Box Culvert Design And Detailing

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Learning Objectives

• Definition and Purpose
• Culvert Types
• ASTM standards related to box culverts
• Other Culvert Specifications
• Software
• Review of plans and information needed to design
• Production considerations
Definition and Purpose

• A culvert is a transverse drain or waterway typically located below a roadway, railway, or taxiway embankment to carry water from one side of the embankment to another.

Definition and Purpose

• Box Culvert is a type of culvert with a square or rectangular cross section
Why Precast Box Culverts?

• Advantages of precast concrete for box culverts
  • Flexible sizes with spans up to 20'
  • Superior hydraulics
  • Accelerated construction
  • Quality of fabrication, structural integrity, and durability
  • NPCA Certified Plants

Demand for Precast Box Culverts

• Significant increase in recent years due to:
  • Increase in design flows resulting in larger openings
  • More frequent failures involving other culvert types
Precast Box Culvert Types

• Monolithic Single Cell

Precast Box Culvert Types

• Monolithic Multi-Cell
Precast Box Culvert Types

• Trench style with separate top slab

Precast Box Culvert Types

• Mid-Seam (Clam-Shell)
Precast Box Culvert Types

• 3-Sided frame with separate footings or separate invert slab

ASTM Standards

• A little history:
• ASTM published the first standards for precast sections in the mid 70’s under the jurisdiction of the C13 Committee on Concrete Pipe
  • ASTM C789 for culverts for earth fills equal to or greater than 2’
  • ASTM C890 for culverts with less than 2’ of earth fill
ASTM Standards

• The committee’s intent was to standardize culvert sizes, slab & wall thicknesses, and reinforcing design.

• Reinforcing Tables:
  • Area-of-steel is based on welded wire reinforcing only and cannot be used for conventional rebar
  • Maximum circumferential spacing = 4”
  • Maximum longitudinal spacing = 8”

• Materials and manufacturing requirements

• Quality control and tolerances
ASTM Standards

• Standard C789 and C850 were combined into ASTM C1433 in 1999
• ASTM C1577 was introduced in 2005 to address AASHTO LRFD design method
• ASTM C1786 was added in 2014 for Segmental Box Sections
• ASTM C1504 was originally approved in 2001 for 3-sided structures

Other Specifications

• AASHTO Standard for Highway Bridges, 17th Edition
  • Covers H and HS truck loadings
  • Section 17.7 Reinforced Concrete Box, Precast
Other Specifications

• AASHTO LRFD Design Specification, 9th Ed. most current
  • HL93 loadings - Standard truck, tandem axle and lane load
  • Buried structures are covered in Chapter 12
Other Specifications

• American Railway Engineering Manual, AREMA
  • Cooper Railroad Loading (E80)

AASHTO Material Specifications

• M259 (Same as ASTM C789)
• M273 (Same as ASTM C850)
Other Specifications

• State Specifications
  • Many state DOTs have their specifications that may differ from ASTM
    • Load rating vehicles (several states)
    • Maine adds 25% to HL93 standard truck load
    • PennDOT – PHL93 and special LR vehicles. All culverts are post-tensioned
    • NYSDOT – Load ratings for all culvert ≥ 5’ span, Min 1.2 Inventory rating
  • Some states have requirements for:
    • Minimum slab & wall thickness
    • Bar cover
    • Epoxy bar requirements

Design Software

• The structural analysis of a rigid frame is somewhat complicated and does not lend itself to hand calculations
Design Software

- **BOXCAR** – First released in 1982 under sponsorship of ACPA
  - Latest Version 3.1 uses AASHTO Standard or LRFD
  - Program no longer supported by ACPA
  - Does not comply with latest LRFD specifications
  - Single cell monolithic box only

Design Software

- **BRASS Culvert** – Wyoming DOT
  - AASHTO Standard or LRFD 9th Edition
  - User defined truck loadings for design and load ratings
  - Multi-cell culverts
Design Software

• CANDE – Culvert Design and Analysis
  • Developed in 1976 under sponsorship of FHWA
  • Primarily used for soil-structure interaction – Arches
  • Not user friendly

Design Software

• Eriksson Culvert – Previously ETCulvert
  • Developed by Eriksson Software
  • Single and multi-cell culverts
  • 3-Sided Frames
  • Segmental Boxes
  • Wingwalls
  • AASHTO Standard and LRFD 9th Edition
  • AREMA and CSA
  • Several state DOT agency recommended settings
  • Design, analysis, and load ratings
Information Needed to Design

