



Standard Specification for Segmental Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD¹

This standard is issued under the fixed designation C1786; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers precast reinforced concrete box sections comprised of separate segments that once properly field assembled make the final structure. These structures are intended to be used for the construction of culverts and for the conveyance of storm water, industrial wastes and sewage.

NOTE 1—This specification is primarily a manufacturing and purchasing specification. However, box culverts manufactured to this standard are intended to meet the design requirements of the AASHTO LRFD Bridge Design Specifications, and as such, design guidance is included in [Appendix X1](#).

NOTE 2—The successful performance of this product depends upon the proper selection of the box section, bedding, backfill, and care that the installation conforms to the construction specifications. The purchaser of the precast reinforced concrete box sections specified herein is cautioned that proper correlation of the loading conditions and the field requirements with the box section specified, and provision for inspection at the construction site, are required.

1.2 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

2. Referenced Documents

2.1 ASTM Standards:²

[A615/A615M](#) Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

[A706/A706M](#) Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement

[A1064/A1064M](#) Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete

[C33](#) Specification for Concrete Aggregates

[C150](#) Specification for Portland Cement

[C260](#) Specification for Air-Entraining Admixtures for Concrete

[C309](#) Specification for Liquid Membrane-Forming Compounds for Curing Concrete

[C494/C494M](#) Specification for Chemical Admixtures for Concrete

[C497](#) Test Methods for Concrete Pipe, Manhole Sections, or Tile

[C595](#) Specification for Blended Hydraulic Cements

[C618](#) Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

[C822](#) Terminology Relating to Concrete Pipe and Related Products

[C989](#) Specification for Slag Cement for Use in Concrete and Mortars

[C1116](#) Specification for Fiber-Reinforced Concrete and Shotcrete

2.2 AASHTO Standards:³

AASHTO LRFD Bridge Design Specifications

AASHTO LRFD Bridge Construction Specifications

2.3 ACI Standards:⁴

ACI 318 Building Code Requirements for Structural Concrete

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *box section*—the completed box culvert unit with all segments adjoined (see [Fig. 1](#) for configuration options).

3.1.2 *box segment*—the individual piece (top slab, bottom slab, or three-sided structure) that gets adjoined to other pieces to complete the final box section

3.2 *Definitions*—For definitions of terms relating to concrete box culvert sections not found above, see Terminology [C822](#).

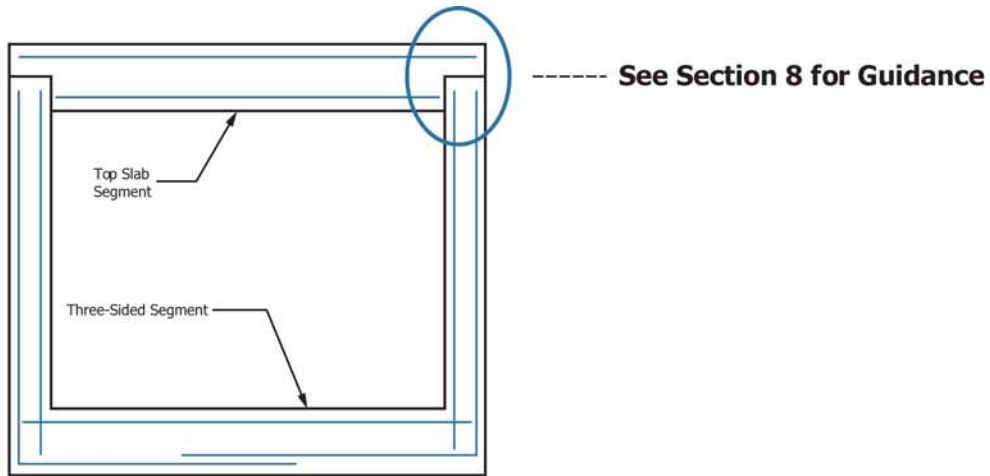
¹ This test method is under the jurisdiction of ASTM Committee C13 on Concrete Pipe and is the direct responsibility of Subcommittee C13.07 on Acceptance Specifications and Precast Concrete Box Sections.

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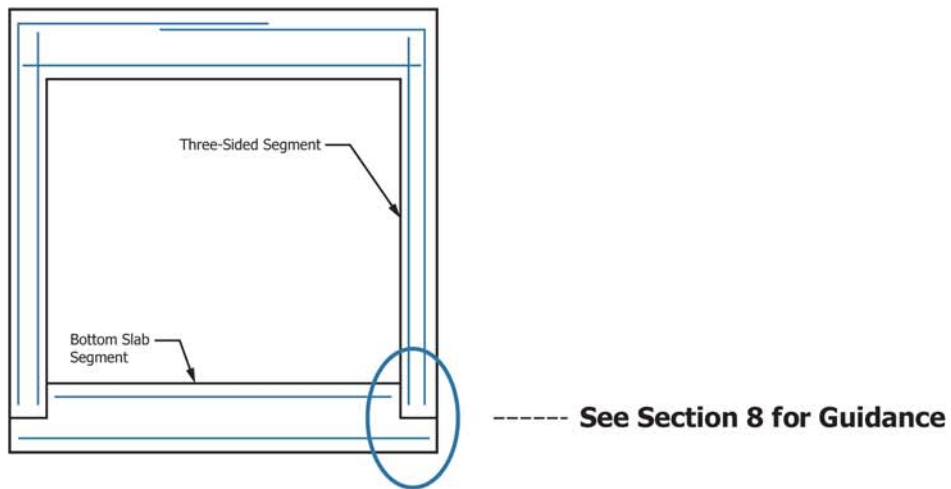
² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, <http://www.transportation.org>.

