Design of Precast Box Culverts to AASHTO LRFD

Josh Beakley
October, 2010
June 20, 2000

Dear Mr. Pope:

Thank you for the letter of June 20, 2000. We appreciate receiving the advice and recommendation of the AASHTO Highway Subcommittee on Bridges and Structures and its member State bridge engineers on the time frames for the use of Load and Resistance Factor Design (LRFD) for the design of bridges. We concur in recommended time frames and would be pleased to work in partnership with the States to attain the stated four goals which, to repeat, are:

1. All new bridges on which States initiate preliminary engineering after October 1, 2007, shall be designed by the LRFD Specifications.

2. All new culverts, retaining walls, and other standard structures on which States initiate preliminary engineering after October 1, 2010, shall be designed by LRFD Specifications, with the assumption that the specifications and software for these structures are "mature" at this time.

3. States unable to meet these dates will provide justification and a schedule for completing the transition to LRFD.

4. For modifications to existing structures, States would have the option of using LRFD Specifications or the specifications which were used for the original design.

A copy of this letter and yours are being provided to the State bridge engineers and FHWA field offices so that they are aware of FHWA's decision on the matter.

Sincerely yours,

[Signature]

An original signed by

[Signature]
LRFD is Coming

2. All new culverts, retaining walls, and other standard structures on which States initiate preliminary engineering after October 1, 2010, shall be designed by LRFD Specifications, with the assumption that the specifications and software for these structures are "mature" at this time.
AASHTO LRFD Bridge Design Specifications

- Section 3 – Loads and Load Factors
- Section 4 – Structural Analysis and Evaluation
- Section 5 – Concrete Structures
- Section 12 – Buried Structures and Tunnel Liners
Outline

- Loads
  - Vertical
  - Horizontal
  - Load Factors
- Capacity
- Research
- ASTM Standards – C 1577 (C 1433)
Loads

- Vertical Loads
- Horizontal Loads
- Reaction Loads
- Load Factors
- Load Modifiers
Vertical Loads

- Live Loads
  - Impact Factor
- Dead Loads
- Earth Loads
Live Load Spacing – HL-93

4000 lb. 14 ft.

12,500 lb. 12,500 lb.

6 ft. 14 ft.

16,000 lb. 16,000 lb.

AASHTO

HS 20 LOAD

12,500 lb. 12,500 lb.

(12,000 lb per STD)

AASHTO

ALTERNATE LOAD
Live Load Shallow Cover

Depth of Fill Less Than 2 Feet
Lane Load – Not Required

- LRFD – 2004 – Truck and Lane Load
  - 64 lbs across a 10 ft width
  - DLA not applied
- LRFD – 2005 – Truck only
- LRFD – Future – ?
- Standard Specification – 3.7.1.1
  - Either truck or Lane Load
  - Truck governs for shorter spans
Axle Width

CLEARANCE AND LOAD LANE WIDTH
10'-0"

2'-0"  6'-0"  2'-0"
CURB
Distribution Width

- LRFD (4.6.2.10)
  - $E = 96 + 1.44S$ (for axle)
  - $E$ in inches and $S$ in feet
- Standard (3.24.3.2)
  - $E = 4 + 0.06S$ (for wheel)
  - $E$ in feet and $S$ in feet
Distribution Width

\[ E = 96 + 1.44(s) \]

E in inches, s in feet
Dynamic Load Allowance

- LRFD – Dynamic Load Allowance (3.6.2.2)
  - \( DLA = 0.33(1.0 - 0.125D_E) \)
- Standard – Impact Factor (3.8.2.3)
  - \( IM = 0.3 \) – 0’-0” to 1’-0” INCL.
  - \( IM = 0.2 \) – 1’-1” to 2’-0” INCL.
  - \( IM = 0.1 \) – 2’-1” to 2’-11” INCL.
Live Load $H \geq 2\text{ft}$
Tire Footprint

- LRFD – 3.6.1.2.6
  - w=20"
  - l=10"
Live Load Area for Depths ≥ 2 ft.

- LRFD (3.6.1.2.6)
  \[ A_L = \left( \frac{20}{12} + 1.15D_E \right) \left( \frac{10}{12} + 1.15D_E \right) \]
  - 1.15 above should be replaced with 1.0 if select granular backfill is not used

- Standard (6.4.1)
  \[ A_L = (1.75D_E)^2 \]
How Far Down?

