Design Considerations & Advantages of Flexible Buried Bridges

2017 Infrastructure Week Webinar
Hosted By the American Galvanizers Association & Short Span Steel Bridge Alliance
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Joel Hahm, P.E.
Senior Engineer
Big R Bridge
Greeley, CO
jhahm@bigrbridge.com
www.bigrbridge.com
Chair of TRB AFF70-1
Presentation Outline

• Introduction to Buried Bridges
• Introduction to Design
• Case studies / applications / innovations
• Questions
Deep Corrugated Buried Bridges

• Definition of Buried Bridges:
  • Bridge defined by AASHTO as a single span or combination of smaller spans totaling at least 20 ft.
  • Buried Bridge is any bridge that derives its support from both the structure and the surrounding soil through soil-structure interaction.
  • Structures consisting of corrugated metal are **Flexible Buried Bridges**.
  • AASHTO LRFD Bridge Design Specifications Section 12.8.9 (design).
  • AASHTO LRFD Bridge Construction Specifications Section 26 (construction).
  • AASHTO Materials Specifications – M167
  • AREMA Chapter 1, Section 4

• **NOT** the same thing as culverts, although perform some similar functions.
Material & Design Properties

- Material properties provided in AASHTO M167 / ASTM A761
- Design properties provided in AASHTO LRFD Section 12 (Appendix A12)
- Construction specifications in AASHTO LRFD Section 26
- Thicknesses up to 0.380” thick.
- Hot dipped galvanized with 3.0 oz/ft² coating weight (50% more than CSP)
- ¾” or ⅞” diameter high strength steel bolts (ASTM A449)
- Granular backfill with same electrochemical requirements as those in AASHTO LRFD Design Section 11.10.6.4.2 for MSE walls. Considers pH, resistivity, chlorides, sulfates, organics. Some design flexibility with mechanical properties.

<table>
<thead>
<tr>
<th>Property</th>
<th>Aluminum (ALSP)</th>
<th>Shallow Corrugated Steel</th>
<th>Deep Corrugated Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry Types</td>
<td>Small arch, box, closed shapes</td>
<td>Arches, closed shapes</td>
<td>Arch, box, pipe, multi-radius arches</td>
</tr>
<tr>
<td>Corrugation Profile</td>
<td>9” x 2.5”</td>
<td>6” x 2”</td>
<td>15” x 5.5”</td>
</tr>
<tr>
<td>Design Yield Strength</td>
<td>24 ksi</td>
<td>33 ksi</td>
<td>44 ksi</td>
</tr>
<tr>
<td>Relative Stiffness</td>
<td>~1.5 x shallow</td>
<td>1 (baseline)</td>
<td>~9 x shallow ~6.25 x ALSP</td>
</tr>
</tbody>
</table>
Steel Corrugation Profiles

- Advantages of Flexible Buried Bridges vs. Traditional Bridges:
- LVR Buried Bridge Applications:
Introduction

• Advantages of Flexible Buried Bridges vs. Rigid Bridges:

  • Lower foundation costs & no bump at the end of the bridge (if foundations properly designed)

  • ABC benefits - No heavy equipment or specialized labor skills needed for construction, Shorter design & material lead times, can be easily staged, no need to coordinate cranes & delivery, & cheaper/easier to transport.

  • Able to accommodate complex site geometries & road profiles, No need to minimize bridge width (allowing for pedestrian access, bike lanes, etc.), Can be lengthened for future road widening

  • Structural redundancy, resilient, aesthetic flexibility, sustainability, enhanced safety benefits, reusing bridge foundations
Introduction

• Buried Bridge Applications:
  • Bridge replacement
  • Limited site access / remote locations
  • Grade separation
  • Staged construction
  • Drainage structures
  • Rehabilitation of existing bridges
  • Wildlife / aquatic crossings
  • Environmentally sensitive crossings
  • Canal / utility crossings
  • Pedestrian access
  • Emergency / temp / detours
  • Single span alternative for multi-cell hydraulic crossings
  • Heavy vehicular loads
  • Any bridge project!
AASHTO LRFD Design Checks