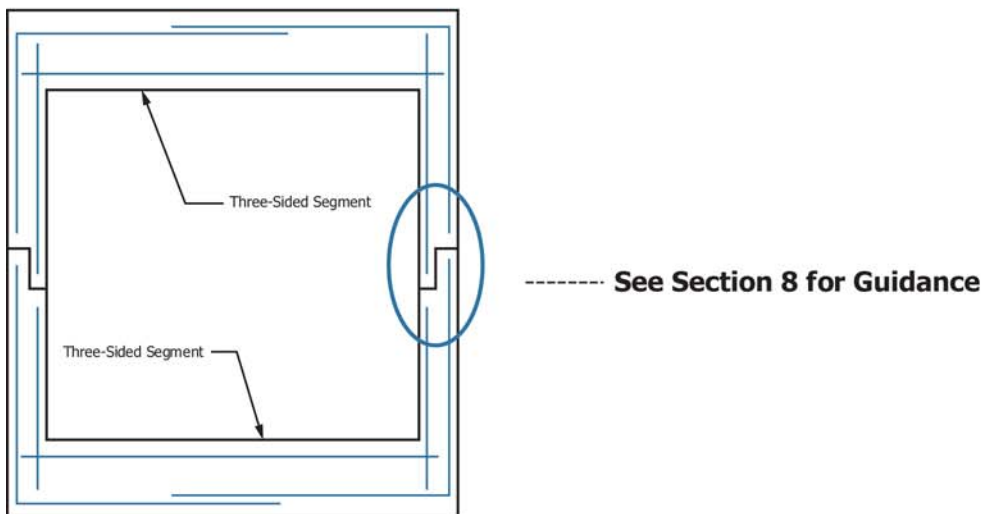
⁴ Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, <http://www.concrete.org>.



Three-sided Section with Top Slab Segment



Three-sided Section with Bottom Slab Segment



Double Three-sided (Clamshell) Configuration

FIG. 1 Segment Configuration Options

4. Basis of Acceptance

4.1 Acceptability of the box sections produced in accordance with this standard shall be determined by the results of the concrete compressive strength tests described in Section 10, by the material requirements described in Section 5, and by inspection of the finished box sections by the owner or their designee.

NOTE 3—The box culvert structure itself is not complete until it is fully assembled in the field. Field assembly is not included in this specification. However, a final field inspection is recommended before the box culvert is considered fit for duty.

5. Material

5.1 *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates and water, in which steel has been embedded in such a manner that the steel and concrete act together.

5.2 Cementitious Materials:

5.2.1 *Cement*—Cement shall conform to the requirements for portland cement of Specification C150 or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of Specification C595, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash.

5.2.2 *Fly Ash*—Fly ash shall conform to the requirements of Specification C618, Class F or Class C.

5.2.3 *Ground Granulated Blast-Furnace Slag*—GGBFS shall conform to the requirements of Grade 100 or 120 of Specification C989.

5.2.4 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in concrete shall be one of the following:

- 5.2.4.1 Portland cement only,
- 5.2.4.2 Portland blast furnace slag cement only,
- 5.2.4.3 Portland pozzolan cement only,
- 5.2.4.4 A combination of portland cement and fly ash,
- 5.2.4.5 A combination of portland cement and ground granulated blast-furnace slag, or
- 5.2.4.6 A combination of portland cement, ground granulated blast-furnace slag (not to exceed 25 % of the total cementitious weight) and fly ash (not to exceed 25 % of the total cementitious weight).

5.3 *Aggregates*—Aggregates shall conform to Specification C33, except that the requirements for gradation shall not apply.

5.4 *Admixtures and Blends*—The following admixtures and blends are allowable:

- 5.4.1 Air-entraining admixture conforming to Specification C260;
- 5.4.2 Chemical admixture conforming to Specification C494/C494M;
- 5.4.3 Chemical admixture or blend approved by the owner.

5.5 *Steel Reinforcement*—Reinforcement shall consist of welded wire reinforcement conforming to Specification A1064/A1064M or billet-steel bars conforming to Specification A615/A615M, Grade 60 or A706/A706M, Grade 60. The box culvert segments shall be manufactured with reinforcement

meeting the yield strengths designated in the design of the box culvert, but the yield strength shall not be less than 60 ksi.

5.6 *Synthetic Fibers*—Collated fibrillated virgin polypropylene fibers may be used at the manufacturer's option, in concrete boxes as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of Specification C1116 shall be accepted.

6. Design

6.1 Each segment of the box shall meet the requirements of the AASHTO LRFD Bridge Design Specifications. Guidance is given in Appendix X1.

6.2 The manufacturer shall maintain on file a copy of a sealed "stamped" design by a professional engineer in accordance with the AASHTO LRFD Bridge Design Specifications and this standard for each structure manufactured.

6.3 The minimum compressive strength of concrete segments produced to this standard shall be 4000 psi, unless otherwise designated by the engineer.