- 3.6.1.2.6
- “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;”
Dead Load (Structural Load)

- LRFD – 3.5.1
  - $\gamma_{\text{conc}} = 140\text{pcf} + 1\text{pcf} \left( f'_c \text{ in kips} \right)$

- Standard – 3.3.6
  - $\gamma_{\text{conc}} = 150\text{pcf}$
Earth Load

- LRFD – 12.10
  - $\gamma_s \geq 110 \text{ pcf}$

- Standard – 6.2.1
  - $\gamma_s = 120 \text{ pcf}$
# Dead Loads – 3.5.1

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit Weight (kcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Alloys</td>
<td>0.175</td>
</tr>
<tr>
<td>Bituminous Wearing Surfaces</td>
<td>0.140</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>0.450</td>
</tr>
<tr>
<td>Cinder Filling</td>
<td>0.060</td>
</tr>
<tr>
<td>Compacted Sand, Silt, or Clay</td>
<td>0.120</td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
</tr>
<tr>
<td>Lightweight</td>
<td>0.110</td>
</tr>
<tr>
<td>Sand-Lightweight</td>
<td>0.120</td>
</tr>
<tr>
<td>Normal Weight with $f'_{c} \leq 5.0$ ksi</td>
<td>0.145</td>
</tr>
<tr>
<td>Normal Weight with $5.0 &lt; f'_{c} \leq 15.0$ ksi</td>
<td>$0.140 + 0.001 f'_{c}$</td>
</tr>
<tr>
<td>Loose Sand, Silt, or Gravel</td>
<td>0.100</td>
</tr>
<tr>
<td>Soft Clay</td>
<td>0.100</td>
</tr>
<tr>
<td>Rolled Gravel, Macadam, or Ballast</td>
<td>0.140</td>
</tr>
<tr>
<td>Steel</td>
<td>0.490</td>
</tr>
<tr>
<td>Stone Masonry</td>
<td>0.170</td>
</tr>
<tr>
<td>Wood</td>
<td></td>
</tr>
<tr>
<td>Hard</td>
<td>0.060</td>
</tr>
<tr>
<td>Soft</td>
<td>0.050</td>
</tr>
<tr>
<td>Water</td>
<td></td>
</tr>
<tr>
<td>Fresh</td>
<td>0.0624</td>
</tr>
<tr>
<td>Salt</td>
<td>0.0640</td>
</tr>
<tr>
<td>Item</td>
<td>Weight per Unit Length (klf)</td>
</tr>
<tr>
<td>Transit Rails, Ties, and Fastening per Track</td>
<td>0.200</td>
</tr>
</tbody>
</table>
Embankment Installation

Soil Prism

Frictional Forces

Natural Ground
Vertical Arching Factor

- $W_E = F_e \gamma_s B_c H$
  - $F_e = 1 + 0.20(H/B_c)$
  - $F_e$ shall not exceed 1.15 for installations with compacted fill along the sides of the box section, or 1.40 for installations with uncompacted fill
  - LRFD – 12.11.2.2.1
  - Standard – 16.6.4.2
“Bedding and Fill Heights for Concrete Roadway Pipe And Box Culverts” – C. Yoo, F. Parker, and J. Kang, Auburn University, June 2005
Bottom Reaction to Vertical Loads
Bottom Reaction to Vertical Loads
LRFD (C12.11.2.3)

“While typical designs assume a uniform pressure distribution across the bottom slab, a refined analysis that considers the actual soil stiffness under box sections will result in pressure distributions that reduce bottom slab shear and moment forces (McGrath et al. 2004).”
LRFD C12.11.2.3

“Such an analysis requires knowledge of in-situ soil properties to select the appropriate stiffness for the supporting soil. A refined analysis taking this into account may be beneficial when analyzing existing culverts.”
Horizontal Loads

- Approaching Live Load
- Earth Loads
- Fluid Loads
Approaching Live Load
Lateral Live Load (Boussinesq)
Lateral Live Load

- LRFD (3.11.6.2)
  - “The horizontal pressure $\Delta_{ph}$ in ksf, on a wall resulting from a point load may be taken as:”

$$\Delta_{ph} = \frac{P}{\pi R^2} \left[ \frac{3ZX^2}{R^3} - \frac{R (1 - 2v)}{R + Z} \right]$$
Live Load Lateral Uniform Pressure

