**SECTION 14A – FLEXIBLE CULVERTS**

**14A-1 INTRODUCTION TO RATING FLEXIBLE CULVERTS**

This section covers the rating of flexible culverts. Flexible culverts include, but are not limited to: metal pipe, metal plate pipe, pipe arch, long span plate structure, thermoplastic pipe, steel reinforced thermoplastic pipe, and fiberglass pipe. This section does not cover rigid pipes such as concrete pipe and concrete box culverts. Flexible culverts are to be rated using the policies and guidelines of the Bridge Rating Manual, Section 1 and Subsections 14A-2 and 14A-3.

When there are no plans available for the flexible culverts being rated, the requirements in Subsection 1-5 of CDOT Bridge Rating Manual, CDOT M&S Standards, or AASHTO Specifications may be used if proven to be representative of the culvert. Field measurement may also be used.

The types of flexible culverts covered by this section are:

- AAC - Aluminum Arch Culvert
- CMP - Corrugated Metal Pipe
- CPP - Corrugated Plastic Pipe
- SAC - Steel Arch Culvert/Multiplate Arch Culvert

The types of culverts not covered by this section are:

- CAC - Concrete Arch Culvert
- CBC - Concrete Box Culvert
- PCBC - Precast Concrete Box Culvert
- RAC - Rubble Arch Culvert
- RCPC - Reinforced Concrete Pipe Culvert
- TBC - Timber Box Culvert
- TTC - Timber Culvert
14A-2 POLICIES AND GUIDELINES FOR RATING FLEXIBLE CULVERTS

I. General

A. Rating or re-rating for flexible culverts built after October 1, 2010 shall be based on AASHTO Load and Resistance Factor Rating (LRFR). Rating or re-rating for flexible culverts built before October 1, 2010 may be based on either the Load Factor Rating (LFR) or (LRFR).

B. A major culvert is defined as a culvert or a group of culverts that have a span of 20 feet of length or greater measured parallel to the centerline of roadway from outside of the first pipe to the outside of the last pipe. A group of culverts are culverts with distance between them of less than or equal to the radius of the smallest culvert in the group.

C. A minor culvert is defined as a culvert or a group of culverts that have a span length of less than 20 feet but greater than 4 feet measured parallel to the centerline of roadway from outside of the first pipe to the outside of the last pipe.

D. Flexible culverts may be rated manually in accordance with AASHTO Specification or by using a program such Excel or one that is acceptable to CDOT Bridge Branch (see flexible culvert rating example in the section). The program must be approved in advance by the Staff Bridge Rating Engineer.

E. Inventory and operating ratings shall be performed for HS20-44 or HL-93 as applicable. Also, an operating rating shall be performed for appropriate legal loads*, Colorado Permit, Modified Tandem, and NRL. Rating for SU4-SU7 vehicles shall be performed if the rating factor (RF) for the NRL vehicle is less than 1.0. Truck configuration for the NRL and SU4-SU7 can be obtained from AASHTO Manual for Bridge Evaluation.


G. “For single-span culverts, the effects of live load may be neglected where the depth of fill is more than 8.0 ft. and exceeds the span length. For multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between inside faces of end walls.” AASHTO LRFD 7th edition. Where these conditions are met, the capacity adequacy shall be verified for dead load and other superimposed loads. The rater shall also verify and document that the fill height meets CDOT M&S Standard fill height limitation.

*Colorado Legal loads or Interstate Legal loads.
H. The structure Inspection and Appraisal report shall be investigated for the culvert condition. Reducing section properties due to loss of cross section or damage shall be investigated and accounted for by a professional engineer. Findings and recommendation shall be discussed with Staff Bridge contact and the Bridge Rating engineer prior to finalizing the rating. If approved, the findings and recommendation shall be clearly documented in the rating package.

I. Refined analysis and/or soil interaction analysis may be used if rating shows that posting or color coding per section 1-15 or 1-16 is required. Geotechnical engineering is required to provide soil interaction properties.

II. Calculations

A. A set of calculations, separate from computer output, shall be submitted with each rating package. These calculations shall include derivations for dead loads, derivation of live load, and any other calculations or assumptions used for the rating.