• Shallow Corrugated Arches – Design Based on Thrust Loads (Section 12.7)
  • Wall Area (12.7.2.3)
  • Buckling (12.7.2.4)
  • Seam Strength (12.7.2.5)
  • Flexibility for Installation (12.7.2.6)

• Shallow Corrugated Boxes – Design Based on Flexure (Section 12.9)
  • Moment Capacity (12.9.4.2, 12.9.4.3)
  • Typically Includes Circumferential Reinforcing (Ribs)
AASHTO LRFD Design Checks

- Traditional Long Span Structures – Design Based on Thrust (Section 12.8)
  - Shallow corrugated structures with a radius > 13 ft
  - Wall Area, Buckling, Seam Strength, Flexibility per Section 12.7
  - Additional Requirements Based on Geometric Limits (Table 12.8.3.1.1-1)
  - Requires Special Features (typically longitudinal stiffeners, concrete relief slab, or ribs)

Table 12.8.3.1.1-1 — Minimum Requirements for Long-Span Structures with Acceptable Special Features

<table>
<thead>
<tr>
<th>Top Arc Minimum Thickness (in.)</th>
<th>15.0</th>
<th>17.0</th>
<th>20.0–23.0</th>
<th>23.0–25.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>6&quot; × 2&quot; Corrugated Steel Plate—Top Arc Minimum Thickness (in.)</td>
<td>0.111</td>
<td>0.140</td>
<td>0.170</td>
<td>0.218</td>
</tr>
</tbody>
</table>

Geometric Limits

- Maximum plate radius—25.0 ft
- Maximum central angle of top arc—80.0°
- Minimum ratio, top arc radius to side arc radius—2
- Maximum ratio, top arc radius to side arc radius—5

Minimum Cover (ft)

<table>
<thead>
<tr>
<th>Top Radius (ft)</th>
<th>≤ 15.0</th>
<th>15.0–17.0</th>
<th>17.0–20.0</th>
<th>20.0–23.0</th>
<th>23.0–25.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel thickness without ribs (in.)</td>
<td>0.111</td>
<td>2.5</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>0.140</td>
<td>2.5</td>
<td>3.0</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>0.170</td>
<td>2.5</td>
<td>3.0</td>
<td>3.0</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>0.188</td>
<td>2.5</td>
<td>3.0</td>
<td>3.0</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>0.218</td>
<td>2.0</td>
<td>2.5</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>0.249</td>
<td>2.0</td>
<td>2.0</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>0.280</td>
<td>2.0</td>
<td>2.0</td>
<td>2.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>
AASHTO LRFD Design Checks

• Deep Corrugated Structures (corrugation profile depth > 5 in) – Design Based on Thrust and Flexure (Section 12.8.9)
  
  • Requires Rigorous Analysis (typically FEA)
  
  • Wall Area, Seam Strength Same as for Long Span Structures
  
  • Check Flexure (includes reduction for connections)
  
  • Global Buckling Check (Eq. 12.8.9.6-1)
  
  • Moment-Thrust Interaction Check (Eq. 12.8.9.5-1)

\[
\left( \frac{T_f}{R_t} \right)^2 + \left| \frac{M_u}{M_n} \right| \leq 1.00
\]

• Flexibility, Special Features, Shape Requirements for Long Span do not Apply (12.8.9.1)

• Includes Requirements for minimum cover and backfill zone width (12.8.9.2 & 12.8.9.4)
General Design Inputs

• Inputs for Shallow Corrugated Structures:
  • Span
  • Soil Cover
  • Wheel Loads (based on LL design vehicle)
  • Plate Radii (for categorizing as arch, long span and box shapes)
  • Structure Section Properties – from Appendix A12

• Inputs for Deep Corrugated Structures:
  • Structure Geometry (dimensions, shape, radii, etc.)
  • Soil Cover & Backfill Zone Width
  • Soil Properties – foundation soils, backfill zone soils, site soils
  • Wheel Loads (based on LL design vehicle)
  • Structure Section Properties – from Appendix A12
  • Foundation Type & Approximate Dimensions
Design Considerations

