
- The stages were intended to simulate the progression of load re-distribution
- All three stages <u>were not</u> performed for each of the 40+ culverts



Moment distribution under LL

Refined Load Ratings (cont.)

- Representative results (10 tested culverts)
  - Typical improvement (significant) in load rating results due to refined load distribution
  - Change in controlling section, due to redistribution of loads in the staged analysis
  - Majority of culverts most likely have experienced similar level of loads used in the refined analysis

No.	Previous Ratings		Refined Ratings		Rating Improv. Ratio
	Inventory	Operating	Inventory	Operating	
1	0.43	0.72	2.40	4.01	5.58
2	8.74	14.58	12.56	20.93	1.44
3	0.55	0.92	2.37	3.96	4.31
4	4.31	7.19	8.23	13.72	1.91
5	0.87	1.45	4.34	7.24	4.99
6	DL FAIL	DL FAIL	6.27	10.45	N/A
7	0.53	0.88	1.15	1.91	2.17
8	0.54	0.91	0.77	1.28	1.43
9	0.51	0.86	0.97	1.61	1.90
10	0.59	0.99	1.55	2.59	2.63

Summary and Conclusions

- This project focused on refinement of load ratings of an inventory of in-service bridge-class culverts
  - Designed and constructed prior to 1999 using the Allowable Stress Design method.
  - Majority have been carrying unrestricted traffic for many years with no signs of significant distress.
  - Some received low ratings per previous load rating analysis.

- The project entailed a multi-step process to gain a better understanding of in-service performance and load distribution behavior of this class of culverts, and came up with a refined analytical approach that would help resolve the low ratings (potential for posting) of this target group of culverts
  - A group of ten culverts were load tested.
  - 3D FE models developed and calibrated using test results.
  - 2D models with calibrated attributes used for refined load ratings.
  - A multi-step linear elastic analysis was conducted to refine the ratings of 40+ culverts.

Questions?

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