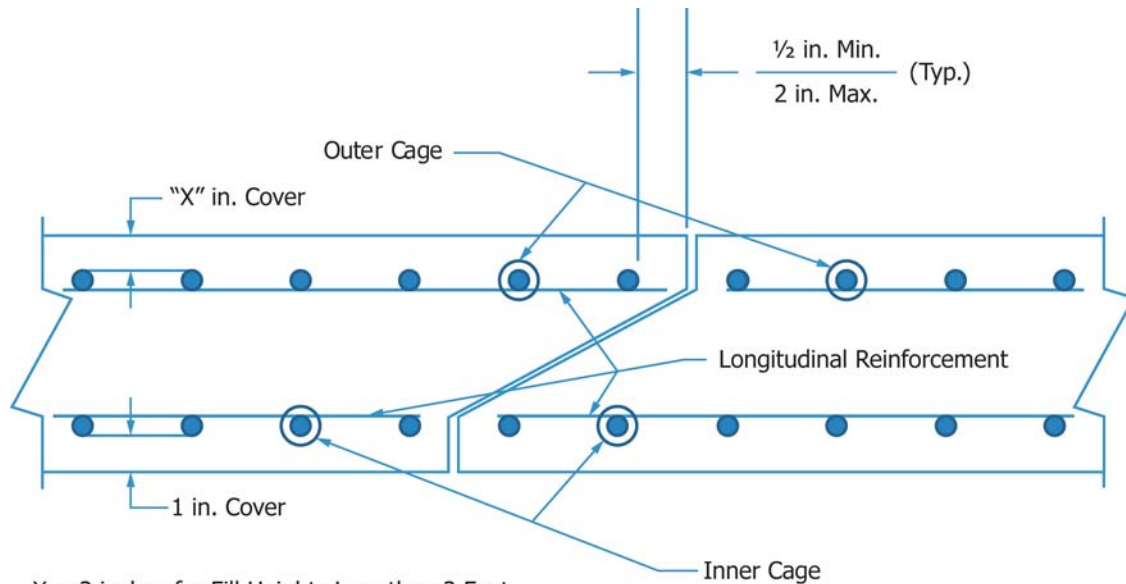
6.4 The manufacturer shall produce box culvert segments meeting the design requirements designated in the design of the segmental precast box structure. As a minimum, the box culvert segments shall meet the reinforcement layout, concrete cover, and all other manufacturing details required by this standard.

6.5 The manufacturer may request approval by the purchaser for modified designs which differ from the requirements in this standard. When such modified designs are approved, it shall be so indicated on the manufactured box with the designation "C1786-Modified."

NOTE 4—(Advisory)—Construction procedures, such as heavy equipment movement or stockpiling of material over or adjacent to a box structure can induce higher loads than those used for the structure's final design. These construction and surcharge loads are allowable as long as the final steel areas in the box are equal to or larger than those required for the construction phase. The design engineer shall take into consideration the potential for higher loads induced by construction procedures in determining the final design of the box structure.

7. Reinforcement

7.1 *Placement of Reinforcement*—Reinforcement shall be assembled utilizing any combination of single or multiple layers of welded wire reinforcement, not to exceed three layers, or utilizing single or double layers of deformed billet steel bars. The cover of concrete over the circumferential reinforcement shall be 1 in. except for when the box culvert has less than 2 ft of earth cover, then the concrete cover over the top slab reinforcement shall be 2 inches (see Figs. 2 and 3). Concrete cover shall be subject to the provisions of Section 11. The welded wire reinforcement shall be composed of circumferential and longitudinal wires meeting the spacing requirements of 7.2 and shall contain sufficient longitudinal wires extending through the box section to maintain the shape and position of reinforcement. Longitudinal distribution reinforcement shall be welded-wire reinforcement or deformed billet-steel bars and shall meet the spacing requirements of 7.2. The ends of the longitudinal distribution reinforcement shall not be more than



X = 2 inches for Fill Heights Less than 2 Feet.
X = 1 inch for Fill Heights 2 Feet and Greater

FIG. 2 Top Slab Reinforcement Placement
(Joint configuration is for illustration purposes only, and other configurations are acceptable.)

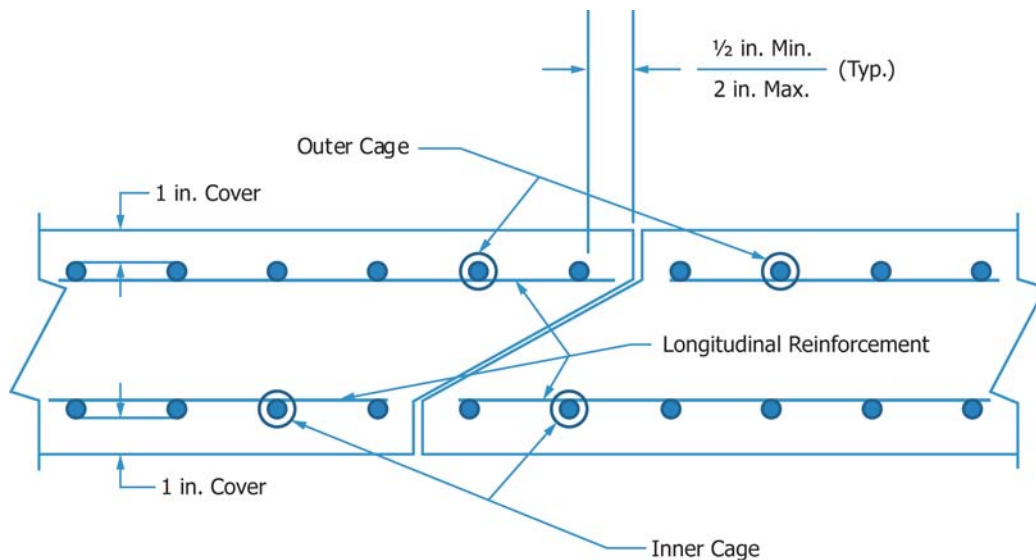


FIG. 3 Bottom Slab Reinforcement Placement
(Joint configuration is for illustration purposes only, and other configurations are acceptable.)

