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7 Culvert Design

This section of *Bridge Design Manual* follows the AASHTO LRFD Specifications and the following documents and related software:

- Cast-in-place box culverts
  - "CulvertCalc™ IA Technical Manual", available with downloaded CulvertCalc™ IA software
  - "CulvertCalc™ IA User Manual", available with downloaded CulvertCalc™ IA software
- Precast box culverts
  - "Precast Box Culvert Standards, Barrel and End Section Design Methodology", dated March 11, 2021

7.1 General

7.1.1 Policy overview

A culvert is a drainage structure that passes under a roadway. In the Bureau, a culvert is located and designed by the Preliminary Bridge Design Unit based on site hydrology and hydraulic principles [BDM 4]. Small culverts generally are constructed with standard pipe, and larger culverts are constructed with box sections, either cast-in-place or precast. For a reinforced concrete box culvert, the Preliminary Bridge Design Unit will set the height and opening width for one to three box culvert barrels, as well as the inlet and outlet components. Inlet and outlet components are intended to control water flow and sediment and to prevent erosion or scour.

Generally, for typical site conditions the Bureau now designs alternate cast-in-place and precast reinforced concrete single, twin and triple box culverts. A cast-in-place or precast box culvert must be designed structurally based on live load and the height of fill above the culvert. For standard cast-in-place single box culvert plans, the height of fill can range from zero, in which case traffic rides on the top slab of the culvert, to 55 feet for 3' to 12' span culverts and zero to 16 feet for 14' and 16' span culverts. The fill range is zero to 25 feet for cast-in-place double or triple box culverts. For standard single, twin and triple precast box culverts the height of fill can range from 2 to 25 feet for 6' to 12' spans and 2 to 16 feet for 14' and 16' spans. When using the Bureau standard plans the designer needs to give the height of fill on the plans so that the contractor can select the appropriate reinforcing and quantities.

For design of typical cast-in-place reinforced concrete box culverts the Bureau relies on standard plans for single, twin, or triple barrels; bell joints; flared wing headwalls; parallel wing headwalls; flumes; flume bell joints; and flume basins. Cast-in-place barrel sections generally are limited in length to 38 feet, and the total length of the culvert should consist of 38-foot sections plus shorter varying length end sections needed to meet the overall length. For design of cast-in-place reinforced concrete box culverts that do not fit standard plans the Bureau uses CulvertCalc IA, LRFD software specially developed for the Bureau. Additional features such as tapered or drop inlets, scour floors, handrails, trash racks, and fish baffles are specially designed and added to project plans as needed.

For design of precast box culverts the Bureau provides standard plans for barrels, end sections, and some special details. For production of typical precast box culverts the Bureau has three options. Option A or B must be used if those options fit the project requirements. Option C is only allowed for non-standard designs. Fabricators shall not substitute their own designs and details for any of the three options.

- Option A: ASTM C1577 barrels and Iowa DOT end sections from Single Precast Reinforced Concrete Box Culvert Standards
- Option B: Iowa DOT Single Precast Reinforced Concrete Box Culvert Standards
- Option C: ETCulvert barrel design (or equivalent) for non-standard designs and Iowa DOT end sections from Single Precast Reinforced Concrete Box Culvert Standards

All options require shop drawing submittals for review and documentation. The Contractor shall allow 30 working days for the Engineer's shop drawing review. Precast box culverts also may be used for culvert

extensions in some cases, and the Bureau has prepared several detail sheets for the connection between an existing box culvert and the precast extension.

When precast box culverts are used in stage construction the projects will need to be carefully planned so that the tongue and groove at the end of the first stage fits the tongue and groove at the start of the second stage. This may be accomplished by special attention to detailing of the tongue and groove for the start of the second stage or by procuring all the precast sections in one contract and stockpiling the sections for the second stage.

In most cases the designer should develop plans for each reinforced concrete box culvert or box culvert extension as a stand-alone project. However, the culvert or extension usually becomes part of a new road, road widening, or road resurfacing project of the Design Bureau (DB). Considering the overall road project, the Contracts and Specifications Bureau (CSB) may combine the culvert with other structures and roadwork to assemble an appropriate contract package. Any site-specific issues during construction then are worked out by the local Resident Construction Engineer (RCE).

Reinforced concrete box culverts often are not economical for spans or heights greater than 12 feet. To achieve greater flow-through capacity the Bureau generally uses twin or triple barrels rather than extended spans.

Although a culvert is a drainage structure, if it is more than 20 feet in length along the centerline of roadway between extreme ends of the opening of a single barrel or openings of multiple barrels, it will be classified as a bridge for the National Bridge Inventory. This classification does not affect the design of the culvert, but it ensures that the culvert will be inspected regularly as part of the Iowa DOT's bridge inspection program.

Reinforced concrete box culverts also generally are not economical in sizes less than 3 feet by 3 feet. For relatively small amounts of drainage and heights of fill the Bureau selects standard concrete pipe for culverts under paved roads, corrugated metal pipe for temporary culverts, and unclassified pipe for property entrances. For unclassified pipe the contractor may select from approved pipe materials.

7.1.2 Design information

Typically, the Soils Design Unit will provide a soils package for a box culvert project. The estimated settlement sheet in the package is important for design of camber and use of bell joints. The sheet also will require and show a granular blanket if needed. If the sheet is not provided, the designer shall contact the Soils Design Unit for information.