• Fully Incorporated into AASHTO LRFD Design / Construction / Materials
• Site Geometry Inputs
• Site Soil Conditions & Backfill Properties
• Loading / Performance Requirements
• Other Considerations
Maintenance / Inspection

- Same methods & frequency as currently used for bridges & precast structures.
- Drones, cameras, scans, visual, boom truck (larger structures).
- Check dimensions, deflection, general condition, evidence of erosion at inlet/outlet (hydraulic applications), pavement condition.
- Clear unwanted vegetation, debris, silt, etc.
Durability & Service Life

• Buried bridges typically have no invert

• Steel structures have 50% more galvanizing than CSP and are available in much higher steel thicknesses (currently ~1/3 inch)

• Backfill electrochemical requirements apply for soil & water in contact with the structure – not necessarily site soil conditions.

• Use same backfill electrochemical requirements as those in AASHTO LRFD Design Section 11.10.6.4.2 for MSE walls. Considers pH, resistivity, chlorides, sulfates, organics.

• Added features/detailing like splash walls & stem walls can limit exposure.

• Secondary coatings (polyurea, epoxy, asphalt, polymer, etc.) can be used in harsh conditions.

• Barriers can be used to shed surface water to prevent leaking and protect from de-icing chemicals

• Service life primarily depends on proper installation, maintenance, and what structure is exposed to. End user (owner) has greatest impact on service life – just like with any other type of bridge.
Case Studies / Applications

• Lawrence Road Bridge Replacement – Gray, ME (with design example)
• NC State Veterans Home – Black Mountain, NC
• Emergency Bridge Replacement – Cape Girardeau County, MO
• RR Grade Separation – Randolph, NE
• Current projects in & Other Applications
Lawrence Rd. Bridge Replacement
Gray, Maine
Custom Small Span Box Structure
28’1½ ” span x 6’ 3½ ” rise
Design Requirements

• Short span bridge replacement

• Height limitations

• Bridge foundations to remain

• New headwall configuration
Load & Resistance Factors

**FEA Inputs:**
27’3” span, medium dense granular foundation soils, A-1 backfill, silty/sandy site soils, HL93 loading, 2’ cover, span/5 backfill zone, spread footings, 15x5.5 profile, 1 gauge
Loads are applied incrementally…
Live load applied at last step – design governed by HL93 Tandem

Moment diagram of all load steps (LL in pink)
Obtain loads from FEA output

Last Load Step (DL+LL)
Obtain loads from FEA output

Last Dead Load Step
Design loads obtained using FEA based on SSI & load factors applied

Total Factored Thrust: 25.9 k/ft.
Total Factored Applied Moment: 23.0 k-ft./ft.

Structure capacities calculated based on AASHTO LRFD Equations

### Calculated Capacity

<table>
<thead>
<tr>
<th>Category</th>
<th>Formula</th>
<th>Value</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Buckling Resistance</td>
<td>$R_b = 78.3 \text{ k/ft.}$</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>Factored Wall Resistance</td>
<td>$R_n = 142.8 \text{ k/ft.}$</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>Nominal Seam Resistance</td>
<td>$SS = 98.5 \text{ k/ft.}$</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>Factored Moment Resistance</td>
<td>$M_f = 26.9 \text{ k-ft./ft.}$</td>
<td>OK</td>
<td></td>
</tr>
<tr>
<td>Factored Moment Resistance across seam</td>
<td>$M_{f10%} = 24.7 \text{ k-ft./ft.}$</td>
<td>OK</td>
<td></td>
</tr>
</tbody>
</table>

Check moment-thrust interaction:

\[
\left( \frac{T_f}{R_t} \right)^2 + \left| \frac{M_u}{M_n} \right| \leq 1.00
\]

\[
\left( \frac{25.9}{142.8} \right)^2 + \left| \frac{23.0}{26.9} \right| = 0.89 \leq 1.00
\]
Contractor shall submit shop drawing for footing design including pinning to existing foundation. Design shall be signed and sealed by Maine licensed professional engineer. Final design and configuration may require modifications once existing foundations are exposed. (Typ.)