- LRFD – 3.11.6.4 (equivalent fluid load)
  - $H \leq 5 \text{ ft} - 4 \text{ ft}$
  - $H \leq 10 \text{ ft} - 3 \text{ ft}$
  - $H \leq 20 \text{ ft} - 2 \text{ ft}$
- $\Delta_p = K \gamma_s h_{eq}$
Lateral Uniform Live Load
“In general, LRFD produces greater live load surcharge pressures than Standard for depths of fill of 5 ft or less and less pressure for greater depths. In addition, live load surcharge pressures from AASHTO M 259 and M 273 are much greater than those from LRFD for depths of fill from 0 to 1 ft and less than LRFD for greater fill heights. In spite of the significant differences in live load surcharge pressures, their impact on reinforcement areas is relatively minor.”

“Comparison of AASHTO Standard and LRFD Code Provisions for Buried Concrete Box Culverts” – R. Rund & T. McGrath, STP 1368, 2000, Concrete Pipe for the New Millennium
Lateral Earth Pressure
3.11.5.5 – Equivalent Fluid Method
- Loose Sand or Gravel = 55 pcf
- Dense Sand or Gravel = 45 pcf
3.11.5.2 – At Rest Pressure
- $k_0 = 1 - \sin \phi$
  - $\phi = 30^\circ$, $k_0 = 0.5$, press = 60 pcf
Lateral Earth Load (Min/Max)

3.4.1
- \( EH_{\text{Max}} = 1.35 \)
- \( EH_{\text{Min}} = 0.90 \)

3.11.7 – Reduction Due to Earth Pressure
- “In lieu of more precise information, a 50 percent reduction may be used, but need not be combined with the minimum load factor specified in Table 3.4.1-2.”
Internal Fluid Pressure

$\gamma_w = 62.4\text{pcf}$
Other Loads

- Construction Loads
- External Hydrostatic Loads
Load Factors
LRFD Design
## Load Factors (LRFD)

<table>
<thead>
<tr>
<th>Load</th>
<th>Maximum Factor</th>
<th>Minimum Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead (Structure)</td>
<td>1.25</td>
<td>0.90</td>
</tr>
<tr>
<td>Water</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Earth (vertical)</td>
<td>1.3</td>
<td>0.90</td>
</tr>
<tr>
<td>Earth (horizontal)</td>
<td>1.35</td>
<td>0.90*</td>
</tr>
<tr>
<td>Live</td>
<td>1.75</td>
<td>0</td>
</tr>
</tbody>
</table>

*50% Reduction in earth load may be used in lieu of this Load factor*
Load Modifiers

- LRFD C 1.3.2.1
  - “Ductility, redundancy, and operational importance are significant aspects affecting the margin of safety of bridges.”
# Load Modifiers

*Load Modifier for Operation is dependent upon the specifying agency and the importance of the function and safety of the roadway.*

<table>
<thead>
<tr>
<th>Load</th>
<th>Ductility</th>
<th>Redundancy</th>
<th>Operation*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Water</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Earth</td>
<td>1.0</td>
<td>1.05</td>
<td>1.0</td>
</tr>
<tr>
<td>Live</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Ultimate Load Combinations

Minimum Vertical and Maximum Lateral
- \[ C = 0.9DC + 0.9EV + (1.05)1.35EH + 1.75(1.2)LS \]

Maximum Vertical and Minimum Lateral
- \[ A = 1.25DC + (1.05)1.3EV + (1.35)0.5EH + 1.75(1.2)(1+IM)LL + 1.0WA \]
Ultimate Load Combinations

Maximum Vertical and Maximum Lateral

- $B = 1.25DC + (1.05)1.3EV + (1.05)1.35EH + 1.75(1.2)(1+IM)LL + 1.75(1.2)LS$
Typical Results (12 x 12 @ 20ft)
Design Capacity
Design for:

- Flexure
  - Steel Reinforcement
  - Concrete Compression
- Crack Control
- Shear
- **Fatigue** (not required for box culverts per LRFD)
Phi Factors