B. Dead Loads

1. The final sum of all the individual weight components for dead load calculations may be rounded up to the next 5 pounds.

2. Dead loads shall include fill, pavement, curbs, sidewalks, railing, etc.

3. Fill Dead loads shall be calculated based on 120 lb/cft.

C. Use the minimum design yield strength value Fy from plans or AASHTO Specifications.

14A-3 RATING REPORTING AND PACKAGING REQUIREMENTS

I. Rating Reporting/Package Requirements

A. A copy of the schematic drawing or sketch showing the elevation and applied loads shall be included with the rating package. Rating procedure shall be per section 1-11 or 1-12 as applicable.

B. The rater and checker shall complete the rating documentation as described in Section 1 of the Bridge Rating Manual. Any variation from the original design assumptions shall be added to the Rating Summary Sheet as applicable. The rating package requirements shall be per Section 1-13 and Section 1-14 of the Bridge Rating Manual and as amended herein.
II. Consultant Submittal Requirements

A. Consultant designed/rated flexible culverts: Before finalizing the rating package and when a computer program is used as the analysis tool, the rater shall verify with Staff Bridge that the program being used is acceptable to CDOT. Unapproved program data files may be rejected.

D. When the rating is finalized, the rater shall save the input and output files. The files name shall include the structure number of the rated culvert. The rating package including the program input and output files, the rating summary sheet, and necessary computations shall be transmitted electronically (.xlsx, .xml, etc.) and in PDF format to Staff Bridge for review and archiving.

14A-4 FLEXIBLE CULVERT RATING EXAMPLE

The example presented in this section is based on LFR method. The rating is for Structure # P-02-E, a 3-Cell Corrugated Metal Pipe (CMP) pictured below.
The following information is given:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall Thickness</td>
<td>0.109 in</td>
</tr>
<tr>
<td>Corrugations</td>
<td>6x2 in x in</td>
</tr>
<tr>
<td>Number of Bolts per Foot</td>
<td>4 Bolts/ft</td>
</tr>
<tr>
<td>Bolt Diameter</td>
<td>0.75 in</td>
</tr>
<tr>
<td>Pipe Span length, S</td>
<td>117 in</td>
</tr>
<tr>
<td>Top radius of the structure, Rt</td>
<td>58.3 in</td>
</tr>
<tr>
<td>Pipe Rise, R</td>
<td>79 in</td>
</tr>
<tr>
<td>Pipe Rise to Span Ratio</td>
<td>0.68</td>
</tr>
<tr>
<td>Pavement Thickness</td>
<td>4 in</td>
</tr>
<tr>
<td>Fill Height</td>
<td>20 in</td>
</tr>
</tbody>
</table>

The following information was obtained from CDOT standards and AASHTO Standard Specification Section 12:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement Unit Weight</td>
<td>145 lb/cft</td>
</tr>
<tr>
<td>Soil Unit Weight</td>
<td>120 lb/cft</td>
</tr>
<tr>
<td>Soil Stiffness factor K</td>
<td>0.22</td>
</tr>
<tr>
<td>Pipe material Modulus of Elasticity, Em</td>
<td>29,000,000 psi</td>
</tr>
<tr>
<td>Pipe material Min. Tensile Strength, fu</td>
<td>45,000 psi</td>
</tr>
<tr>
<td>Pipe material Min. Yield Point, Fy</td>
<td>33,000 psi</td>
</tr>
<tr>
<td>Capacity Modification Factor for Wall Area and Buckling, (\Phi_b)</td>
<td>1.00</td>
</tr>
<tr>
<td>Capacity Modification Factor for Seam Strength, (\Phi_s)</td>
<td>0.67</td>
</tr>
</tbody>
</table>
RATING CALCULATION:

Applicability of this procedure:
1- Fill height shall be 2 feet or more per CDOT 2012-M&S Standards.
2- Structural plate size does not exceed the maximum sizes imposed by Article 12.6
3- The culvert is not a “Long-Span Structural Plate Structure” as defined in Section 12.7.
4- The culvert is not a “Structural Plate Box Culvert” as defined in Section 12.8.