Cut existing concrete at approx. EL. 209.75 (Typ.)

Pin proposed foundation to existing foundation (Typ.)

Exact configuration of existing footing unknown
Backfilling & Headwalls
56'5" span x 15' rise box structure
Black Mountain, North Carolina
Design Requirements

• ~15’ distance from creek invert to road
• 48’ min clear span at 6’ above creek invert
• Creek bed soils sensitive to scour (sands)
• Wide span to get beyond limits of disturbance
• Sloping transverse grade
• Considered traditional bridge early on – would have required ~100 ft + span based on creek banks.
As Detailed in Project Documents
Buried Flexible Steel Bridge Option

SITE GEOMETRY
## Cost Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Rigid Bridge Structure Cost</th>
<th>Buried Flexible Steel Bridge Structure Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design, Installation, and Structure</td>
<td>$213,650</td>
<td>$205,950</td>
</tr>
<tr>
<td>Footings / Pile Caps, Ftg Excavation &amp; Dewatering</td>
<td>$52,500</td>
<td>$101,780*</td>
</tr>
<tr>
<td>Sheet Pile Cutoff Walls</td>
<td>$39,250</td>
<td>$39,250</td>
</tr>
<tr>
<td>H-Pile Deep Foundations</td>
<td>$360,000</td>
<td>---</td>
</tr>
<tr>
<td>Backfill Foundation Cut</td>
<td>$10,000</td>
<td>$15,000</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>$675,400</strong></td>
<td><strong>$361,980 (-45%)</strong></td>
</tr>
</tbody>
</table>

* Includes cost for fnd soil improvement. Ftg larger than pipe cap.
US61 Over Buckeye Creek
Cape Girardeau County, Missouri
Twin Custom Box Structures
30’8¼” span x 11’7½” rise
Design Requirements

• Emergency replacement for old steel truss bridge - critical detour route for construction on nearby I-55
• Accelerated Bridge Construction
• Hydraulic requirements (flow area)
Original Concept: 80’ Span Precast Bridge
Twin Box Buried Bridge Option
## Structure Comparison

<table>
<thead>
<tr>
<th>Conventional Precast Plank Bridge</th>
<th>Twin Span Buried Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inverted trapezoidal flow area – limited by sloped abutments</strong></td>
<td><strong>Widened hydraulic flow area at channel elevation with comparable end area</strong></td>
</tr>
<tr>
<td><strong>Required site re-grading</strong></td>
<td><strong>Minimal site grading – mainly finish grading</strong></td>
</tr>
<tr>
<td><strong>Approx. 100 ft of asphalt pavement removal &amp; replacement beyond bridge</strong></td>
<td><strong>Less than 50 ft of asphalt pavement removal &amp; replacement</strong></td>
</tr>
<tr>
<td><strong>Bridge abutments or sloped banks required</strong></td>
<td><strong>No abutments required</strong></td>
</tr>
<tr>
<td><strong>Required deep foundations with pile caps</strong></td>
<td><strong>Shallow foundations</strong></td>
</tr>
<tr>
<td><strong>45 days for design &amp; fabrication of bridge elements only</strong></td>
<td><strong>30 days for design &amp; fabrication of twin box culverts and precast MSE headwalls. Includes design, submittal, approval, material acquisition, fabrication, galvanizing, curing, &amp; delivery.</strong></td>
</tr>
</tbody>
</table>
7 year update
Central Valley Ag RR Crossing

