NC HRP 15-54
Proposed Modifications to AASHTO Culvert Load Rating Specifications
AASHTO T-13 Update

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Overview of research effort

- Phase I - Survey/Literature review
- Phase II - Analysis/Field Testing Plan (Draft Report just submitted)
- Phase III - Field testing/ further analysis
- Phase IV - Recommendations
- Q&A
Disclaimer

“This investigation was sponsored by TRB under the NCHRP Program. Data reported are work in progress. The contents of this presentation has not been reviewed by the project panel or NCHRP, nor do they constitute a standard, specification, or regulation.”
Phase I

- Survey/Literature review
- Culvert selection
- 8 models (2 provisional)
Survey

Responses – Coverage: 37 states
## Phase I

<table>
<thead>
<tr>
<th>Model</th>
<th>Structure Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RC Box (Single)</td>
<td>Precast 16’-20’</td>
</tr>
<tr>
<td>2</td>
<td>RC Box (Multiple Cell)</td>
<td>Cast in place 10’-12’ / cell</td>
</tr>
<tr>
<td>3</td>
<td>RC Box</td>
<td>New precast &gt;10’</td>
</tr>
<tr>
<td>4</td>
<td>Three-sided arch concrete</td>
<td>24’-36’</td>
</tr>
<tr>
<td>5</td>
<td>Metal Arch</td>
<td>6x2” corrugation 30’-35’</td>
</tr>
<tr>
<td>6</td>
<td>Metal box culvert</td>
<td>~25’</td>
</tr>
<tr>
<td>7*</td>
<td>Deep corrugated metal culvert</td>
<td>&gt;40’</td>
</tr>
<tr>
<td>8*</td>
<td>Three sided flat top culvert</td>
<td>~25’</td>
</tr>
</tbody>
</table>
Phase II – Interim Report#2

- Culvert Selection Process
- Analysis model preparation
  - 3D models
  - 2D models
    - CANDE - toolbox
    - BrDR – RC Box culverts
- Proposed areas to review
Phase II – Interim Report#2

- Report submitted in May
- Panel is reviewing
- Panel meeting scheduled end of June/beginning of July
- Phase III begins upon panel/NCHRP approval
Culvert Selection

- 5 states – PA, OH, MD, MA, IL
- Review database (PA)
- Contacts from the culvert industry
  - Ben Hurst/Brian Flint (Contech)
  - Jerry Silagyi (Lane)
  - Joel Hahm (Big R Bridge)
- 7 Models (1 field test)
Model 1 – RC BOX
Single Cell
Model 1 – RC BOX
Single Cell

- 25’ span length
- 3D model LUSAS
- 2D CANDE, BrDR
- With/ without pavement/ varying fills
Model 2 – RC Box Twin Cell
Model 2 – RC Box
Twin Cell

- 10’ spans
- 3D model LUSAS
- 2D CANDE, BrDR
- With/ without pavement/ varying fills
Model 3 – RC Box
New Precast

BMS ID 55 0281 0590 2521
Model 3 – RC Box
New Precast

- 12’ span
- 3D model LUSAS
- 2D CANDE, BrDR
- With/without pavement/ varying fills
Model 4 – RC Concrete
3 sided Arch
Model 4 – RC Concrete 3 sided Arch

- 36’ span
- 3D model LUSAS
- 2D CANDE (from fabricator)
- With/ without pavement/ varying fills
Model 5 – Metal Arch
Model 5 – Metal Arch

- 23’ span
- 3D model LUSAS
- 2D CANDE
- With/ without pavement/
- varying fills
Model 6 – Metal Box
Model 6 – Metal Box

- 19’ span
- 3D model LUSAS
- 2D CANDE (from fabricator)
- With/without pavement/varying fills
Model 7 – Metal Culvert
Deep Corrugated

- Additional Culvert
- New construction
- Available for load testing with and without pavement
- Attleboro, MA
- Field Tested (Later)
Analysis Models

- 2D models
  - CANDE – CANDE Toolbox
  - AASHTOWare BrDR

- 3D models
Analysis Models (2D)

- CANDE
  - Updated with NCHRP 15-28
  - 2D element/soil interaction
  - Does not perform LL analysis
  - Modeling can be difficult at Level 3
  - CANDE Toolbox
Analysis Models (2D)

- CANDE Toolbox
  - Generate Level 3 model from Level 2
  - Add pavement elements to a level 3 model
  - Simulate live loading
  - Calculate a rating factor
Analysis Models (2D)

¬ CANDE Toolbox

¬ Generate Level 3 model from Level 2
Analysis Models (2D)

- CANDE Toolbox
  - Generate Level 3 model from Level 2
Analysis Models (2D)

- CANDE Toolbox
- Add pavement elements to a level 3 model
Analysis Models (2D)

- CANDE Toolbox
- Simulate live loading
Analysis Models (2D)

- CANDE Toolbox
- Simulate live loading

Bending moment (lb-in/in): Load steps 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23.
**Analysis Models (2D)**