Controlling capacity:
- Wall area thrust capacity =
  \[ \Phi b \, F_y \, A_s = 1.0 \times 33,000 \times 1.556 = 51,348 \, \text{lb/ft.} \]  \hspace{1cm} (12.3.1)

- Buckling thrust capacity:
  \[ (r/k) \times \sqrt{24 \, E_m/f_u} = (0.682/\text{.22}) \times \sqrt{(24 \times 29,000,000/45,000)} = 385.53 \, \text{in.} \]  \hspace{1cm} (12.3.2)
  Since span length \( S = 117 \, \text{in} < 385.53 \, \text{in} \)
  Therefore, \( f_{cr} = f_u - (f_u^2/48 \, E_m) (KS/r)^2 \) (Equation 12-8)
  \[ = 45,000 - (45,000^2/48 \times 29,000,000) (0.22/117/0.682)^2 \]
  \[ = 42,927.78 \, \text{psi, less or equal to } F_y = 33,000 \, \text{psi.} \]

  Buckling thrust capacity = \[ \Phi b \, f_{cr} \, A_s \]
  \[ = 1.0 \times 33,000 \times 1.556 = 51,348 \, \text{lb/ft.} \]

Note:
If \( S > 385.53 \, \text{inches} \), then, \( f_{cr} = 12 \, E_m/ (KS/r)^2 \) (Equation 12-9)

- Seam thrust capacity = \( \Phi s \times (\text{seam strength}) \)
  \[ = 0.67 \times 43,000 = 28,810 \, \text{lb/ft.} \]  \hspace{1cm} (12.3.3)

From above, the controlling thrust capacity, \( C = 28,810 \, \text{lb/ft.} \)

Dead Load:
Dead load pressure = 145 (4/12) + 120 (20/12) = 248.3 lb/sft
Dead load thrust = the greater of:

\[ 248.3 \times S/2 = 248.3 \times 117/24 = 1210.6 \, \text{lb/ft.} \]  \hspace{1cm} (12.1.4.2)

Or \[ 248.3 \times R_t = 248.3 \times 58.3/12 = 1206.3 \, \text{lb/ft} \]  \hspace{1cm} (12.1.6.2)

Controlling dead load thrust, \( DL = 1210.6 \, \text{lb/ft} \)
The live load effect of 1 wheel, 1 axle, or multiple axles should be considered. Figure 14A-1 demonstrates the effect of different live load configuration on different pipe sizes and different fill heights.

Figure 14A-1 - Effect of different wheel/ axle arrangement on different culvert conditions.

NOTES:
1. Example one - small culvert size & shallow fill height.
2. Example two - large culvert size & deep fill height.
X = Axle spacing (Typ.)
Y = Wheel spacing (Typ.)
Using:
- Wheel length in the direction of the roadway = 10 inches (3.30)
- Wheel width normal to the roadway = 20 inches (3.30)
- H = fill height + pavement thickness = 20 + 4 = 24 inches = 2 feet

Based on H and Section 3.8.2.3, the live load impact = 20%.

- One wheel distributed area length = \( \frac{10\"}{12} + 1.75H \) (6.4.1)
  \[ = 0.83 + 1.75 \times 2 = 4.33 \text{ ft.} \]
- One wheel distributed area width = \( \frac{20\"}{12} + 1.75H \) (6.4.1)
  \[ = 1.67 + 1.75 \times 2 = 5.17 \text{ ft.} \]

Therefore, one wheel live load pressure = \( \frac{16,000 \times 1.2}{4.33 \times 5.17} \) = 857.7 psf

- One axle distributed area length = same as one wheel = 4.33 ft.
- One axle distributed area width = the lesser of:
  - Axle spacing + 5.17 = 6 + 5.17 = 11.17 ft.
  - 2 wheels distributed width = 2 \times 5.17 = 10.34 ft.

Therefore, one axle live load pressure = \( \frac{32,000 \times 1.2}{4.33 \times 10.34} \) = 857.7 psf

(Note: Axle load may control in deeper fill.)