2 in. from the ends of the box section. The exposure of the ends of longitudinals, stirrups, and spacers used to position the reinforcement shall not be a cause for rejection.

7.2 Laps, Welds, and Spacing—When deformed billet steel bars are utilized for the primary reinforcing, the requirements in the AASHTO LRFD Bridge Design Specifications, Section 5.11 for splices and development of reinforcement shall be followed. When wire reinforcement is utilized, the requirements of this section shall be followed. Splices in the circumferential reinforcement shall be made by lapping. The overlap measured between the outermost longitudinal wires of each reinforcement sheet shall not be less than the space containing two longitudinal wires of each mesh plus 2 in., but not less than

10 inches. No splicing is permitted in individual slab segments. The outside circumferential reinforcement in the top or bottom slab of a three-sided segment shall be continuous with, or lapped with the outside circumferential reinforcement in the sides. If welds are made to welded wire circumferential reinforcement, they shall be made only to selected circumferential wires that are not less than 18 in. apart along the longitudinal axis of the three-sided section. When spacers are welded to circumferential wires, they shall be welded only to these selected circumferential wires. There shall be no welding to other circumferential wires. No welds shall be made to the inside circumferential wires in the middle third of the top span. No welds shall be made to the outside circumferential wires in

the top span within one fourth of the span from the corners or in any location in either leg. Welding of deformed billet steel bar circumferential reinforcement is prohibited in all cases. When distribution reinforcement is fastened to a cage by welding, it shall be welded only to longitudinal wires or bars and only near the ends of the three-sided section. The spacing center to center of the circumferential reinforcement shall not be less than 2 in. nor more than 4 in. for welded wire reinforcement, or less than 2 in. nor more than 8 in. for deformed billet steel bars. The spacing center to center of the longitudinal reinforcement shall not be more than 8 in. for welded wire reinforcement or more than 12 in. for deformed billet steel bars. If welds are made to Grade 60 reinforcing bars, weldable bars conforming to Specification **A706/A706M** shall be used.

NOTE 5—(Advisory)—The AASHTO LRFD Bridge Design Specifications should be consulted for weld requirements and development lengths not directly addressed in this standard.

7.3 Minimum Reinforcement—Box culvert sections with less than 2 ft of earth or pavement cover shall contain distribution reinforcement in the bottom of the top slab in accordance with Article 9.7.3.2 of the AASHTO LRFD Bridge Design Specifications, but shall be no less than $0.02 \cdot A_g$ in accordance with Article 12.11.4.3.

7.4 Substitution of Reinforcing—Deformed billet steel bars cannot be substituted as a replacement for steel areas based on a welded wire reinforcement design without approval by the engineer.

NOTE 6—Because of the difference in yield stress between bars and wire, and the differences in spacing required for larger and smaller diameter reinforcement, the steel area for deformed bars may have to be increased to account for flexure and/or crack control.

8. Joints

8.1 The ends of the box segments shall be of such design that each segment can be fitted together to form a complete box section unit. The ends of the box section units shall be so formed that the sections can be laid together to make a continuous line of box sections compatible with the permissible variations given in Section 11.

8.2 Longitudinal joints shall be designed to carry the applied vertical forces, and so formed so that they can be assembled to transmit forces and provide joint tightness consistent with the requirements for transverse joints.

9. Manufacture

9.1 Mixture—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a thoroughly mixed concrete of such quality that the box section will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.50 by weight. Cementitious materials shall be as specified in 5.2 and shall be added to the mix in a proportion not less than 470 lb/yd³ unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the box section meet the requirements of this specification.

9.2 Curing—The box segments shall be cured for a sufficient length of time so that the concrete will develop the specified compressive strength by the time of delivery. Any one of the following methods of curing or combinations thereof shall be used:

9.2.1 Steam Curing—The box segments shall be low pressure, steam-cured by a system that will maintain a moist atmosphere.

9.2.2 Water Curing—The box segments shall be water-cured by any method that will keep the sections moist.

9.2.3 Membrane Curing—A sealing membrane conforming to the requirements of Specification **C309** shall be applied and shall be left intact until the required concrete compressive strength is attained. The concrete temperature at the time of application shall be within 10°F of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

9.3 Forms—The forms used in manufacture shall be sufficiently rigid and accurate to maintain the box section dimensions within the permissible variations given in Section 10. All casting surfaces shall be of smooth nonporous material.

9.4 Handling—Handling devices or holes are not prohibited in each box segment for the purpose of handling and laying.

10. Physical Requirements

10.1 Type of Test Specimen—Compression tests for determining concrete compressive strength shall be allowed to be made on either standard rodded concrete cylinders or concrete cylinders compacted and cured in like manner as the box segments, or on cores drilled from the box section.