49’7” Span x 17’2” Rise Flexible Buried Bridge
Randolph, Nebraska
Current Projects & Other Applications
St. Johnsbury Rd Bridge Replacement
St. Johnsbury, Vermont
Bridge Replacement over Former Rail Bed (AREMA Clearance)
St. Johnsbury Rd Bridge Replacement
St. Johnsbury, Vermont
Bridge Replacement over Former Rail Bed (AREMA Clearance)
Temporary I-95 Bridge
Attleboro, Massachusetts
Temporary I-95 Bridge
Attleboro, Massachusetts
Temporary I-95 Bridge
Attleboro, Massachusetts
Grants, New Mexico
2.7m lbs. Mining Shovel, 47 ft span
Spokane, Washington
US2 Improvements – VE Staged Construction, Fish Passage
Lincoln County, Colorado
County Rd Bridge Replacement
Fort Knox Gold Mine
Fairbanks, Alaska
1.8m lbs. Mining Shovel, 46 ft span
Fort Knox Gold Mine
Fairbanks, Alaska
1.8m lbs. Mining Shovel, 46 ft span
Vicksburg, Mississippi
Bridge Replacement / High Cover / Slope Stability Improvements
Vicksburg, Mississippi
Bridge Replacement / High Cover / Slope Stability Improvements
Greensboro, South Carolina
53’ span, significant settlement
Thank You!

Joel Hahm, PE
Senior Engineer
Big R Bridge
Greeley, CO
jhahm@bigrbridge.com
www.bigrbridge.com
Introduction to Structural Design of Buried Steel Bridges (Non-Seismic)

Michael McGough, PE
Director of Technical Services
National Corrugated Steel Pipe Association

- Founded in 1956
- Organized to promote the responsible use of corrugated steel products used primarily in drainage applications
Key Messages

Service Life: 100+ year lifespan attainable
Sustainability:
  - 100% recyclable
  - LEED points ready
  - Cost-effective
Strength: Go deeper and steeper
Traceability: Certified Mill Test Reports and Buy America compliance
Technical Resources

Visit www.transportation.org
- AASHTO Materials Specifications M167, M218, and M243
- LRFD Bridge Design (Section 12) and Construction (Section 26) Specifications

Visit www.astm.org
- ASTM Specifications A761, A796, A807, A929 and A964

Visit www.NCSPA.org to see steel in action
- NCSPA Corrugated Steel Pipe Design Manual
- NCSPA Installation Guide
• https://ncspa.org/resources/calculators-charts-tools/service-life-calculator-plate/
<table>
<thead>
<tr>
<th>Desired Service Life (Years)</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistivity (Ohm-cm)</td>
<td>2500</td>
</tr>
<tr>
<td>pH</td>
<td>6</td>
</tr>
<tr>
<td>Abrasion Level</td>
<td>Level 1: Non-abrasive</td>
</tr>
<tr>
<td>Is the culvert an open-bottom structure?</td>
<td>No</td>
</tr>
<tr>
<td>Is the culvert asphalt coated?</td>
<td>No</td>
</tr>
<tr>
<td>Are concrete paved inverts being installed?</td>
<td>No</td>
</tr>
<tr>
<td>Will road salts be used near the structure?</td>
<td>No</td>
</tr>
</tbody>
</table>
# Service Life Calculator (Plate)

<table>
<thead>
<tr>
<th>Gage</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>N/A</td>
</tr>
<tr>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>1</strong></td>
<td><strong>82</strong></td>
</tr>
<tr>
<td>5/16</td>
<td>94</td>
</tr>
<tr>
<td>3/8</td>
<td>100</td>
</tr>
</tbody>
</table>

- **Desired Service Life (Years):** 75
- **Resistivity (Ohm-cm):** 2500
- **pH:** 6
AISI Chart for Estimating Average Invert Life for Galvanized CSP

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>1.3</th>
<th>1.6</th>
<th>2.0</th>
<th>2.8</th>
<th>3.5</th>
<th>4.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(in)</td>
<td>.052</td>
<td>.064</td>
<td>.079</td>
<td>.109</td>
<td>.138</td>
<td>.168</td>
</tr>
<tr>
<td>Gage</td>
<td>18</td>
<td>16</td>
<td>14</td>
<td>12</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Factor</td>
<td>0.7</td>
<td>1.0</td>
<td>1.3</td>
<td>1.8</td>
<td>2.3</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Aluminum Coated Type 2: See Discussion

Years = 3.82R^{0.41}

Resistivity (R), ohm-cm

Years = 35.85 (\log_{10} R - \log_{10} (2160-2490 \log_{10} pH))
eSPAN140 is a complimentary web-based design tool which provides customized steel solutions for bridges up to 140 feet.