Based on culvert’s span, fill height, and truck configuration, the above are the only load arrangements need to be investigated to rate this structure for HS20-44. Other arrangement may control for other span lengths or other vehicles, i.e. interstate legal, Colorado legal, permit, NRL or SHVs.

Accordingly, the controlling HS 20-44 (Live load + Impact) thrust, \((LL+I)\) = the greater of:

857.7 \( \times \frac{S}{2} \) = 857.7 \( \times \frac{117}{24} \) = 4181.2 lb/ft. (12.1.4.2)

Or 857.7 \( \times \frac{R_t}{12} \) = 857.7 \( \times \frac{58.3}{12} \) = 4167 lb/ft (12.1.6.2)

Controlling (Live Load + Impact) thrust, \((LL+I)\) = 4181.2 lb/ft.

**Rating results:**

\[
\text{HS 20-44 Inventory Rating Factor,} \\
\text{Inventory RF} = \frac{(C - 1.95 \text{ DL})}{[2.17 \times (LL+I)]} = 2.92 \\
\Rightarrow \text{Inventory Rating} = 2.92 \times 36 \text{ ton} = 104.94 \text{ tons.}
\]

\[
\text{HS 20-44 Operating Rating Factor,} \\
\text{Operating RF} = \frac{(C - 1.95 \text{ DL})}{[1.3 \times (LL+I)]} = 4.87 \\
\Rightarrow \text{Operating Rating} = 4.87 \times 36 \text{ ton} = 175.17 \text{ tons.}
\]

This procedure should be repeated to calculate other vehicles rating as required.
This procedure was repeated to calculate other vehicle ratings for this culvert and the rating results are summarized below:

<table>
<thead>
<tr>
<th>Rating Summary:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HS20-44 - Inventory Rating =</td>
<td>104.94</td>
<td>Tons</td>
<td>2.92</td>
</tr>
<tr>
<td>HS20-44 - Operating Rating =</td>
<td>175.18</td>
<td>Tons</td>
<td>4.87</td>
</tr>
<tr>
<td>Colorado Legal Type 3 - Operating Rating =</td>
<td>202.20</td>
<td>Tons</td>
<td>7.49</td>
</tr>
<tr>
<td>Colorado Legal Type 3S2 - Operating Rating =</td>
<td>318.28</td>
<td>Tons</td>
<td>7.49</td>
</tr>
<tr>
<td>Colorado Legal Type 3-2 - Operating Rating =</td>
<td>318.28</td>
<td>Tons</td>
<td>7.49</td>
</tr>
<tr>
<td>Colorado Interstate Type 3 - Operating Rating =</td>
<td>199.70</td>
<td>Tons</td>
<td>8.32</td>
</tr>
<tr>
<td>Colorado Interstate Type 3S2 - Operating Rating =</td>
<td>316.20</td>
<td>Tons</td>
<td>8.32</td>
</tr>
<tr>
<td>Colorado Interstate Type 3-2 - Operating Rating =</td>
<td>324.52</td>
<td>Tons</td>
<td>8.32</td>
</tr>
<tr>
<td>Colorado Permit - Operating Rating =</td>
<td>553.64</td>
<td>Tons</td>
<td>5.77</td>
</tr>
<tr>
<td>Colorado Modified Tandem – Operating Rating =</td>
<td>299.56</td>
<td>Tons</td>
<td>5.99</td>
</tr>
<tr>
<td>AASHTO NRL - Operating Rating =</td>
<td>352.42</td>
<td>Tons</td>
<td>8.81</td>
</tr>
<tr>
<td>AASHTO SU4 - Operating Rating =</td>
<td>237.88</td>
<td>Tons</td>
<td>8.81</td>
</tr>
<tr>
<td>AASHTO SU5 - Operating Rating =</td>
<td>273.13</td>
<td>Tons</td>
<td>8.81</td>
</tr>
<tr>
<td>AASHTO SU6 - Operating Rating =</td>
<td>306.17</td>
<td>Tons</td>
<td>8.81</td>
</tr>
<tr>
<td>AASHTO SU7 - Operating Rating =</td>
<td>341.41</td>
<td>Tons</td>
<td>8.81</td>
</tr>
</tbody>
</table>