10.2 Compression Testing of Cylinders:

10.2.1 Cylinders shall be prepared, cured, and tested in accordance with Section 11 of Test Methods **C494/C494M**. Cylinders shall be exposed to the same curing conditions as the manufactured box segments and shall remain with the segments until tested.

10.2.2 Prepare not less than three test cylinders from each concrete mix used within a lot (one day's production) of box segments.

10.2.3 Acceptability on the Basis of Cylinder Test Results:

10.2.3.1 When the average compressive strength of all cylinders tested is equal to or greater than the design concrete strength, not more than 10 % of the cylinders tested have a compressive strength less than the design concrete strength, and no cylinder tested has a compressive strength less than 80 % of the design concrete strength, the lot shall be accepted.

10.2.3.2 Box segments that fail to meet the strength requirements under 10.2 shall not be retested under 10.3 without the approval of the purchaser.

10.2.3.3 When the compressive strength of the cylinders is unavailable, the acceptability of the lot shall be determined in accordance with the provisions of 10.3.

10.3 Compression Testing of Cores:

10.3.1 Cores shall be obtained, prepared, and tested for compressive strength in accordance with the provisions of Test Methods **C497**.

10.3.2 Three separate box sections shall be selected at random from each group of 15 box sections or fraction thereof, of a single size from each continuous production run. Cores shall be taken from each individual box segment comprising the full box section.

10.3.3 *Acceptability by Core Tests:*

10.3.3.1 Concrete represented by these core tests shall be considered acceptable if the average of the core strengths is equal to or greater than 85 % of the required compressive strength of the concrete with no one core less than 75 % of the required compressive strength.

10.3.3.2 If the compressive strength of the cores does not meet the requirements of 10.3.3.1, the individual segment from which the cores were taken shall be rejected. Two additional box segments from the remainder of that segment group (bottom slab, top slab, or three-sided) shall be selected at random and one core shall be taken from each and tested. If both cores have a strength equal to or greater than 85 % of the required strength, the remainder of the group is acceptable. If the compressive strength of either of the two cores tested is less than 85 % of the required strength of the concrete, the remainder of the group of box segments shall be rejected, or, at the option of the manufacturer, each box segment of the remainder of the group shall be cored and accepted individually, and any of these box segments that have core strengths less than 85 % of the required strength of the concrete shall be rejected.

NOTE 7—(Advisory)—The percentage shown for acceptance of core tests are in accordance with ACI 318 which states that, “To expect core tests to be equal to f'_c is not realistic, since differences in the size of specimens, conditions of obtaining samples, and procedures for curing do not permit equal values to be obtained.” The variations of the specimens such as length to diameter ratio, drilling direction and process, aggregate size and sample preparation may all have an effect on the test results. Embedded steel reinforcement affects the test results because of the loss of concrete continuity.

10.4 *Plugging Core Holes*—The core holes shall be plugged and sealed by the manufacturer in a manner such that the box section will meet all of the test requirements of this specification. Box sections so sealed shall be considered as satisfactory for use.

10.5 *Test Equipment*—Every manufacturer furnishing box sections under this specification shall furnish all facilities and personnel necessary to carry out the tests required.

11. Permissible Variations

11.1 *Internal Dimensions*—The internal dimensions shall not vary more than 1 % from the design dimensions. If haunches are used, the haunch dimensions shall not vary more than ¼ in. from the design dimensions.

NOTE 8—The size of the haunches shall be established by the Engineer. The use of haunches is not required. However, maintaining the proper concrete cover, while still maintaining the minimum reinforcement bending radius of four times the reinforcement diameter may require the use of haunches for manufacturing purposes. The design engineer should take this into account in their design.

11.2 *Slab and Wall Thickness*—The slab and wall thickness shall not be less than that shown in the design by more than 5 % or 3/16 in., whichever is greater. A thickness more than that

required in the design shall not be a cause for rejection. Slab and wall thicknesses greater than 4 inches shall have two layers of reinforcement.

11.3 *Length of Opposite Box Segments*—Variations in lengths of two opposite surfaces of the box segments shall not be more than 1/8 in./ft of internal span, with a maximum of 5/8 in. for all sizes through 7 ft internal span, and a maximum of 3/4 in. for internal spans greater than 7 ft, except where beveled ends for laying of curves are specified by the purchaser.

11.4 *Length of Box Segments*—The underrun in length of a segment shall not be more than 1/8 in./ft of length with a maximum of 1/2 in. in any box segment.

11.5 *Length of Opposite Box Section Surfaces*—When fitted together, the variation in laying lengths of two opposite surfaces of the box section shall not be more than 1/8 in./ft of internal span, with a maximum of 5/8 in. for all box section sizes having a 7 ft internal span or less, and a maximum of 3/4 in. for internal spans greater than 7 ft, except where beveled ends for laying of curves are specified by the purchaser.

11.6 *Length of Legs and Slabs*—The variation in length of the legs shall not be more than 1/8 in./ft of the rise of the leg per leg with a maximum of 5/8 inches. The differential length between opposing legs of the same segment shall not be more than 1/2 inch. Length of independent top slab spans shall not vary by more than 1/8 in./ft of span of the top slab, with a maximum of 5/8 inches. The length of the span of shall not vary by more than 1/2 in. when measured at the top middle, and bottom of the rise of the assembled culvert.