7.1.3 Definitions

Apron refers to the reinforced concrete floor between wing walls at a typical reinforced concrete box culvert inlet or outlet. At an outlet a scour floor may be added beyond the apron. Apron also refers to the flared end section at the inlet and outlet for a pipe culvert.

Barrel refers to the main culvert component of rectangular or square cross section that passes under the roadway. The barrel functions as a pipe for ditch and small stream drainage.

Curtain wall, curtain, scour curtain, cut-off wall, return wall, or toe wall is the downturned edge at the outer end of a culvert inlet or outlet floor, flume, or flume basin. For sites that are difficult to excavate and dewater, construction personnel may allow the contractor the option of using sheet piling. See *Construction Manual,* Article 11.82 [BDM 7.1.5.2].

Double and Twin are interchangeable terms for two parallel box culvert barrels. Twin is the more traditional term and is found on standard plans.

Drop inlet is an inlet device that minimizes right-of-way by elevating a ditch or by reducing head-cutting of a draw upstream. A drop inlet typically is 3 to 20 feet tall.

Effective floor thickness is the thickness of the cast-in-place culvert barrel floor or headwall apron after an assumed two-inch thick mud mat is deducted. The effective floor thickness is used in structural design of the floor.

Effective slab thickness is the thickness of the cast-in-place culvert slab after an assumed half-inch built-in (or integral) wearing surface is deducted when the slab also serves as the roadway surface. The effective slab thickness is used in structural design of the slab.

End wall is placed between headwall wings at a reinforced concrete box culvert or pipe culvert inlet to reduce right-of-way, to allow a location for tile outlets, or to match a streambed elevation for a culvert that is buried for environmental reasons or is buried to get below the road grade elevation. An end wall typically is one to two feet tall.

Fill height indicates the amount of soil above the top slab of the culvert. This dimension also is termed earth cover in ASTM C1577.

Floor (or base slab or footing) is the bottom slab in the barrel of a box culvert. The Iowa floor profile provides level surfaces on each side of a wall for placement of wall forms and a recess between them, which is called a frost trough. Iowa has used this frost trough profile rather than a flat floor since the 1930s.

Flume or flume chute is the parabolically curved device between parallel wings at a culvert outlet that provides a significant drop in elevation from culvert floor to downstream streambed elevation. Usually a flume terminates at a flume basin but, in some cases, a stub flume without a basin may be appropriate.

Flume basin is at the end of a flume chute and is typically buried 5 feet below streambed elevation. A flume basin helps contain the scour resulting from the energy dissipated from the flume.

Frost trough (or flow channel) refers to the depression in the floor of a reinforced concrete box culvert barrel. Generally, the frost trough detail has been used by the Bureau since the 1930s. The frost trough is omitted in cases where a box culvert is used as a pedestrian underpass.

Headwalls include the parapet, wings, apron, and curtain wall.

Height (H) is measured inside the culvert barrel from underside of slab to top of floor at a wall in a cast-in-place box. Typically, a frost trough depression is 4 inches below the start of the height dimension.

Interior wall is a wall between barrels in a twin or triple reinforced concrete box culvert. In a twin culvert the interior wall also may be called a center wall. Interior walls extend onto the apron at both ends of the culvert to strengthen the end section, protect the interior barrel wall, and channelize debris.

Length of a reinforced concrete cast-in-place or precast box culvert is measured back to back of parapets. On the Bureau standard plans the precast box culvert parapets are referred to as lintel beams.

Mud mat is the bottom 2 inches of concrete in a cast-in-place box culvert floor. The mud mat is neglected in structural design.

Parapet is the upturned edge of the top slab at the end of a culvert barrel. It may also be called a lintel beam.

Reinforced concrete box (RCB), without further description, usually refers to a cast-in-place, reinforced concrete box culvert. This terminology developed in the Bureau before precast box culverts were available. In a few cases context will indicate that reinforced concrete box refers to both cast-in-place and precast box culverts. In this manual section the term “precast” will be added to specifically indicate a precast reinforced concrete box.

Scour floor is a slab placed between reinforced concrete box culvert headwalls near their ends at the outlet but below the apron.

Slab or top slab is the top of a reinforced concrete box culvert.

Span (S) is measured across the culvert barrel from inside surface of wall to inside surface of wall.

Stabilization berm is constructed at the toe of an embankment slope to provide a counterweight to resist a deep rotational slope failure. It generally has the effect of lengthening a culvert because the culvert needs to be extended through the stabilization berm.

Tapered inlet is a slope tapered inlet used to increase capacity of a culvert designed for inlet control. See Figure 7.2.4.7.5.

Triple is the term for three parallel box culvert barrels.

Wing or wing wall refers to each of the pair of flared or parallel walls at the inlet or outlet of a reinforced concrete box culvert.