• Controlling Specification
• Clear span and clear rise
• Min & Max earth fill over top of culvert
  • Measure earth fill within the roadway limit
• Design loads (Vehicles)
• Direction of traffic (skew)
  • Parallel to main reinforcing
  • Perpendicular to main reinforcing

Analysis vs Design

• Design Mode
  • Enter span, rise, fill depth, bar cover, design spec, and loading
  • Program performs iterations to determine slab/wall thickness and reinforcing
• Analysis Mode
  • Enter all above information plus member thickness and reinforcing
  • Program checks for strength and serviceability against specification requirements
Culvert Layout

• Determine individual section lay length
  • Considerations:
    • Form limits – typically 8’
    • Max weight – may be determined by contractor
    • Hook height within the plant
    • Shipping

Culvert Layout

• Determine individual section lay length
  • Uniform section length = overall length/# sections
    • Example L = 42’ ÷ 6 Sections = 7'/section
  • Adjust section length for joint gap
    • Joint gap = 1/2”
    • L = 42’ x 12” – 1/2” x 5 joints ÷ 6 Sections = 83.5833” ~ 6’-11 9/16”
  • Do all 6 sections need to be equal length?
Culvert Layout

• Let’s make the outlet end a little shorter
  • Inlet end and standard section L = 83 ¾” (6'-11 ¾”)
    • Length with joints = 5 x 83.75” x 5 joints x ½” = 421.25” = 35' - 1¼"
  • Outlet end
    • L = 42’ x 12 – 421.25 = 82.75” = 6’-11 ¼”
    • Make up the ½” difference with a plate over the pallet
Joint Design

• ASTM C1433 Section 9.1
  • “The precast reinforced concrete box sections shall be produced with tongue and groove ends. The ends shall be of such design and the ends of the box sections so formed that the sections can be laid together to make a continuous line of box sections.”
    • Primarily for proper alignment
    • NOT for load transfer across the joint
    • Annular space is needed for installation and to prevent load transfer

Joint Design

• ASTM C1433 Section 9.2
  • “Joints may conform to the requirements of Specification C990, Specification C1677, or other established joint type as approved by the owner including, but not limited to, mortar, sealant, or fabric-wrapped joints...”
    • C990 – Preformed Flexible Joint Sealants (Butyl)
    • C1677 – Rubber Gaskets
  • Unless the joint is required to be watertight (silt-tight is typically acceptable), recommend closed cell neoprene gasket conforming to ASTM D1056, Grade #2A1 or #2A2
Joint Design

• Male end of joint should point downstream

Lifting and Handling

• Lifter type and placement considerations
  • Position and orientation of culvert sections for casting, yard storage, shipping, and installation
  • Weight of section being lifted
  • Center-of-gravity
  • Rigging and overturning
    • Lifter orientation will switch from shear to tension
  • Handling Stress
    • Local stress – lifter breakout
    • Global stress – Cracking moment
**Lifting and Handling**

Large cantilever moment

Cracking moment

\[ M_{cr} = f_r \times S \]

\[ f_r = \text{Modulus of rupture} = 5\sqrt{f'c} \]

\[ S = \text{Section Modulus} = b \times h^2/6 \]

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Smaller cantilever moment

Cracking moment

\[ M_{cr} = f_r \times S \]

\[ f_r = \text{Modulus of rupture} = 5\sqrt{f'c} \]

\[ S = \text{Section Modulus} = b \times h^2/6 \]
Reinforcing

- Rebar – ASTM A615
- Weldable Bar – ASTM A706
- Welded Wire Reinforcing – A1064
  - Smooth or deformed
- Fibers – Synthetic and non-synthetic may only be used as a nonstructural material, i.e. crack control
- Bar cover – Unless otherwise specified, 1” all locations and 2” in top of top slab if earth fill < 2’

Reinforcing Cover

- Rebar – ASTM A615
- Weldable Bar – ASTM A706
- Welded Wire Reinforcing – A1064
  - Smooth or deformed
**Reinforcing Designations**