11.7 *Position of Reinforcement*—The maximum variation in the position of the reinforcement of 5-in. or less slab and wall thickness shall be $\pm 3/8$ in., and for greater than 5-in. slab and wall thickness shall be $\pm 1/2$ inch. In no case, however, shall the cover over the reinforcement be less than 5/8 in., as measured to the internal surface or the external surface except the cover over the reinforcement for the external surface of the top slab for boxes with under 2 ft of cover shall not be less than 1 5/8 inches. The preceding minimum cover limitation does not apply at the mating surfaces of the joint.

11.8 *Area of Reinforcement*—The areas of steel reinforcement shall be as specified by the Engineer when performing the design in accordance with the AASHTO LRFD Bridge Design Specifications. Fig. 4 identifies the appropriate sections of the AASHTO LRFD Bridge Design Specifications that govern minimum reinforcement design. Steel areas greater than those required shall not be cause for rejection. The permissible variation in diameter of any wire in finished reinforcement shall conform to the tolerances prescribed for the wire before fabrication by Specification A1064/A1064M. If steel bars (Grade 60) are used in lieu of welded wire reinforcement, the steel areas shall be based on a yield strength of 60 ksi instead of the minimum yield strength of 65 ksi for wire. Steel spacing, concrete cover, and crack control for the welded wire reinforcement and steel bars shall be checked accordingly.

12. Repairs

12.1 Box sections shall be repaired, if necessary, because of imperfections in manufacture or handling damage and will be

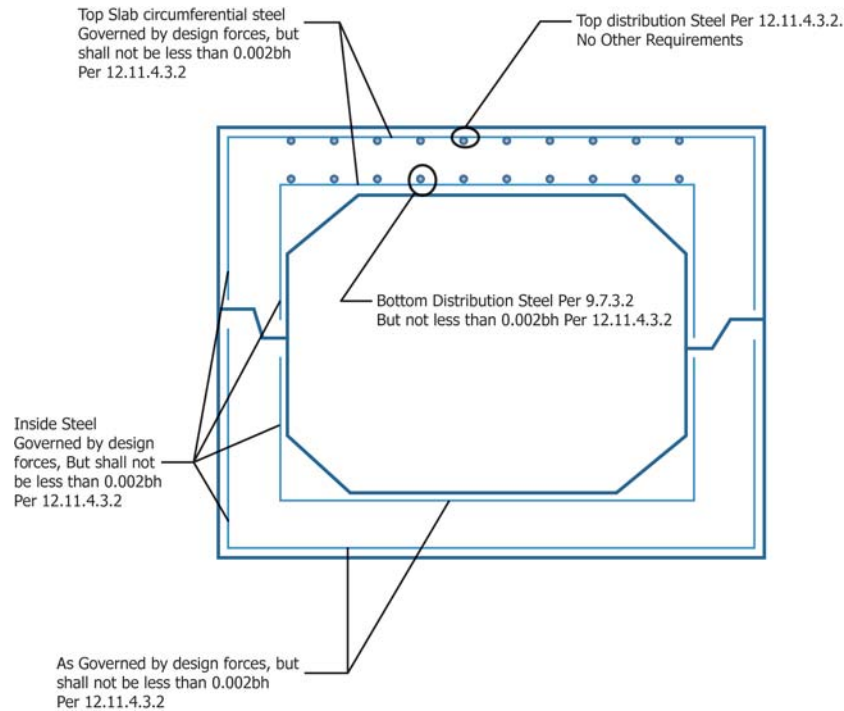


FIG. 4 Minimum Steel Requirements per AASHTO LRFD Bridge Design Specifications

acceptable if, in the opinion of the purchaser, the repaired box section conforms to the requirements of this specification.

13. Inspection

13.1 The quality of materials, the process of manufacture, and the finished box sections shall be subject to inspection by the purchaser.

14. Rejection

14.1 Individual box segments, as well as the completed box sections are subject to rejection on account of failure to conform to any of the specification requirements. Box segments and/or box sections are subject to rejection because of any of the following:

14.1.1 Fractures or cracks passing through the wall or slab, except for a single end crack that does not exceed the depth of the joint,

14.1.2 Defects that indicate mixing and molding not in compliance with 9.1, or honeycombed or open texture that would adversely affect the function of the box sections, and

14.1.3 Damaged ends, where such damage would prevent making a satisfactory joint.

15. Marking

15.1 The following information shall be legibly marked on each box segment by indentation, waterproof paint, or other approved means:

15.1.1 Box section span, rise, maximum and minimum design earth cover, and specification designation.

15.1.2 Date of manufacture, and

15.1.3 Name or trademark of the manufacturer.

15.2 Each segment of the box section shall be clearly marked. The top of the box section shall be marked "top" on the outside face of the slab.

APPENDIX

(Nonmandatory Information)

X1. DESIGN GUIDANCE IN ACCORDANCE WITH THE AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS

X1.1 Bedding Assumptions

X1.1.1 The bedding should provide a slightly yielding, uniformly distributed support over the bottom width of the box section. Reference Section 27 of the AASHTO LRFD Bridge Construction Specifications for standard installation practices.

X1.2 Criteria for Loads

X1.2.1 Design loads are based on the American Association of State Highway and Transportation Officials (AASHTO LRFD Bridge Design Specifications).