- Strength Reduction Factors
  - $\phi_f = 1.0$
  - $\phi_v = 0.9$
  - LRFD – 12.5.5-1
  - Standard – 16.7.4.6
Flexure

\[
Asi = \frac{g \cdot \phi_f \cdot d - Nu - \sqrt{g \cdot \left(g \cdot (\phi_f \cdot d)^2 - Nu \cdot (2 \cdot \phi_f \cdot d - t) - 2 \cdot Mu\right)}}{fy}
\]

Equation 12.10.4.2.4a-1 – For Pipe

Section 5.7.2 – Assumptions for Strength and Extreme Event Limit States takes a broader view of flexural design
Flexure (Minimum Steel)
LRFD - 12.11.4.3.2: STD - 16.7.4.8

- $A_{s_{\text{min}}} = 0.002 \, b \, h$
  - $b = 12$ inch unit width
  - $h =$ thickness of member in inches

- LRFD (12.11.4.3.2)
- Standard (16.7.4.8)
7.12.2.1 — Area of shrinkage and temperature reinforcement shall provide at least the following ratios of reinforcement area to gross concrete area, but not less than 0.0014:

(a) Slabs where Grade 40 or 50 deformed bars are used ........................................... 0.0020

(b) Slabs where Grade 60 deformed bars or welded wire reinforcement are used .............................. 0.0018

(c) Slabs where reinforcement with yield stress exceeding 60,000 psi measured at a yield strain of 0.35 percent is used .............................. \( \frac{0.0018 \times 60,000}{f_y} \)
Flexure (maximum steel)

- For box culverts it is 75% of the steel area for a balanced condition (steel will always yield before concrete crushes)
- Other concrete structures design for concrete crushing with lower phi factors
Tension Controlled - Ductile
Phi Factors

Phi graph related to strain.

\[ \rho := 0.75 \rho_s \]

\[ N_1 := 0 \text{psi} \]

Thrust

Strain = 0.004047

\[ \Phi = 0.92 \]

\[ \phi_1 := 0.583 + \frac{0.25}{\frac{0.03 + \varepsilon_1}{0.03}} - 1 \]

Prestressed Assumed for Precast

Compression Controlled

Transition

Tension Controlled

\[ \varepsilon_1 := 0.004047 \]
Crack Control (LRFD – 5.7.3.4)

\[
s \leq \frac{700 \cdot \gamma_e}{\beta_s \cdot f_s} - 2 \cdot d_c
\]

- LRFD Concerns itself with steel spacing
- Standard Specification concerns itself with stress in the steel (maximum of 0.6 fy?)
Service Load Stress

\[ f_s = \frac{M_s + N_s \cdot \left( d - \frac{h}{2} \right)}{A_s \cdot j \cdot i \cdot d} \]

Equation C12.11.3-1
Factors affecting crack control

\[ \beta_s = 1 + \frac{d_c}{0.7(h - d_c)} \]

where:

\[ \gamma_e \]

- exposure factor
- \( = 1.00 \) for Class 1 exposure condition
- \( = 0.75 \) for Class 2 exposure condition
Exposure Conditions

Class 1 exposure condition applies when cracks can be tolerated due to reduced concerns of appearance and/or corrosion. Class 2 exposure condition applies to transverse design of segmental concrete box girders for any loads applied prior to attaining full nominal concrete strength and when there is increased concern of appearance and/or corrosion.
Shear

LRFD – 5.14.5.3: STD – 8.16.6.7

Slabs under 2 feet or more of fill

\[ V_c = \left( 0.0676 \cdot \sqrt{f'_c} + 4.6 \cdot \frac{A_s}{b \cdot d_e} \cdot \frac{V_u \cdot d_e}{M_u} \right) \cdot b \cdot d_e \]

Need not be taken less than

\[ V_c = 0.0948 \cdot \sqrt{f'_c} \cdot b \cdot d_e \]

Equivalent to \( \beta = 3 \)
Shear
LRFD – 5.8.3.3: STD – 8.16.6.2.1
Slabs with less than two feet of cover, and sidewalls

\[ V_c = 0.0316 \cdot \beta \cdot \sqrt{f_c \cdot b_v \cdot d_v} \]

\( \beta \) is based on the dimensions of the element and the strain in the steel
When sections do not contain at least the minimum amount of shear reinforcement, the value of $\beta$ may be as specified in Eq. 5.8.3.4.2-2:

$$\beta = \frac{4.8}{(1 + 750\varepsilon_s)} \frac{51}{(39 + s_{xe})} \quad (5.8.3.4.2-2)$$

$$\varepsilon_s = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + \left|V_u - V_p\right| - A_{ps}f_{po}\right)}{E_s A_s + E_p A_{ps}} \quad (5.8.3.4.2-4)$$