7.1.4 Abbreviations and notation

[AASHTO-LRFD 1.3.2.1, 3.6.1.1.2, 5.7.2.8, 5.7.3.4.2]

CMP, corrugated metal pipe

d_v, effective shear depth (inches) [AASHTO-LRFD 5.7.2.8]

H, height measured inside the culvert barrel from underside of slab to top of floor at a wall

Iowa DNR, Iowa Department of Natural Resources

MCFT, modified compression field theory [AASHTO-LRFD 5.7.3.4.2]

MPF, multiple presence factor [AASHTO-LRFD 3.6.1.1.2]

PEP, polyethylene pipe

RCB, reinforced concrete box

RCE, resident construction engineer

RCP, reinforced concrete pipe

S, span measured across the culvert barrel from inside surface of wall to inside surface of wall

SU8, the notional rating load (truck) given on page 6-67 of *The Manual for Bridge Evaluation, First Edition*

TS&L, type, size, and location

η_i, load modifier [AASHTO-LRFD 1.3.2.1]

7.1.5 References

7.1.5.1 Direct

Throughout the culvert section there are frequent, direct references to specific portions of standards and publications. Direct references are included in brackets [ ] using the abbreviations given below. Applicable references to the AASHTO LRFD Specifications and, in a few cases, to the Standard Specifications are given with each article heading.

Although the latest editions are listed below there are some circumstances in which referenced documents have been prepared on the basis of previous editions.

[AASHTO division article, table, or figure] refers to AASHTO *Standard Specifications for Highway Bridges, 17th Edition (2002)* with current errata changes - design, seismic design, or construction division with article, table, or figure number.

[AASHTO-LRFD article, table, or figure] refers to *AASHTO LRFD Bridge Design Specifications, 5th Edition (2010)* with article, table, or figure number.

[BDM article, table, figure, or note] refers to *LRFD Bridge Design Manual* with article, table, figure, or plan note number. (Available on the Internet at http://www.iowadot.gov/bridge/manuallrfd.htm)

[IDOT SS article] refers to Iowa Department of Transportation *Standard Specifications for Highway and Bridge Construction, Series 2009* with article number. (Available on the Internet at: http://www.iowadot.gov/erl/current/GS/Navigation/nav.pdf/)

[BSB SS sheet number] refers to a Bridges and Structures Bureau (BSB), “Standard Sheet” with sheet number. (Available on the Internet at: http://www.iowadot.gov/bridge/v8ebrgstd.htm)

[DB DM article, table, or figure] refers to the Design Bureau, *Design Manual* with article, table, or figure number. (Available on the Internet at: http://www.iowadot.gov/design/dmanual/manual.html?reload)

[DB RDD sheet number] refers to the Design Bureau, “Road Design Details” with sheet number. Formerly the detail manual was referred to as the “green book.” (Available on the Internet at: http://www.iowadot.gov/design/desdet.htm)

[DB SRP sheet number] refers to an Design Bureau, “Standard Road Plan” with sheet number. Formerly the plan manual was referred to as the “red book.” (Available on the Internet at: http://www.iowadot.gov/design/stdrdpln.htm)

[CMB IM number] refers to Construction and Materials Bureau, Iowa Department of Transportation Instructional Memorandum number. (Available on the Internet at: http://www.iowadot.gov/erl/current/IM/Navigation/nav.pdf)

7.1.5.2 Indirect

Indirect references are general and infrequent sources of information that usually are not linked with specific article or section numbers.

American Association of State Highway and Transportation Officials (AASHTO). *Highway Drainage Guidelines, 4th Edition.* Washington: AASHTO, 2007.

American Association of State Highway and Transportation Officials (AASHTO). *Manual for Bridge Evaluation, First Edition.* Washington: AASHTO, 2008.

American Association of State Highway and Transportation Officials (AASHTO). *Roadside Design Guide, 4th Edition 2011.* Washington: AASHTO, 2008.

American Concrete Institute (ACI). *Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary (ACI 318R-11).* Farmington Hills: ACI, 2011.

American Galvanizers Association. *GalvaSource.* Aurora: American Galvanizers Association, 2011 (Available on the Internet at: http://www.galvanizeit.org/images/uploads/publicationPDFs/North_American_Galvanizers_Listing.pdf)

American Institute of Steel Construction (AISC). *Steel Construction Manual, Fourteenth Edition.* Chicago: AISC, 2011.

American Society for Testing and Materials (ASTM). *2001 Annual Book of ASTM Standards*. West Conshohocken: ASTM, 2001.

Kirkham Michael, *US20 Precast Culvert Settlement Monitoring: Woodbury & Ida Counties*. Final Report prepared for the Iowa DOT (unpublished), September 6, 2018.

Construction and Materials Bureau. *Construction Manual.* Ames: Construction and Materials Bureau, Iowa Department of Transportation, 2011. (Available on the Internet at: http://www.erl.dot.state.ia.us/)

Sicking, D.L., R.W. Bielenberg, J.R. Rohde, J.D. Reid, R.K. Faller, and K.A. Polivka. “Safety Grates for Cross-Drainage Culverts. *Transportation Research Record 2060-08.* Transportation Research Board, National Research Council, Washington, DC, 2008.

Sunday, Wayne and Kyle Frame. *New Bridge Construction Handbook.* Ames: Construction and Materials Bureau, Iowa Department of Transportation, 2000. (Available on the Internet at: http://www.iowadot.gov/construction/structures/bridge_construction_handbook.pdf)

7.2 Reinforced concrete box (cast-in-place)

Following are the plan development guidelines for projects that include cast-in-place culverts.

- Preliminary Bridge shall prepare the preliminary design (TS&L) for a cast-in-place culvert length. If the culvert structure is a candidate for either a precast or cast-in-place culvert, Preliminary Bridge will prepare the preliminary design (TS&L) for the cast-in-place culvert alternate. Refer to Section 7.3 for further information concerning the precast alternate.
- Preliminary Bridge should note the following when determining the cast-in-place culvert length:
    - The foreslope for a cast-in-place culvert should intercept the top of the parapet as shown in Figure 7.2.
    - The overall length for the cast-in-place culvert should be adjusted so it is a whole foot length (converted to meters) needed to achieve the minimum back to back parapet length.
    - For parallel wing headwalls show Class E revetment around both headwalls as shown on the standard sheet [BSB SS 1092].