<table>
<thead>
<tr>
<th>MK#</th>
<th>ASTM</th>
<th>Location</th>
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<tbody>
<tr>
<td>A100</td>
<td>As2</td>
<td>Top slab inside</td>
</tr>
<tr>
<td>A200</td>
<td>As3</td>
<td>Bottom slab inside</td>
</tr>
<tr>
<td>A300</td>
<td>As7</td>
<td>Top slab outside</td>
</tr>
<tr>
<td>A400</td>
<td>As8</td>
<td>Bottom slab outside</td>
</tr>
<tr>
<td>A1</td>
<td>As1</td>
<td>Wall outside</td>
</tr>
<tr>
<td>B1</td>
<td>As4</td>
<td>Wall inside</td>
</tr>
<tr>
<td>C100</td>
<td>As5</td>
<td>Top slab longit. Inside</td>
</tr>
<tr>
<td>C200</td>
<td></td>
<td>Bottom slab longit. inside</td>
</tr>
<tr>
<td>C1-TF</td>
<td>As6</td>
<td>Top slab longit. outside</td>
</tr>
<tr>
<td>C1</td>
<td></td>
<td>Wall longitudinal</td>
</tr>
</tbody>
</table>

**Joint Reinforcing**

- 3/8" MIN COV ON LONGIT BARS
- 1" CLOSED CELL NEOPRENE GASKET, TYP
- 3/8" MIN 2" MAX COV ON CIRC. BARS ALONG JOINT SURFACE ONLY


Case Study

New York State Department of Transportation  
Contract #D264902  
Culvert Replacement on NY Route 2 and Moses Road  
Town of Petersburgh, NY

NYSDOT Culvert C140138

- Design Parameters
  - Clear Span = 8'-0"
  - Frame Rise = 8'-4"
  - Length = 57'-0"
  - Minimum Fill Depth = 3'
  - Maximum Fill Depth = 5'
  - Skew Angle = 26.60°
  - Design Load = AASHTO HL93
  - Culvert Type – 3-Sided Frame w/Invert Slab
Section Length and Skewed End Dimensions

Invert Slab Length and Cut-off Wall Depth
3-Sided Frame Design

**REFERENCES:**
1. AASHO LRFD Specification for Highway Bridges, 6th Edition
2. W.DOT Specification 502
3. Design using Element Code V8.0

**DESIGN CRITERIA**

<table>
<thead>
<tr>
<th>Member Type</th>
<th>Design Criteria</th>
<th>Member Thickness</th>
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</tbody>
</table>

**Concrete | Weight**
- 1.74 kbf | 1.60 kbf

**Concrete | Weight**
- 1.74 kbf | 1.60 kbf

**Plan View**

**Typical Section**

Shop Drawings
Project Photos

Project Photos
Project Photos

![Image of a construction site with precast concrete elements]

Project Photos

![Image of a worker installing precast concrete units]

51

52
Project Photos

Case Study

New York State Department of Transportation  
Contract #D264939  
NY Route 41 Over Wilkens Brook  
Town of Coventry, NY
NYSDOT Culvert C920116

- **Design Parameters**
  - Clear Span = 10’-0”
  - Clear Rise = 6’-0”
  - Length = 58’-2”
  - Minimum Fill Depth = 2’
  - Maximum Fill Depth = 3.8’
  - Direction of Traffic – Parallel to Main Reinforcing
  - Design Load = AASHTO HL93
  - Culvert Type – 4-Sided Sing-Cell Monolithic

### Section Lengths

<table>
<thead>
<tr>
<th>Span (ft)</th>
<th>Top Shell (in)</th>
<th>Bottom Shell (in)</th>
<th>Wash (in)</th>
<th>Length (ft)</th>
<th>Height (ft)</th>
<th>Standard Section Length (ft)</th>
<th>Length along Contour (ft)</th>
<th>Joint Depth (in)</th>
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<tbody>
<tr>
<td>10.00</td>
<td>12.00</td>
<td>16.00</td>
<td>0.00</td>
<td>58.2</td>
<td>16.00</td>
<td>69.5</td>
<td>69.5</td>
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<td>55.00</td>
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<td>105.00</td>
<td>0.00</td>
<td>56.2</td>
<td>16.00</td>
<td>70.6</td>
<td>70.6</td>
<td>10.00</td>
</tr>
</tbody>
</table>

- **End Sect Slope Angle**: 8 deg
- **No. of Bid Sections**: 6
- **Outside Culvert with**: 11.33 ft
- **Length w/ Parts**: 52.46 ft
- **Length w/ Joints**: 62.95 ft
- **Outlet End Length**: 68.60 ft
- **Joint Spacing**: 3.00 ft
Project Photos

![Project Photos](image1)

![Project Photos](image2)
Project Photos

Questions
Contact Information

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