X1.2.2 Live loads for designs are HL-93 loadings as defined in the AASHTO LRFD Specifications. For spans not exceeding 15 ft, the lane load need not be applied. Dynamic load allowances are in accordance with the AASHTO specification. The HL-93 live load consists of the design truck (32 000 lb axle, identical to the HS 20 truck of the Standard Specifications) or a design tandem (two 25 000 lb axles spaced 4 feet apart).

X1.2.3 For box sections with less than 2 ft of cover, where the traffic travels parallel to the span of the culvert, wheel loads are distributed perpendicular to the span by the use of longitudinal distribution reinforcement in the bottom of the top slab. The width of the live load distribution for an entire axle at these depths is $E = 96 \text{ (in.)} + 1.44\text{Span (ft)}$ where E = distribution width in inches. The length of the applied load is $L = 10 \text{ (in.)} + 1.15H \text{ (in.)}$. For box sections with 2 ft or more of cover, the wheel load is applied as a tire footprint of $w = 20 \text{ (in.)}$ by $l = 10 \text{ inches}$ on the surface and distributed through the soil to the top of the box with dimensions equal to the tire footprint plus $1.15H$ in each direction assuming use of a select granular backfill above the culvert.

X1.2.3.1 If live load is at an angle greater than 30 degrees, from parallel to the span, and the earth cover is less than 5 feet, than an analysis that takes the skew into consideration shall be performed. In lieu of designing for the exact skew angle, the culvert may be analyzed as if the live load is perpendicular to the span in accordance with X1.2.4.

X1.2.4 For box sections with less than 2 feet of cover, where the traffic travels parallel to the span of the culvert, wheel loads are distributed $26 \text{ (in.)} + 6.6\text{Span (ft)}$ for positive moments, and $48 \text{ (in.)} + 3.0\text{Span (ft)}$ for negative moments. The length of the applied load is $L = 20 \text{ (in.)} + 1.15H \text{ (in.)}$. For box sections with 2 ft or more of cover, the wheel load is applied as a tire footprint of $w = 20 \text{ (in.)}$ by $l = 10 \text{ inches}$ on the surface and distributed through the soil to the top of the box with dimensions equal to the tire footprint plus $1.15H$ in each direction assuming use of a select granular backfill above the culvert.

X1.2.5 Cover loads are the weight of a column of earth of a width equal to the outside width dimension of the box section and a height equal to the depth of cover over the top of the

section multiplied by the appropriate AASHTO soil structure interaction factor (See Table X1.1).

X1.2.6 Lateral earth pressure from weight of earth above and adjacent to a box section is taken as 0.50 times the vertical pressure. This value is increased by the load factor of 1.35 for the maximum lateral earth pressure used in design. The box culverts are also evaluated for a minimum lateral earth pressure, which may result in increased steel areas in certain locations of the box culvert. AASHTO allows for a 50 % reduction in the lateral earth pressure in lieu of applying a minimum earth load factor of 0.90. This results in a minimum lateral earth pressure design value of 0.25 times the maximum vertical earth pressure. This minimum value is 50 % of the maximum value. Additional lateral pressure in lbf/ft^2 from approaching truck wheel loads is added when determining steel areas only at sections where area is increased by increased lateral pressure (see Table X1.1).

X1.3 Methods of Analysis

X1.3.1 The structural effects of the loads described in X1.2 should be evaluated based on the elastic method of structural analysis, unless detailed information regarding the surrounding soil properties is furnished. Vertical earth loads and their reactions shall be distributed uniformly across the top and bottom slabs. Design moments, shears, and thrusts shall be evaluated based on maximum stress resultants at critical sections caused by the most severe combination of design loads, including dead, soil, live, hydrostatic, and hydraulic uplift. A mechanical means of attaching the top slab shall be utilized when the hydraulic uplift force exceeds the dead and soil loads. Box sections shall be evaluated considering the wall restrained by the slab connection, and unrestrained by the slab connection, including load combinations of:

X1.3.1.1 Maximum Vertical Load with Maximum Internal Lateral Load and Minimum External Load

X1.3.1.2 Maximum Vertical Load with Maximum External Lateral Load and Minimum Internal Load

X1.3.1.3 Minimum Vertical Load with Maximum Internal Lateral Load and Minimum External Load

X1.3.1.4 Minimum Vertical Load with Maximum External Lateral Load and Minimum Internal Load

X1.4 Method of Design

X1.4.1 Box design is based on load and resistance factor design provisions given in AASHTO LRFD Bridge Design Specifications. Reinforcement areas are governed by either, ultimate load yield stress limitation of f_y , fatigue live load service limitation of f_s , service total load stress limitation (cracking) of f_s , or maximum shear capacity using flexural reinforcement. Capacity reduction factors of 0.95 for flexure and 0.90 for shear shall be used. Concrete slabs and walls shall be designed as singly reinforced members with no compression

steel considered. Longitudinal distribution reinforcement, when required for individual top slabs, or the top slabs of three-sided segments shall be in accordance with distribution reinforcement formulas given in the AASHTO specification for bridge decks. Longitudinal reinforcement is also required in the outside face of these segments in accordance with AASHTO. Distribution reinforcement shall either be welded wire reinforcement or deformed Grade 60 bars, subject to the provisions of 11.6. A slab thickness equal to or greater than $[1.2(s + 10)]/30$ for individual top slabs and $(s + 10)/30$ for continuous span slabs encompasses the recommended minimum section depth and deflection requirements in Commentary C9.7.1.1 of the AASHTO LRFD Bridge Design Specifications.