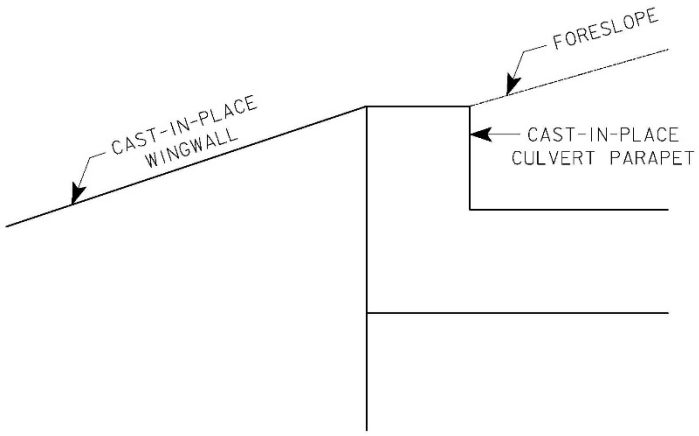


Figure 7.2. Foreslope-parapet intersection diagram

7.2.1 Loads

[AASHTO-LRFD C12.6.1]

Except in very unusual cases there will be no barrier rail or headwall components exposed to potential vehicular collision [AASHTO-LRFD C12.6.1], and thus the vehicular collision load (CT) may be neglected in the design of typical reinforced concrete box (RCB) culvert components.

The configuration of typical RCB culverts is such that ice does not have a significant loading effect, and the designer may neglect ice load (IC).

For lateral pressures on culvert barrel walls and wings, the designer shall assume earth pressure at rest, except in the unusual case where wings are detached. In that case the designer may assume active soil pressure.

For typical skewed, rectangular or square reinforced concrete box (RCB) culverts and their components the designer may neglect the overall effects of unbalanced horizontal load. For skews greater than 45 degrees, however, the designer should consider the effects of imbalance in horizontal loads at culvert ends because the imbalance may cause a significant sliding force.

7.2.1.1 Dead

[AASHTO-LRFD 3.5.1, 12.6.1, 12.11.2.2.1]

Self-weight (DC) shall be applied in the design of all reinforced concrete box (RCB) culvert components except floors. Pavement weight (DW) and earth fill weight (EV) shall be applied when applicable in the design of RCB barrels. The designer shall determine the loads from the following:

- Culvert self-weight (DC): 0.150 kcf
- Pavement weight (DW): 0.150 kcf for concrete or as given for other pavement materials in the AASHTO LRFD Specifications [AASHTO-LRFD Table 3.5.1-1] and applied as a surcharge load, and
- Earth fill weight (EV): 0.120 kcf for dry soil, unless more specific information is available.

Height of fill is measured from top of pavement to top of culvert. If there is pavement above the culvert without fill, apply the pavement load, and consider fill height to be 0 feet. For fill heights greater than 2 feet, round fill heights to the nearest foot. In some cases, especially with stabilization berms, there will be multiple fill heights, and the culvert will need to be analyzed and designed for several heights. As with barrel extensions [BDM 7.2.3.3] the designer should consider the option of varying the barrel design to fit the different load conditions.

The earth fill load should be modified for soil-structure interaction [AASHTO-LRFD 12.11.2.2.1]. Except for unusual site conditions that require trench installation the designer shall use the soil-structure interaction factor for embankment installation.

When developing load combinations for culvert barrels, the designer shall apply the maximum or minimum load factor to the earth fill weight [AASHTO-LRFD 12.6.1], depending on the objectives of the load combination.

7.2.1.2 Live

[AASHTO-LRFD 3.6.1.2.6, 3.6.1.3.3, 4.6.2.10, 12.11.2.1]

The designer shall apply HL-93 vehicular live load (LL) to culvert barrels as required by the AASHTO LRFD Specifications and, whenever LL is applied and the objective of the load combination is to maximize horizontal pressure, the designer shall also apply live load surcharge (LS). The designer need not apply the HL-93 lane load if using the approximate strip method for analysis [AASHTO-LRFD 3.6.1.3.3]. The designer shall apply LL to parapets in an extreme event limit state as indicated at the end of this article.

For box culvert barrels, live load is treated differently depending on the direction of traffic with respect to the culvert and depending on the amount of fill [AASHTO-LRFD 12.11.2.1]. For typical box culverts, except for skew angles greater than 45 degrees, traffic primarily will be parallel with the barrel span and AASHTO LRFD Case I will apply [AASHTO-LRFD 4.6.2.10.2].

For typical box culverts with less than 2.0 feet of fill, the designer shall apply wheel loads from the HL-93 vehicles using 20-inch wide by 10-inch long tire patches [AASHTO-LRFD 4.6.2.10] and shall distribute the live load based on the height of fill using a fill interaction factor (i.e. live load distribution factor) of 1.15.

The designer shall distribute live loads parallel with the span. For twin and triple barrel culverts the span of a single cell shall be used In the AASHTO LRFD formula for the distribution width perpendicular to the span [AASHTO LRFD Eq. 4.6.2.10.2-1].