For sections with an overall depth less than 16 inches, and no tension, $\beta$ can be assumed equal to 2.
Top Slab

12X12 @20'}
Side Wall

12X12 @ 20’
## 5.8.3 Method versus 5.14.5.3 Method

### 8 X 8 Box

<table>
<thead>
<tr>
<th>Wire Spacing (IN)</th>
<th>( p = \frac{A_s}{bd} )</th>
<th>( \beta_{5.8.3} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.011</td>
<td>2.7</td>
</tr>
<tr>
<td>2 - 4_{LRFD}</td>
<td>0.012</td>
<td>2.8</td>
</tr>
<tr>
<td>4</td>
<td>0.013</td>
<td>2.9</td>
</tr>
<tr>
<td>N/A</td>
<td>0.015</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Fatigue

STD – 8.16.8.3

\[ f_f = 21 - 0.33f_{\text{min}} + 8 \left( \frac{r}{h} \right) \]

LRFD – 5.5.3.1

“Fatigue need not be investigated for concrete deck slabs in multigirder applications or reinforced-concrete box culverts.”
Distribution Steel

Fill Height Less than 2 ft

Fill Height 2 ft and Greater

H = Haunch Dimension
T_s = Sidewall Thickness
T_b = Bottom Thickness
T_t = Top Thickness
M = Total of the theoretical cut-off length plus the required anchorage

SEE FIG. 5 AND 6 FOR TYPICAL REINFORCING DETAIL.

SEE FIG. 2 FOR JOINT REINFORCEMENT THIS AREA

MINIMUM LENGTH EQUAL TO SPACING OF 1 LONGITUDINAL WIRES PLUS 2 IN. (Typ)

SEE FIG. 3 AND 4 FOR TYPICAL REINFORCEMENT ARRANGEMENT
Distribution Steel

- In bottom of top slab (LRFD 9.7.3.2)
  - Percentage of main positive moment reinforcement = \( \frac{100}{S^{1/2}} \)
  - \( S \) = span in feet
  - Need not be more than 50 percent

- In top of top slab
  - \( A_{s6} = 0.002 \times A_g \)
Research Has Helped
Load Transfer Across the Joints
UTA Research on Shear in Box Culverts
4.6.2.10.4 Precast Box Culverts

For precast box culverts with top slabs having span to thickness ratios (s/t) of 18 or less and segment lengths equal to or greater than 4 feet in length, shear transfer across the joint need not be provided.
AASHTO LRFD Results

12.11.2.1

For cast in place box culverts, and for precast box culverts with top slabs having span to thickness ratios \((s/t)\) greater than 18 or segment lengths less than 4.0 ft., edge beams shall be provided as specified in Article 4.6.2.1.4
Fatigue
UNO Fatigue Evaluation for Reinforced Concrete Box Culverts
Fatigue

LRFD – 5.5.3.1

“Fatigue need not be investigated for concrete deck slabs in multigirder applications or reinforced-concrete box culverts.”
ASTMs

Designation: C 1577 – 08
Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD

Designation: C 1433 – 08
Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers
Boxes for all depths

