Load Rating Corrugated Metal Culverts with Thin Cover in Anniston, Alabama

J. Brian Anderson, Jim Davidson, Mike Stallings, Chukwuma Okator, Bujing Liu, and Olga Rojas

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Outline

• Motivation
• Objectives
• Brief review of Corrugated Metal Culvert Load Rating Practice
• Testing Anniston Culverts
• Results and Conclusions

ALDOT 930-987: Load Rating for Corrugated Metal Culverts - Motivation

• Load rating CM culverts is a complex task
• There are a number of these structures that are part of ALDOT’s bridge inventory
• Particular issues exist with the rating of “low cover” structures

ALDOT 930-987: Load Rating for Corrugated Metal Culverts - Objectives

• Load rate CM culverts in Anniston AL
• Develop method for load rating low profile arch and pipe arch CM culverts for ALDOT

Anniston Culverts

• All but one is on former Ft. McClellan
• Annexed by the city of Anniston
• Culverts are nearly 80 years old
• Double barrel constructed from 5 galvanized plates
• Concrete pedestal foundations on rock
Load Rating Corrugated Metal Culverts with Thin Cover in Anniston, Alabama

Rating Factor Definition

- The procedures and criteria for load rating and posting of existing bridges are defined by the Manual for Bridge Evaluation (MBE).
- The complexity of the rating methodology for a given structure therefore depends upon the complexity of the structure and its behavior under loading (i.e., linear or nonlinear response).

Rating Factor Definition

- Definitions are provided for Allowable Stress, Load Factor, and Load and Resistance Factor ratings (ASR, LFR, LRFR, respectively).
- The MBE does not dictate which rating approach (ASR, LFR, or LRFR) must be used; rather, the rating method is typically decided based upon the original adopted design philosophy.

Rating Factor Definition

- The lowest rating factor defines the load rating for the structure. To generate the load rating for a bridge, the rating factor is multiplied by the weight of the rating vehicle.
- Although applied to culverts, MBE was developed with typical steel and concrete superstructure bridges in mind.
- **“Rating of Reinforced Concrete Box Culverts”** is relatively mature, but rating procedures for other categories of buried structures is recognized as lacking.

Rating Factor Definition

- When soil cover is less than L/8 (low cover), CM culverts rate below 1 when using simplified methods. This is exacerbated by inability to account for pavement.
- Original ODOT > RF = H2/h2 < 1 when cover is less than AASHTO minimum (1.25ft).
- Modified ODOT attempted to improve by adding work by Galambos (1998). MDOT improved resistance definitions (does not compare cover, evaluates structural limit states).

Analysis Options

- Beam global stiffness state-space models are permitted in ODOT as well as AASHTO.}
- Rating of calculation is based on resisting flexural strength and flexural stiffness.
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- Improved load rating calculations account for loading (i.e., linear or nonlinear response).

Consequences of Low Cover

- When soil cover is less than L/8 (low cover), CM culverts rate below 1 when using simplified methods. This is exacerbated by inability to account for pavement.
- Original ODOT > RF = H2/h2 < 1 when cover is less than AASHTO minimum (1.25ft).
- Modified ODOT attempted to improve by adding work by Galambos (1998). MDOT improved resistance definitions (does not compare cover, evaluates structural limit states).

<table>
<thead>
<tr>
<th>Analysis Options</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Stiffness State-space Models</td>
<td>Calculations of RF by state-space models are typically decided based upon the original adopted design philosophy.</td>
</tr>
<tr>
<td>Modified ODOT</td>
<td>Improved load rating calculations account for loading (i.e., linear or nonlinear response).</td>
</tr>
<tr>
<td>Multi-Phase Stress (MPSS)</td>
<td>Developed specifically for culvert analysis.</td>
</tr>
<tr>
<td>Finite Element Analysis (FEA)</td>
<td>Can predict the accuracy of any other analytical method.</td>
</tr>
<tr>
<td>Load Transfer</td>
<td>Can improve the accuracy of any other analytical method.</td>
</tr>
</tbody>
</table>
Impact of Load Testing on Rating

Per AASHTO MBE (2018)

\[ RF_L = RF_K K_1 \]

and \[ K_1 = \frac{\varepsilon_T}{\varepsilon_C} - 1 \]

where \( \varepsilon_T \) is the maximum measured member strain during load test and \( \varepsilon_C \) is the corresponding theoretical strain for the test vehicle at the same position in the load test.