When the fill height is 2.0 feet or greater, the designer shall follow the guidelines for distribution of wheel loads through earth fills [AASHTO-LRFD 3.6.1.2.6]. The designer shall distribute the live load based on the height of fill using a fill interaction factor (i.e. live load distribution factor) of 1.15. The designer shall consider a wheel load to be distributed uniformly over a 20-inch wide by 10-inch long tire patch. If the load distribution from live load plus dynamic load allowance based on distribution through an earth fill exceeds the load distribution determined from Case I above, the designer shall use the lower, Case I load distribution for determining moment, thrust, and shear.

Generally the designer should apply live load as follows:

- Run the HL-93 vehicles forward and backward.
- For fills less than 2 feet, apply HL-93 vehicular loads in a single lane with the appropriate multiple presence factor (MPF).
- For fills 2 feet and greater, apply HL-93 vehicular loads in one or more lanes with appropriate MPFs.

For single box culverts, when the fill height exceeds both 8 feet and the span length, live load effects may be neglected [AASHTO-LRFD 3.6.1.2.6]. For twin and triple culverts, only when the fill height exceeds the distance between the inside faces of end walls may the live load be neglected.

During development of CulvertCalc IA software the notional rating load, SU8 truck, was checked for all of the standard reinforced concrete box designs. The SU8 truck never controlled the design.

For a reinforced concrete box culvert parapet the designer shall assume a modified extreme event, in which the full force of an HL-93 truck wheel impacts the parapet as follows.

- Single 16-kip wheel load
- Multiple presence factor 1.20
- Load factor 1.00 (not 1.75)
- Dynamic load allowance 1.33

7.2.1.3 Dynamic load allowance

[AASHTO-LRFD 3.6.2.2]

The designer shall apply dynamic load allowance (IM) with the HL-93 truck and tandem in the design of culvert barrels and IM with the HL-93 truck wheel load in the design of culvert parapets.

For fill heights less than 8 feet, the designer shall determine the dynamic load allowance (IM) from the AASHTO LRFD Specifications [AASHTO-LRFD 3.6.2.2]. No dynamic load allowance is required when the fill height is greater than 8 feet.

7.2.1.4 Water

[AASHTO-LRFD 3.7.3.1]

The designer shall apply water loads (WA) to culvert barrels, aprons, and curtain walls as discussed below.

The designer shall check a culvert barrel with internal water pressure (WA) considering the culvert to be completely full, along with maximum downward load and minimum horizontal inward load. The designer also shall check the culvert without internal water pressure considering the culvert to be empty, along with minimum downward load and maximum inward horizontal load.

The designer shall consider buoyancy in loading of the apron.

Although there is no usual lateral water load on a culvert curtain wall, soil may be scoured away in front of the wall. To consider that condition the designer shall check the design of the wall for a stream pressure load of 15 ft/s [AASHTO-LRFD 3.7.3.1].

7.2.1.5 Earth pressure

[AASHTO-LRFD 3.4.1, 3.11.5.5, 3.11.6.4, 3.11.7]

The designer shall apply horizontal earth pressure (EH) to culvert barrel walls, wing walls, and parapets.

Unless more site-specific information is available or the Soils Design Unit recommends otherwise, the designer may use horizontal earth pressures (EH) based on equivalent fluid weights of 0.060 kcf and 0.030 kcf for barrels, wings, and parapets. This equivalent fluid loading is based on free-draining backfill [AASHTO-LRFD 3.11.5.5]. The lower fluid weight should not be combined with the minimum load factor assigned for horizontal earth pressures [AASHTO-LRFD 3.11.7, Table 3.4.1-2]; therefore, use a load factor of 1.00 with the 0.030 kcf minimum load.

For load cases with live load and the objective to maximize horizontal pressure the designer shall apply to culvert barrel walls a uniform horizontal pressure from live load surcharge (LS) as for abutments perpendicular to traffic [AASHTO-LRFD Table 3.11.6.4-1]. For the culvert barrel the “abutment height”

shall be taken from the top of pavement to bottom of floor, and the equivalent height then interpolated from the AASHTO LRFD table.

7.2.1.6 Construction

Reserved.

7.2.2 Load application

7.2.2.1 Load modifier

[AASHTO-LRFD 1.3.2, 3.4.1, 12.5.4]

Factored loads shall be adjusted by the load modifier, η_i, which is the product of modifiers for ductility, redundancy, and operational importance [AASHTO-LRFD 1.3.2, 3.4.1]. For typical cast-in-place or precast reinforced concrete culverts the modifiers for ductility and operational importance shall be taken as 1.0. For dead load, live load, dynamic load allowance, and construction loads the modifier for redundancy shall be taken as 1.0, but for earth loads EH_{max} and EV_{max} only, the modifier for redundancy shall be taken as 1.05 [AASHTO-LRFD 12.5.4].

7.2.2.2 Limit states

[AASHTO-LRFD C12.5.3]

Buried structures such as box culverts are shielded from many typical bridge loads. As a result, typical box culverts need to be investigated only as follows:

- Service I for crack control
- Strength I for flexure, compression, and shear

The designer need not investigate the fatigue limit state [AASHTO-LRFD C12.5.3].

7.2.3 Analysis and design

Cast-in-place reinforced concrete box (RCB) culverts shall be designed structurally by the load and resistance factor design (LRFD) method. For design conditions that do not fit the available standard designs, such as variable fill over the length of a RCB culvert barrel, the Bureau prefers that the designer use CulvertCalc IA, LRFD software on which the standard culvert barrel designs are based.