Fill Height Less than 2 ft

Fill Height 2 ft and Greater
**C 1433 Design Criteria**

### TABLE X1.1 Specific Criteria Used for Tables 1 and 2

<table>
<thead>
<tr>
<th>Material Properties:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Welded wire reinforcement, minimum specified yield stress</td>
<td>65,000 psi</td>
</tr>
<tr>
<td>Deformed bars, minimum specified yield stress</td>
<td>60,000 psi</td>
</tr>
<tr>
<td>Concrete, minimum specified compressive strength</td>
<td>5,000 psi</td>
</tr>
<tr>
<td>Soil Data:</td>
<td></td>
</tr>
<tr>
<td>Unit weight</td>
<td>120 lb/ft²</td>
</tr>
<tr>
<td>Ratio of lateral to vertical pressure from weight to earth</td>
<td>0.50 max to 0.25 min</td>
</tr>
<tr>
<td>Additional lateral pressure from approaching truck wheels</td>
<td>700 + H, lb/ft² or 800 lb/ft² when H &lt; 1 ft, where H = earth cover, ft below box section invert</td>
</tr>
<tr>
<td>External water table</td>
<td>1.15</td>
</tr>
<tr>
<td>Soil structure interaction factor</td>
<td></td>
</tr>
<tr>
<td>Capacity reduction factors (from AASHTO Bridge Specifications):</td>
<td></td>
</tr>
<tr>
<td>Shear</td>
<td>0.90</td>
</tr>
<tr>
<td>Axial compression combined with bending</td>
<td>0.95</td>
</tr>
<tr>
<td>Loading Data:</td>
<td></td>
</tr>
<tr>
<td>Load factor = (BDL + BLL)</td>
<td></td>
</tr>
<tr>
<td>Truck axle load:</td>
<td></td>
</tr>
<tr>
<td>H2O (Table 1)</td>
<td>32,000 lb</td>
</tr>
<tr>
<td>Interstate (Table 2)</td>
<td>2 at 24,000 lb each</td>
</tr>
<tr>
<td>Impact (variable with depth) (see AASHTO Bridge Specifications):</td>
<td>0 to 30%</td>
</tr>
<tr>
<td>Uniform Internal pressure</td>
<td>0.0</td>
</tr>
<tr>
<td>Depth of water in box section</td>
<td>equal to inside height</td>
</tr>
<tr>
<td>Structural Arrangement:</td>
<td></td>
</tr>
<tr>
<td>Concrete cover over steel</td>
<td></td>
</tr>
<tr>
<td>Top slab</td>
<td></td>
</tr>
<tr>
<td>Slab thickness</td>
<td></td>
</tr>
<tr>
<td>Side wall thickness</td>
<td></td>
</tr>
<tr>
<td>Haunch dimensions</td>
<td></td>
</tr>
<tr>
<td>Circumferential wire spacing</td>
<td></td>
</tr>
<tr>
<td>Minimum reinforcing inside face slabs and side walls, outside face side walls and corners of slabs</td>
<td>0.002 ft</td>
</tr>
</tbody>
</table>

---

*The structural arrangement and details are shown in Fig. 1.*
TABLE 1 Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions

Note 1—Design earth covers and reinforcement areas are based on the weight of a column of earth over the width of the box section as defined in Appendix X1.
Note 2—Concrete design strength 5000 psi.
Note 3—The design earth cover indicated is the height of fill above the top of the box section. Design requirements are based on the material and soil properties, loading data, and typical section as included in Appendix X1. For alternative or special designs, see 7.2.
Note 4—Design steel area in square inches per linear foot of box section at those locations which are indicated on the typical section included in Fig. 1.
Note 5—The top section designation, for example, 3 ft by 2 ft by 4 in. indicates (interior horizontal span in feet) by (interior vertical rise in feet) by (wall and slab thickness in inches).
Note 6—In accordance with the acceptance criteria in 7.2, the manufacturer may interpolate the steel area requirements for fill heights between noted increments or may submit independent designs.

<table>
<thead>
<tr>
<th>Span ft</th>
<th>Rise ft</th>
<th>Top in.</th>
<th>Bottom in.</th>
<th>Side in.</th>
<th>Haunch in.</th>
<th>Design Earth Cover ft</th>
<th>Circumferential Reinforcement Areas, in.²/ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A₁₁</td>
<td>A₁₂</td>
</tr>
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<td>0.18</td>
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<td>4</td>
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<td>0.21</td>
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<td>4</td>
<td>4</td>
<td>4</td>
<td>0.10</td>
<td>0.21</td>
</tr>
</tbody>
</table>
### TABLE X1.1 Specific Criteria Used for Table 1*

<table>
<thead>
<tr>
<th>Material Properties:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel reinforcement, minimum specified yield stress</td>
<td>65 000 psi</td>
</tr>
<tr>
<td>Concrete, minimum specified compressive strength</td>
<td>5000 psi</td>
</tr>
<tr>
<td><strong>Soil Data:</strong></td>
<td></td>
</tr>
<tr>
<td>Unit weight</td>
<td>120 lb/ft²</td>
</tr>
<tr>
<td>Ratio of lateral to vertical pressure from weight of earth</td>
<td>0.50 max to 0.25 min</td>
</tr>
<tr>
<td>External water table</td>
<td>below box section invert</td>
</tr>
<tr>
<td>Soil structure interaction factor</td>
<td>$F_s = 1 + 0.20(H/R_s)$</td>
</tr>
<tr>
<td>$B_o$ = outside width of culvert</td>
<td></td>
</tr>
<tr>
<td>$F_s$ max = 1.15</td>
<td></td>
</tr>
</tbody>
</table>