Load Testing for Load Rating

- Anecdotally, the Anniston culverts appear to have sufficient capacity to rate higher than 1, even though the soil cover is minimal.
- Limited load testing was proposed to prove that the culverts indeed carry a representative overload.
- Prove that pavement contributes to the capacity of these types of structures.

Initial Rating by CANDE

Linear Analysis, Pavement Included

<table>
<thead>
<tr>
<th>BIN</th>
<th>Vehicle</th>
<th>PA</th>
<th>LPA</th>
<th>LPA</th>
<th>LPA</th>
<th>LPA</th>
<th>LPA</th>
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<tr>
<td></td>
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<td>12.9</td>
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<td>12.6</td>
<td>12.5</td>
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<td></td>
<td>TWO-AXLE</td>
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<td>11.8</td>
<td>11.7</td>
<td>11.7</td>
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<tr>
<td></td>
<td>TRI-AXLE</td>
<td>1.6</td>
<td>9.0</td>
<td>9.3</td>
<td>9.2</td>
<td>9.1</td>
<td>9.1</td>
<td>9.0</td>
<td>8.9</td>
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<tr>
<td></td>
<td>CONCRETE</td>
<td>1.7</td>
<td>9.5</td>
<td>9.6</td>
<td>9.5</td>
<td>9.5</td>
<td>9.5</td>
<td>9.4</td>
<td>9.6</td>
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<tr>
<td></td>
<td>18 WHEELER</td>
<td>3.8</td>
<td>13.4</td>
<td>13.5</td>
<td>13.5</td>
<td>13.5</td>
<td>13.5</td>
<td>13.4</td>
<td>13.4</td>
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<tr>
<td></td>
<td>6 AXLE</td>
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<td>12.7</td>
<td>12.9</td>
<td>12.8</td>
<td>12.8</td>
<td>12.8</td>
<td>12.7</td>
<td>12.6</td>
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<tr>
<td></td>
<td>SCHOOL BUS</td>
<td>6.5</td>
<td>23.8</td>
<td>23.8</td>
<td>23.8</td>
<td>23.8</td>
<td>23.8</td>
<td>23.8</td>
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</tbody>
</table>

Anniston Culvert Selection

- All culverts had thin covers
- Some culverts were in secure areas behind fences and gates
- One culvert was highly skewed, and pavement removed (road closed)
- Significant tree roots and other issues were observed as well
- Choice was made to load test two representative structures

Load Rating Corrugated Metal Culverts with Thin Cover in Anniston, Alabama
**Berman Road**
- Likely least amount of cover of all structures on one barrel
- Ease of access for instrumentation

**Soil Profile**
- Non-destructive seismic testing used to determine soil profile
- MASW, Seismic Refraction, Direct Wave