- CANDE Toolbox
- Calculate rating factors loading

<table>
<thead>
<tr>
<th>DESIGN-CRITERION</th>
<th>LOAD STEP</th>
<th>LOCAL NODE</th>
<th>DEAD-LOAD DEMAND</th>
<th>LIVE-LOAD DEMAND</th>
<th>EFFECTIVE CAPACITY</th>
<th>*RATING FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEEL YIELDING (psi)</td>
<td>8</td>
<td>20</td>
<td>27851.62</td>
<td>25164.83</td>
<td>58500.00</td>
<td>1.22</td>
</tr>
<tr>
<td>CONCRETE CRUSHING (psi)</td>
<td>8</td>
<td>20</td>
<td>1167.21</td>
<td>1078.15</td>
<td>3750.00</td>
<td>2.40</td>
</tr>
<tr>
<td>SHEAR FAILURE (lbs/in)</td>
<td>13</td>
<td>4</td>
<td>166.54</td>
<td>452.46</td>
<td>973.00</td>
<td>1.78</td>
</tr>
<tr>
<td>RADIAL-TENSION FAIL (psi)</td>
<td>13</td>
<td>1</td>
<td>0.02</td>
<td>0.03</td>
<td>61.10</td>
<td>2036.00</td>
</tr>
</tbody>
</table>
Analysis Models (2D)

- BrDR (AASHTO Ware)
  - Models 1-3 (Can be reviewed at varying fills)
  - CalTrans models (100+ models)
- Regression Testing – Modify and check
3D Modeling

- **LUSAS FEA Software**
- **Culvert Structure Elements**: Shell Elements (3-noded flat), Linearly Elastic
  - Isotropic shell elements are used for concrete, and smooth metal culverts
  - Orthotropic shell elements are used for corrugated metal and profile wall culverts
- Soil-culvert interface logic permits arbitrary interface strength and stiffness
- Soil – 3D continuum (solid) elements
3D Modeling

- Single Cell Culvert – 32K Axle – Vertical Displacement
3D Modeling

- Single Cell Culvert – 32K Axle – Top Fiber Von Mises Strain
3D Modeling

- Twin Cell Culvert - 32K Axle - Vertical Displacement of Solid Elements
3D Modeling

- Twin Cell Culvert - 32K Axle - Vertical Displacement of Culvert
Field Testing (Model 7)
(other field testing in Phase III)

- New construction
- Testing of with/without pavement
- No pavement - May, 2017
- Pavement - June 2, 2017
- Larger corrugated arch
- Improvement with pavement (CANDE)
Field Testing (Model 7)

- 56.5’ Inside span
- Temporary structure carrying I-95 near Attleboro, Massachusetts
Field Testing (Model 7)

- Testing with/without pavement
- Larger corrugated arch
Field Testing (Model 7)
Field Testing (Model 7)

- Testing with/without pavement
- Larger corrugated arch
Review of results (2D)

- Shear capacity (2’ fill depth) (RC)
- Live load distribution at 2’ fill depth
- Effects of deeper fill depths
- Effects of pavement
- With or without haunches (RC)
- LRFR/LFR ratings for RC boxes
Review of results (2D)

Shear capacity (2’ fill depth) (RC)

5.8.3.3—Nominal Shear Resistance

The nominal shear resistance, $V_n$, shall be determined as the lesser of:

$$V_n = V_c + V_s + V_p$$  \hfill (5.8.3.3-1)

$$V_n = 0.25 f_c' b_y d_y + V_p$$  \hfill (5.8.3.3-2)

in which:

$$V_c = 0.0316 \beta \sqrt{f_c'} b_y d_y$$, if the procedures of Articles 5.8.3.4.1 or 5.8.3.4.2 are used  \hfill (5.8.3.3-3)

$V_c$ = the lesser of $V_{cd}$ and $V_{cw}$, if the procedures of Article 5.8.3.4.3 are used

5.14.5.3—Design for Shear in Slabs of Box Culverts

The provisions of Article 5.8 apply unless modified herein. For slabs of box culverts under 2.0 ft or more fill, shear strength $V_c$ may be computed by:

$$V_c = \left( 0.0676 \sqrt{f_c'} + 4.6 \frac{A_t}{bd} \frac{V_u d_e}{M_u} \right) bd_e$$  \hfill (5.14.5.3-1)

but $V_c$ shall not exceed $0.126 \sqrt{f_c'} bd_e$
### Shear capacity (2’ fill depth) (RC)

<table>
<thead>
<tr>
<th>Fill depth</th>
<th>Inv Rating</th>
<th>Oper Rating</th>
<th>Conc Shear Resist $V_c$ (kips)</th>
<th>Steel Shear Resist $V_s$ (kips)</th>
<th>Shear Resist $V_r$ (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert M1C1 (1.99’ fill)</td>
<td>HL-93 (US)</td>
<td>0.727</td>
<td>0.943</td>
<td>14.9</td>
<td>0</td>
</tr>
<tr>
<td>Culvert M1C1 (2.00’ fill)</td>
<td>HL-93 (US)</td>
<td>1.063</td>
<td>1.378</td>
<td>24.7</td>
<td>0</td>
</tr>
</tbody>
</table>
Phase III

- Field Testing of Models 1-6
- Refine analysis
- Recommendations for spec changes
- Regression test spec changes
Phase III

Interim Report #2 meeting end of June/beginning of July
Questions?