RCB culverts less than 3 feet by 3 feet in cross section are not economical, and the designer should consider pipe culverts for relatively small cross sections. For RCB barrels and headwalls the following minimum thicknesses apply:

- Slab: 8 inches
- Walls: the larger of 9 inches or one inch per foot of clear height, H
- Floor: 10 inches, which includes a 2-inch mud mat that is not considered structural
- Apron: 11 inches, which includes a 2-inch mud mat that is not considered structural

Unless otherwise specified, cast-in-place reinforced concrete materials shall be:

- Normal weight reinforced concrete with unit weight of 0.150 kcf,
- Class C concrete with f'_c = 4 ksi, and
- Grade 60 reinforcement with f_y = 60 ksi.

When the Soils Design Unit or geotechnical consultant does not provide site-specific information the designer should use the following cohesionless soil properties in design.

- Angle of internal friction (φ) 30 degrees
- Unit weight of saturated soil 0.135 kcf

- Unit weight of dry soil 0.120 kcf
- Unit weight of water 0.0624 kcf

In general, the designer should model components of box culverts using typical 12-inch wide strips for analysis and design.

7.2.3.1 Barrels

[AASHTO-LRFD 3.4.1, 4.6.2.1.4, C5.6.3.2, 5.6.3.3, 5.6.7, 5.6.4.2, 5.7.3.4.1, 5.10.6, 5.12.4.1, 5.12.7.3, 12.5.5, 12.11.2.1, C12.11.3, 12.11.4.2, 12.11.4.3.1]

The designer shall develop Strength I and Service I load combinations for design of RCB barrels. As a minimum, the factored load combinations shall include: (1) maximum vertical and minimum horizontal load, (2) minimum vertical and maximum horizontal load, and (3) maximum vertical and maximum horizontal load. The designer shall use AASHTO LRFD maximum and minimum load factors for dead load and earth pressure [AASHTO-LRFD Table 3.4.1-2], except that the minimum load factor for earth pressure (EH) should be taken as 1.00 [BDM 7.2.1.5]. For typical barrels the designer may apply lateral loads under balanced conditions so that there are no sliding forces.

The designer should model the culvert barrel as a slice through the barrel, a 12-inch wide rigid frame with sidesway that will occur only with unsymmetrical live load. The frame should be idealized with members at the centerlines of slab, walls, and floor. Section properties shall not include corner fillets, the mud mat below the floor, or the integral wearing surface used when the roadway is on the top slab.

The designer should design a barrel wall for the larger of the computed moments or the moment from a minimum axial load eccentricity (e):

$$e = 0.6 + 0.03H \geq 1.0 \text{ inch}$$

There are two options that the designer may consider for the soil pressure below the floor: uniform or linearly varying based on unsymmetrical loads, as for a rigid body. The standard culvert barrel designs are based on the second option. For significantly unsymmetrical loads the rigid body analysis option will indicate negative soil pressure (tension) below part of the floor, which may be assumed to exist for the analysis. The designer does not need to consider skew effects when the skew is 45 degrees or less.

The reinforcing pattern for the rigid frame generally should follow the standard culvert barrel designs. Single barrels are designed with straight, full length bars on the inside of the slab, walls, and floor; partial length bars on the outside of slab and floor; and spliced full-length bars on the outside of walls. Double and triple barrels are designed with straight short and full-length bars inside; short and full length bars outside; spliced full length bars in outside walls; and full length bars in interior walls. Guidelines for bar identification and detailing are given in the reinforcement article [BDM 7.2.4.4.4].

Review the reinforcement article [BDM 7.2.4.4.4] and consider the following when selecting reinforcement:

- Provide shrinkage and temperature reinforcement on the inside faces of culvert slabs, walls, and floors and in the top of the slab for culverts with no fill [AASHTO-LRFD 5.10.6].
- For a culvert barrel slab with 2 feet or less of fill, provide transverse distribution reinforcement in the bottom of the slab [AASHTO-LRFD 5.12.4.1].

The designer shall use the flexure and shear resistance factors given in the AASHTO LRFD Specifications for reinforced concrete cast-in-place box structures [AASHTO-LRFD Table 12.5.5-1].

When determining tension reinforcement for flexure, the designer shall neglect reinforcement on the compression side. Set $\rho_{max} = 0.634\rho_{balanced}$ to ensure a tension controlled section with $\varphi = 0.90$. The designer shall provide minimum reinforcement for flexure [AASHTO-LRFD 12.11.4.3.1, 5.6.3.3].

When determining the maximum negative moment reinforcement, the designer shall use the moment at the section where the combined depth of the uniform member (slab or wall) and haunch is 1.5 times the thickness of the member [AASHTO-LRFD C5.6.3.2.1]. See below for the definition of the haunch in a floor with a frost trough. The Bureau does not use the optional location for maximum negative moment in culverts [AASHTO-LRFD 12.11.4.2].

For the transverse edges of a culvert barrel slab with less than 2 feet of fill, except at the parapets, the designer shall check the need for an edge beam [AASHTO-LRFD 12.11.2.1, 4.6.2.1.4b]. Typically an edge beam will not be required and, in that case, the designer shall provide extra reinforcement by spacing reinforcement at 3 inches, 4.5 inches, and 4.5 inches from the end. The additional edge reinforcement also may require adjustment of wall reinforcing.