**Soil Profile**
- In situ/Natural Material:
  - \( V_p = 370 \text{ m/s} \) (measured compressive wave velocity)
  - \( V_s = 210 \text{ m/s} \) (measured shear wave velocity)
  - \( p = 1800 \text{ kg/m}^3 \) (assumed mass density)
  - \( \gamma = 0.25 \) (Poisson's Ratio)
  - \( G = 79.4 \text{ MPa} = 1600 \text{ ksf} \) (Shear Modulus determined from \( V_s \))
  - \( E = 198.5 \text{ MPa} = 4150 \text{ ksf} \) (Young's Modulus determined from \( G \))
- Compacted fill:
  - \( V_p = 240 \text{ m/s} \) (measured compressive wave velocity)
  - \( V_s = 140 \text{ m/s} \) (measured shear wave velocity)
  - \( p = 1800 \text{ kg/m}^3 \) (assumed mass density)
  - \( \gamma = 0.25 \) (Poisson's Ratio)
  - \( G = 35.3 \text{ MPa} = 740 \text{ ksf} \) (Shear Modulus determined from \( V_s \))
  - \( E = 88.3 \text{ MPa} = 1840 \text{ ksf} \) (Young's Modulus determined from \( G \))

**Posting/Design Vehicles**

**Loading Schedule**

<table>
<thead>
<tr>
<th>Load Line</th>
<th>Stoppage Points</th>
<th>Number of Passes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck centered in lane (L1)</td>
<td>start, ½, crown, end</td>
<td>3</td>
</tr>
<tr>
<td>Truck centered in lane (L1)</td>
<td>end, ½, crown, start</td>
<td>1</td>
</tr>
<tr>
<td>Right wheels over lane center (L2)</td>
<td>start, ½, crown, end</td>
<td>3</td>
</tr>
<tr>
<td>Right wheels over lane center (L2)</td>
<td>end, ½, crown, start</td>
<td>1</td>
</tr>
</tbody>
</table>
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Load Rating Adjustment

\[
K_a = \frac{\varepsilon_a}{\varepsilon_T} - 1 = \frac{10.32E-04}{2.43E-04} - 1 = 3.24
\]

\[
K_b = K_{b1}K_{b3}
\]

(select \(K_{b1} = 0.5\) and \(K_{b3} = 1\)) so \(K_b = 0.5\)

\[
K = 1 + K_aK_b = 1 + (3.24)(0.5) = 2.62
\]

Results and Conclusions

- Two of the Anniston Culverts were load tested to measure vertical displacement and radial strain using a load truck with LC-5 load combination.
- The maximum vertical displacement measured was around 0.12 in <0.1% of span.
- The largest strain measured during testing was approximately 243\(\mu\varepsilon\) for Berman Rd.
- Results increased load rating by a factor of 2.62.

Rating Factor Comparison

Concrete Truck / 13-inch cover / LRFR

<table>
<thead>
<tr>
<th></th>
<th>CANDE Level 1</th>
<th>CANDE Level 2</th>
<th>3D-FEM</th>
<th>ODOT1</th>
<th>ODOT2</th>
<th>MDOT</th>
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<tbody>
<tr>
<td>BIN 20441</td>
<td>0.44</td>
<td>2.40</td>
<td>2.80</td>
<td>0.40</td>
<td>1.47</td>
<td>1.03</td>
</tr>
<tr>
<td>Test K factor</td>
<td>1.18</td>
<td>1.88</td>
<td>1.06</td>
<td>X</td>
<td>X</td>
<td>2.62</td>
</tr>
<tr>
<td>Adjusted RF</td>
<td>12.11</td>
<td>4.51</td>
<td>2.97</td>
<td>0.40</td>
<td>1.47</td>
<td>2.70</td>
</tr>
</tbody>
</table>

Conclusions

- Load rating of CM culverts is a complex process.
- Previous theoretical approaches made assumptions to simplify the rating calculations, often resulting in very conservative results.
- Current spreadsheet solutions based on these approaches carry these limitations when considering low cover and pavement.
- CANDE is a more sophisticated approach but has a steep learning curve and requires experience to properly model and interpret results.

Conclusions

- Engineers considering load rating CM culverts should follow these steps:
  - Attempt a simple spreadsheet rating (these may fail due to cover or pavement considerations)
  - If < 1, utilize CANDE to determine a rating using the prescribed method
  - If still < 1, consider a full finite element analysis and/or rating load test
  - Otherwise, post the structure
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