**Capacity Reduction Factors**
(from AASHTO LRFD Bridge Design Specifications):

- **Shear:** 0.90
- **Axial compression combined with bending:**

**Loading Data:**

**Load Modifiers:**
- Ductile Structures
- For earth fill: non-redundant member
- For live load: redundant member
- Typical Bridge

**Load Factors:**
- Dead Load
- Earth Load (Vertical)
- Earth Load (Horizontal)
- Live Load
- Multiple Presence Factor
- Live Load HL-90

**Greater of:**
- Truck Axle Load
- Tandem Axle Load

- Max DL = 1.25, Min DL = 0.90
- Max ELV = 1.10, Min ELV = 0.90
- Max ELH = 1.25 (see X1.2.5)
- LL = 1.75
- MPF = 1.2 (for one lane)

**H < 2 ft**
- Area of box section resisting truck axle load
  - Direction Perpendicular to span
  - Direction Parallel to Span

**H ≥ 2 ft**
- Area of box section resisting truck wheel load
  - Direction Perpendicular to Span
  - Direction Parallel to Span

**Dynamic Load Allowance (variable with depth):**
- Uniform Internal pressure
- Depth of water in box section
- External ground water pressure

**Lateral Live Load Pressure:**
- 0.0 psi

**Structural Arrangement:**
- Reinforcement Spacing
- Concrete cover over steel
- Top slab (outside face)

**Slide wall thickness:**
- 4.0 in.
- 1.0 in.
- 1.0 in. for fill heights 2 ft and greater,
- 2.0 in. for fill heights under 2 ft
- ½ times inside span plus 1.0 in. up to 7-ft span,
- ½ inside span above 7-ft span

**Slab thickness:**
- Equal to sidewall thickness unless otherwise noted

**Haunch dimensions:**
- Vertical and horizontal dimensions both equal to side wall thickness
- 0.002 ft

---

*The structural arrangement and details are shown in Fig. 1.

Refer to Fig. X1.1 for wheel load arrangements.
**Reinforcement Tables**

### TABLE 1 Design Requirements for Precast Concrete Box Sections Under Earth, Dead and HL-93 Live Load Conditions

**Note 1**—Design earth loads and reinforcement areas are based on the weight of a column of earth over the width of the box section multiplied by a soil-structure interaction factor as defined in Appendix X1.

**Note 2**—Concrete design strength 5000 psi.

**Note 3**—Steel areas are based on an HL-93 live load without the lane load as permitted by AASHTO, using either the design truck or the design tandem and taking the controlling case.

**Note 4**—The design earth cover indicates the height of fill above the top of the box section. Design requirements are based on the material and soil properties, loading data, and typical section as included in Appendix X1. For alternative or special designs, see 7.2.

**Note 5**—Design steel area in square inches per linear foot of box section at those locations which are indicated on the typical section shown in Fig. 1.

**Note 6**—The top section designation, for example, 3 ft by 2 ft by 4 in. indicates (interior horizontal span in feet) by (interior vertical rise in feet) by (wall and slab thickness in inches).

**Note 7**—In accordance with the acceptance criteria in 7.2, the manufacturer is not prohibited from interpolating steel area requirements or submitting independent designs for fill heights between noted increments.

**Note 8**—The "M" dimension given in the tables is the required distance that $A_{x1}$ shall be extended into the top and bottom slabs if it is used as reinforcement for the negative moment in these areas. This distance is based on the location where the negative moment in the slab becomes zero, plus an additional development length. Because the live load can be applied at any location along the top slab as the truck drives over it, it is possible for the "M" dimension to exceed one-half the length of the slab.

**Note 9**—(Advisory)—The reinforcing areas are based on 4 inch circumferential wire spacing. Under design conditions where crack control governs, an analysis following the design criteria in Table X1.1 with closer steel spacing may result in a reduction in steel area over those in the table.