The designer shall consider compression forces in design of culvert barrel walls but need not consider compression forces in design of the slab and floor. The designer need not consider slenderness effects in design of box culvert barrel walls.

Based on past practice the Bureau limits the maximum percentage of vertical reinforcement in walls to 4%. The minimum percentage of vertical reinforcement may be based on a reduced effective area [AASHTO-LRFD 5.6.4.2], but the effective area shall not be less than 50% of the gross area. The reduced area, as well as the gross area, shall be capable of resisting all applicable load combinations.

The designer shall check shear at a distance d_v from the end of a corner haunch for all barrel members except for slabs with less than 2 feet of fill, in which case the designer shall check at the end of the haunch. The haunch in a floor with a frost trough should be defined as a 45-degree haunch with a size the smaller of the (1) vertical or (2) sum of horizontal dimensions (a relatively unlikely case).

After considerable study of the AASHTO LRFD Specifications and research publications and numerous trial runs of CulvertCalc IA the Bureau has decided to use the following concrete shear resistances for standard designs, and these resistances should be used for special designs. The Bureau does not use shear reinforcement.

- Single box, slab and floor, less than 2 feet of fill [AASHTO-LRFD 5.7.3.4.1]

$$v_c = 2\sqrt{f'_c}(psi) = 0.0632\sqrt{f'_c}(ksi)$$

- Single box, slab and floor, 2 feet or more of fill [AASHTO-LRFD 5.12.7.3]

$$v_c = 2.14\sqrt{f'_c} + 4600\rho\frac{V_u d}{M_u}(psi) = 0.0676\sqrt{f'_c} + 4.6\frac{A_s}{bd_e}\frac{V_u d_e}{M_u}(ksi)$$

$$v_c \geq 3\sqrt{f'_c}\,(psi) = 0.0948\sqrt{f'_c}\,(ksi)$$

$$v_c \leq 4\sqrt{f'_c}\,(psi) = 0.126\sqrt{f'_c}\,(ksi)$$

Note: $V_u d_e/M_u \leq 1.0$

- Single box, walls [AASHTO-LRFD 5.7.3.4.1]

$$v_c = 2\sqrt{f'_c}\,(psi) = 0.0632\sqrt{f'_c}(ksi)$$

- Double and triple box, slab and floor, less than 2 feet of fill [AASHTO-LRFD 5.7.3.4.1]

$$v_c = 2\sqrt{f'_c}\,(psi) = 0.0632\sqrt{f'_c}(ksi)$$

- Double and triple box, slab and floor, 2 feet or more of fill [AASHTO-LRFD 5.12.7.3]

$$v_c = 2.14\sqrt{f'_c} + 4600\rho\frac{V_u d}{M_u}\,(psi) = 0.0676\sqrt{f'_c} + 4.6\frac{A_s}{bd_e}\frac{V_u d_e}{M_u}(ksi)$$

$$v_c \leq 4\sqrt{f'_c}\,(psi) = 0.126\sqrt{f'_c}\,(ksi)$$

Note: $V_u d_e/M_u \leq 1.0$

- Double and triple box, walls [AASHTO-LRFD 5.7.3.4.1]

$$v_c = 2\sqrt{f'_c}\,(psi) = 0.0632\sqrt{f'_c}(ksi)$$

For a special project for which the designer has approval to use modified compression field theory (MCFT) [AASHTO-LRFD 5.7.3.4.2] in lieu of the shear resistances above, the maximum aggregate size should be taken as ¾ inch.

The designer shall use the smaller of the actual clear cover or 2.25 inches when checking crack control [AASHTO-LRFD 5.6.7]. The designer may consider thrust to reduce crack control requirements [AASHTO-LRFD C12.11.3]. Crack control exposure factor shall be taken as 1.00 except when the roadway is on the top slab, in which case the exposure factor shall be taken as 0.75.

7.2.3.2 Headwalls

[AASHTO-LRFD 5.10.6]

All headwall components shall be designed for crack control with an exposure factor of 1.00. The designer shall provide shrinkage and temperature reinforcement for all exposed surfaces [AASHTO-LRFD 5.10.6].

7.2.3.2.1 Wings

The designer shall develop Strength I and Service I load combinations for maximum effects for design of RCB wings. Unless wings are isolated from the culvert barrel, earth pressure should be based on the at-rest condition (K_o = 0.500) because the wings are supported laterally at the culvert barrel. The back slope for determining earth pressure should be based on the skew of the wall with respect to the typical 3:1 (horizontal to vertical) highway foreslope. Load combinations need not include live load surcharge (LS).

The typical culvert wings should be modeled with vertical 12-inch wide strips. At the barrel the wing strip may be idealized as a propped cantilever, and from the three-quarter height location to the end may be idealized as a cantilever.

The designer should consider reducing vertical reinforcement at mid-length of a wing. Horizontal reinforcement shall extend into the barrel beyond the back of the parapet the larger of (1) 2 feet or (2) a Class B lap splice.

7.2.3.2.2 Parapet

In addition to dead load and earth pressure in Strength I and Service I, the designer shall apply the live load of an HL-93 truck wheel in a modified extreme event limit state [BDM 7.2.1.2].

Minimum longitudinal reinforcement in a parapet shall be 2 - #7 with minimum transverse #4 bent bars at 6 inches.