You can create a customized steel solution in 3 simple steps:

**Step 1.**
Create a User's Account

**Step 2.**
Input Your Specific Project Details

**Step 3.**
View Your Instant Customized Solutions Books

- Standard designs for rolled beam, plate girder, corrugated structural plate, and corrugated steel pipe.
- Manufacturer's customized pre-fabricated solutions
- Durability solutions
- Contacts to design and build your bridge
- Access to complimentary design support

See a Sample Solutions Book - Sample version contains limited information to reduce file size

"eSpan140 provides county engineers with all of the information necessary to select a cost-effective steel bridge or culvert customized to their specific project needs."

Mark Servi - President-Elect, National Association of County Engineers

See More Testimonials
May 18, 2017

What is the Short Span Steel Bridge Alliance?

Who are its members?

Show slide from video.

NCSPA

Steel: Proven 100-Years Strong

eSPAN140.com
A Resource for short span steel bridge applications

- Case Studies
- Videos
- eSPAN140.com – Free Design Software
- Access to Members and Bridge Technology Center

www.shortspansteelbridges.com
www.espan140.com
**New Project**

**Step 1. Project Information**
Let's begin by naming the project and entering the location.

View a demonstration video

Please note the following when entering the bridge span length, skew angle, and overhang width:

<table>
<thead>
<tr>
<th>Solution Type*</th>
<th>Bridge Span Length</th>
<th>Skew Angle</th>
<th>Overhang Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolled Beam (40' to 100')**</td>
<td>0' 20' 40' 60' 80' 100' 120' 140'</td>
<td>+/- 20 degrees</td>
<td>3'3&quot; or less</td>
</tr>
<tr>
<td>Homogeneous Plate Girder (60' to 140')**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid Plate Girder (80' to 140')**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrugated Steel Pipe/Structural Shape (0' to 85')</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturer's Steel Solutions (all)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* For bridges/culverts outside of this range, standard designs will not appear in your solutions book.
** Standard designs for rolled beam and plate girder solutions are rounded in five (5) foot increments.
Project Name*
Infrastructure Week Test Project

Project Status*
- Final Design
- Select One
- Informational Only
- Not yet scheduled
- Planning
- Preliminary Design
- Final Design
- Bid Process
- Construction

# of Striped Traffic Lanes*
3

Roadway Width*
- 45 Feet
- 0 Inches

Individual Parapet Width
- 5 Feet
- 0 Inches

Individual Deck Overhang Width
- 0 Feet
- 0 Inches

Pedestrian Access?
- No

Skew Angle
- 0 Degrees

Average Daily Traffic
- Over 2,000

Design Speed
- 0-45 mph
Step 3. Corrugated Steel Pipe & Structural Plate Details

(Optional) Details regarding possible corrugated steel pipe solutions. If you do not have this information, leave the input fields blank and click on "Next".

Waterway Area

225
Square Feet

Height Of Cover

17 0
Feet  Inches

H_{min} = minimum allowable cover dimension

NOTE: The minimum cover dimension is not to be confused with the fill height used for calculation purposes, which shall be from the top of the pipe to the top of the surface, regardless of the pipe type or pavement type.
Corrugated Steel Pipe Solutions

Round Pipe 6x2 - Double

Diameter

With

Total Span

MINIMUM COVER

<table>
<thead>
<tr>
<th>SPECIFIED THICKNESS</th>
<th>COVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.218 inches</td>
<td>36 inches</td>
</tr>
<tr>
<td>0.249 inches</td>
<td>36 inches</td>
</tr>
<tr>
<td>0.28 inches</td>
<td>36 inches</td>
</tr>
<tr>
<td>0.318 inches</td>
<td>36 inches</td>
</tr>
<tr>
<td>0.38 inches</td>
<td>36 inches</td>
</tr>
</tbody>
</table>