<table>
<thead>
<tr>
<th>Design Earth</th>
<th>Circumferential Reinforcement Areas, In²/ft</th>
<th>3 ft by 2 ft by 4 In.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover, ft</td>
<td>$A_{x1}$</td>
<td>$A_{x2}$</td>
</tr>
<tr>
<td>0-2²</td>
<td>0.17</td>
<td>0.25</td>
</tr>
<tr>
<td>2-3</td>
<td>0.13</td>
<td>0.19</td>
</tr>
<tr>
<td>3-5</td>
<td>0.10</td>
<td>0.11</td>
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<tr>
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<tr>
<td>15</td>
<td>0.10</td>
<td>0.13</td>
</tr>
<tr>
<td>20</td>
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<td>0.17</td>
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<tr>
<td>25</td>
<td>0.14</td>
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<td>30</td>
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<td>0.25</td>
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<tr>
<td>35</td>
<td>0.20</td>
<td>0.29</td>
</tr>
</tbody>
</table>
C 1577 – One Table

Live Load HL-93:*
Greater of:
- Truck Axle Load 32000 lbf
- Tandem Axle Load 2 at 25000 lbf each

C 1433 - Two Tables

Truck axle load:
- H2O (Table 1) 32000 lbf
- Interstate (Table 2) 2 at 24000 lbf each
Assumptions in the Tables of C 1577

- $f_c = 5,000$
- $f_y = 65,000$
- Circumferential spacing is 4 inches
- Traffic parallel to the span
  - OK for skews 15° or less
Comparison of C 1577 versus previous ASTM Standards

- 0 to 3 feet of cover has less steel overall
  - Fatigue does not govern with C 1577
- 3 to 5 feet of cover has more steel overall
  - 1.15 live load distribution versus 1.75 live load distribution in C 1433, and higher impact factors results in higher live load pressures
- At deeper fills C 1577 has less steel overall
  - Crack control in C 1577 is more liberal
The End

This presentation can be downloaded at:

http://xfer.concrete-pipe.org/

Password: “LRFDBOX”
Lane Load
Applied Live loads

- 3.6.1.3.3 Design Loads for Decks, Deck Systems, and the Top Slabs of Box Culverts
  - Where the slab spans primarily in the transverse direction, only the axles of the design truck of Article 3.6.1.2.2 or design tandem of Article 3.6.1.2.3 shall be applied to the deck slab of the top of box culverts.
Applied Live loads

- 3.6.1.3.3 Design Loads for Decks, Deck Systems, and the Top Slabs of Box Culverts
  - Where the slab spans primarily in the longitudinal direction:
  - For top slabs of box culverts of all spans and for all other cases, including slab-type bridges where the span does not exceed 15.0 ft, only the axle loads of the design truck or design tandem of Articles 3.6.1.2.2 and 3.6.1.2.3, respectively, shall be applied.
Lateral Uniform Live Load

- LRFD (3.11.6.4)
  - “A live load surcharge shall be applied where vehicular load is expected to act on the surface of the backfill within a distance equal to one-half the wall height behind the back face of the wall.”
Soil Load (Assumed)
Vertical Pressures
Soil Pressures

Normal pressure (psi)

Top Corner

Bottom Corner
Soil Pressures
Standards/Specifications for Box Culverts

- M 259 (C789)
- M 273 (C 850)
- C1433 (Standard)
- C1577 (LRFD*)
First Precast Box Culvert Standards

- C 789 – “Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers”
  - Originally Published in 1974
  - Adopted by AASHTO as M 259
- C 850 – “Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 ft of Cover Subjected to Highway Loadings”
  - Originally Published in 1976
  - Adopted by AASHTO as M 273
“Structural Design of Precast Concrete Box Sections for Zero to Deep Earth Cover Conditions and Surface Wheel Loads”

- By F.J. Heger and K.N. Long
- Written in 1977
- “The standard designs presented in ASTM Specification C 789-74 were generated by a computerized design method developed at Simpson Gumpertz & Heger Inc. (SHG) under contract to ACPA, and were verified by a test program carried out by ACPA with SGH assistance.”
ASTM C 1433

- “Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers”
  - Originated in 1999
  - Developed to more closely follow the AASHTO Specifications
  - Combined shallow and deep fill heights in one standard
  - ASTM C 789 and C 850 Discontinued in 2000
ASTM C 1577

“Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD”

Originated in 2005