X1.5 Multiple Cell Installations

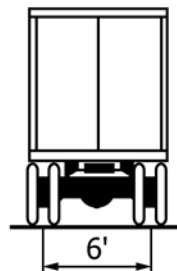
X1.5.1 The design guidance given herein are for single-cell precast reinforced concrete box sections. The units shall be allowed to be used in parallel for multicell installations if means of positive lateral bearing by continuous contact between the sides of adjacent boxes are provided. Compacted earth fill, granular backfill, flowable fill, or grouting between the units are considered means of providing such positive bearing.

TABLE X1.1 Summary of LRFD Design Criteria

Material Properties:	
Steel reinforcement, yield stress	$f_y \geq 60\,000\text{ psi}$
Concrete, compressive strength	$f'_c \geq 4000\text{ psi}$
Soil Data:	
Unit weight	120 lbf/ft ³
Ratio of lateral to vertical pressure from weight of earth	0.50 max to 0.25 min
External water table	below box section invert
Soil structure interaction factor	$F_e = 1 + 0.20(H/B_c)$ $B_c = \text{outside width of culvert}$ $F_{e\text{max}} = 1.15$
Capacity Reduction Factors	
(from AASHTO LRFD Bridge Design Specifications):	
Shear	0.90
Axial compression combined with bending	0.95
Loading Data:	
Load Modifiers:	
Ductile Structures	$\eta = 1.0$
For earth fill: non-redundant member	$\eta = 1.05$
For live load: redundant member	$\eta = 1.0$
Typical Bridge	$\eta = 1.0$
Load Factors:	
Dead Load	Max DL = 1.25, Min DL = 0.90
Earth Load (Vertical)	Max ELV = 1.30, Min ELV = 0.90
Earth Load (Horizontal)	Max ELH = 1.35 (see X1.2.5)
Live Load	LL = 1.75
Multiple Presence Factor	MPF = 1.2 (for one lane)
Live Load HL-93:	
Greater of:	
Truck Axle Load	32 000 lbf
Tandem Axle Load	2 at 25 000 lbf each
$H < 2\text{ ft}$ (With Traffic Parallel to Span)	
Area of box section resisting truck axle load	
Direction Perpendicular to Span	$E = 96\text{ (in.)} + 1.44\text{Span (ft)}$
Direction Parallel to Span	$L = 10\text{ (in.)} + 1.15H\text{ (in.)}$
$H < 2\text{ ft}$ (With Traffic Perpendicular to Span)	
Area of box section resisting truck axle load	
Direction Perpendicular to Span	$E = 26.0\text{ (in.)} + 6.6\text{ Span (ft) (+M)}$
Direction Parallel to Span	$E = 48.0\text{ (in.)} + 3.0\text{ Span (ft) (-M)}$ $L = 10\text{ (in.)} + 1.15H\text{ (in.)}$
$H \geq 2\text{ ft}$	
Area of box section resisting truck wheel load	
Direction Perpendicular to Span	$W = 20\text{ (in.)} + 1.15H\text{ (in.)}$
Direction Parallel to Span	$L = 10\text{ (in.)} + 1.15H\text{ (in.)}$
Dynamic Load Allowance (variable with depth)	$= 0.33(1 - 0.125H)$
Uniform internal pressure	0.0
Depth of water in box section	equal to inside height
External ground water pressure	0.0
Lateral Live Load Pressure:	
From 0 to 5 ft	160 psf
$5 \geq 10\text{ ft}$	$160 - [(H-5)/(10-5)](160-120)\text{ psf}$
$10 \geq 20\text{ ft}$	$120 - [(H-10)/(20-10)](120-80)\text{ psf}$
20 ft or greater	80 psf
Structural Arrangement:	
Minimum concrete cover over steel	1.0 in.
Top slab (outside face)	1.0 in. for fill heights 2 ft and greater, 2.0 in. for fill heights under 2 ft
Minimum Circumferential Reinforcing, inside and outside face of slabs and walls	0.002 bt

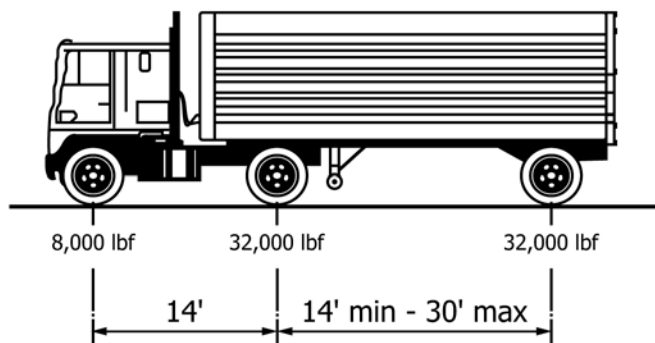
WHEEL SPACING

Design Truck
and
Design Tandem



AXLE LOADS

Design Truck



AXLE LOADS

Design Tandem

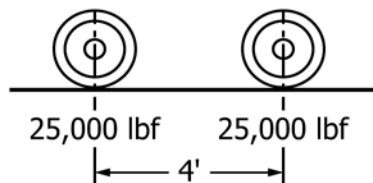


FIG. X1.1 Axle Loads for Box Section Standard Designs

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