MAXIMUM COVER

<table>
<thead>
<tr>
<th>SPECIFIED THICKNESS</th>
<th>COVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.218 inches</td>
<td>45 feet</td>
</tr>
<tr>
<td>0.249 inches</td>
<td>54 feet</td>
</tr>
<tr>
<td>0.28 inches</td>
<td>60 feet</td>
</tr>
<tr>
<td>0.318 inches</td>
<td>66 feet</td>
</tr>
<tr>
<td>0.38 inches</td>
<td>82 feet</td>
</tr>
</tbody>
</table>
Low Profile Arch 6x2 - Double

### Minimum Cover

<table>
<thead>
<tr>
<th>SPECIFIED THICKNESS</th>
<th>COVER</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.111 inches</td>
<td>33.38 inches</td>
</tr>
<tr>
<td>0.140 inches</td>
<td>33.38 inches</td>
</tr>
<tr>
<td>0.170 inches</td>
<td>33.38 inches</td>
</tr>
<tr>
<td>0.186 inches</td>
<td>33.38 inches</td>
</tr>
<tr>
<td>0.216 inches</td>
<td>33.38 inches</td>
</tr>
<tr>
<td>0.249 inches</td>
<td>33.38 inches</td>
</tr>
<tr>
<td>0.280 inches</td>
<td>33.38 inches</td>
</tr>
<tr>
<td>0.316 inches</td>
<td>33.38 inches</td>
</tr>
<tr>
<td>0.360 inches</td>
<td>33.38 inches</td>
</tr>
</tbody>
</table>

### Maximum Cover

For specific details on maximum height of cover requirements for this gauge, profile, and shape, please contact the NCSPA.

### Dimensions

<table>
<thead>
<tr>
<th>SPAN - ft-in</th>
<th>RISE - ft-in</th>
<th>BOTTOM SPAN - ft-in</th>
<th>WATERWAY AREA - ft²</th>
<th>RADIUS - ft-in</th>
<th>SOIL WIDTH - ft-in</th>
<th>TOTAL SPAN - ft-in</th>
<th>TOTAL WATERWAY AREA - ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>22-3&quot;</td>
<td>7-11&quot;</td>
<td>22-1&quot;</td>
<td>140'</td>
<td>14-0&quot;</td>
<td>4-6&quot;</td>
<td>2'</td>
<td>46'-6&quot;</td>
</tr>
</tbody>
</table>
Box Culvert 15x5.5

<table>
<thead>
<tr>
<th>SPAN (ft-la)</th>
<th>RISE (ft-in)</th>
<th>WATERWAY AREA (ft²)</th>
<th>CROWN RADIUS (Rc) (in)</th>
<th>HAU (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45' 3''</td>
<td>10' 0''</td>
<td>383.3'</td>
<td>646.9'</td>
<td></td>
</tr>
</tbody>
</table>
Corrugated Steel Pipe Solutions

Box Culvert 15x5.5 - Double

MINIMUM COVER
For specific details on minimum height of cover requirements for this gauge, profile, and shape, please contact the NCSPA.

MAXIMUM COVER
For specific details on maximum height of cover requirements for this gauge, profile, and shape, please contact the NCSPA.

<table>
<thead>
<tr>
<th>SPAN (ft.-in)</th>
<th>RISE (ft.-in)</th>
<th>WATERWAY AREA (ft²)</th>
<th>CROWN RADIUS (Rc) (ft)</th>
<th>HAUNCH RADIUS (Rh) (ft)</th>
<th>SIDE ANGLE</th>
<th>SOIL WIDTH (ft.-in)</th>
<th>TOTAL SPAN (ft.-in)</th>
<th>TOTAL WATERWAY AREA (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22'-10 3/8&quot;</td>
<td>5'-10 3/4&quot;</td>
<td>114.8</td>
<td>347.2&quot;</td>
<td>40&quot;</td>
<td>1.98</td>
<td>2&quot;</td>
<td>47' 8.75&quot;</td>
<td>229.600</td>
</tr>
</tbody>
</table>
THANK YOU!!!

QUESTIONS???