When the culvert barrel slab thickness joining the headwall is greater than 18 inches, the headwall parapet height shall be extended so the top of the parapet is a minimum of 6 inches above the culvert barrel slab. The extended height of the parapet shall be to the nearest whole inch. This detail is available as a cell and shall be completed for the headwall size and included in the plans in lieu of a modified headwall standard sheet.

7.2.3.2.3 Apron

For the apron in Strength I and Service I limit states, in addition to the effects of loads caused by frame action from the wings, the designer shall consider buoyant forces [BDM 7.2.1.4].

Reinforcement in the top of the apron should be adequate to resist at least $1.2M_{cr}$, which often controls.

7.2.3.2.4 Curtain wall

Generally there is no horizontal load on the curtain wall but, to design conservatively in case there is streambed scour, in Strength I and Service I the designer shall assume a steam flow design pressure [BDM 7.2.1.4].

For sites that are difficult to excavate and dewater, construction personnel may allow the contractor the option of using sheet piling in place of the reinforced concrete curtain wall. See *Construction Manual,* Article 11.82 [BDM 7.1.5.2].

7.2.3.3 Barrel extensions

At sites where the shoulder slopes are being improved for safety reasons or where additional traffic lanes are being added, culverts are replaced or extended. For extensions of single box culverts the Bureau has three standard sheets [BSB SS 1043, 1044, and 1047]. The first standard [BSB SS 1043] has two sheets that are for all single barrel extensions, the second [BSB SS 1044] is for extensions to single barrel

culverts with existing flared headwalls, and the third [BSB SS 1047] is for parapet and transition details. Guidelines for use of the standard sheets are given in the standard plans article [BDM 7.2.4.1].

As a general rule the culvert extension should be designed for the same loads as a new culvert and for the maximum height of either existing or new fill. This will ensure that the extension will be adequately designed should the roadway be widened again at some future date.

If traffic will ride directly on the extension slab, the slab must be designed accordingly, and the slab steel must be epoxy coated. Also, the designer shall add corbels to the walls to support the approach pavement [BDM 7.2.4.5.1].

When skewed culverts are extended, the transverse bars and corner bars may be placed parallel with the skewed headwall. When this occurs, the designer shall account for the increased span length. See the detailing article for additional information [BDM 7.2.4.9].

7.2.3.4 Flumes and flume basins

The Bureau prefers that the designer use standard flume and flume basin designs [BSB SS 1070-03 to 1079-14]. For special designs, unless site conditions clearly indicate otherwise, the designer should assume a 2:1 horizontal to vertical back slope for flume and flume basin design. See the detailing article for additional information [BDM 7.2.4.8.1].

7.2.3.5 Other

A slope tapered inlet is designed for the span at the back face of the parapet and one foot of fill, which ensures a conservative design. See the detailing article for additional information [BDM 7.2.4.7.5].

7.2.4 Detailing

7.2.4.1 Standard plans

In April 2012 the Bureau released new RCB Culvert Standards designed according to the AASHTO LRFD Specifications and interpretations and policies given in this section of the Bridge Design Manual. The general categories of standard sheets are outlined below.

Single Reinforced Concrete Box Culvert Standards

- RCB: General information and barrel details
- PWH: Parallel wing headwalls
- CBJ: Culvert bell joints

Twin Reinforced Concrete Box Culvert Standards

- TWRCB: General information and barrel details
- TWH: Flared wing headwalls
- TWCBJ: Culvert bell joints

Triple Reinforced Concrete Box Culvert Standards

- TRRCB: General information and barrel details
- TRH: Flared wing headwalls
- TRCBJ: Culvert bell joints

These RCB Culvert Standards are quite similar to previous standards except that the headwalls for single RCBs are parallel rather than flared.

Following are guidelines for use of the standards for new culvert designs and culvert extension designs.

Case 1: New culvert, standard size, standard fill height, all skews

- Develop front sheet with additional culvert notes not listed on appropriate G1-20 Sheet.

- Refer to RCB Culvert Standards for barrel and headwall details, or detail appropriate inlet.

Case 2: New culvert, standard size, non-standard fill height

- Develop front sheet with culvert notes.
- Modify the appropriate barrel standard sheet, deleting all data and details that do not apply to the project, and include the sheet in the plans.
- Refer to RCB Culvert Standards for headwall details, or detail appropriate inlet.

Case 3: New culvert, non-standard size

- Develop front sheet with culvert notes.
- Modify the appropriate barrel standard sheet, deleting all data and details that do not apply to the project, and include the sheet in the plans.
- Modify the appropriate headwall details sheet, and include the sheet in the plans, or detail appropriate inlet.

Case 4: Culvert extension, standard size, standard fill height, 0-degree skew

- Use Standard Sheets 1043s1 and 1043s2 for front sheet.
- Use Standard Sheet 1047 for detailing concrete transition details.
- Refer to RCB Culvert Standards for barrel and headwall details, or detail appropriate inlet.

Case 5: Culvert extension, standard size, non-standard fill height, 0-degree skew

- Use Standard Sheets 1043s1 and 1043s2 for front sheet.
- Use Standard Sheet 1047 for detailing concrete transition details.
- If additional barrels are required, modify the appropriate barrel standard sheet, deleting all data and details that do not apply to the project, and include the sheet in the plans.
- Refer to RCB Culvert Standards for barrel and headwall details, or detail appropriate inlet.

Case 6: Culvert extension, non-standard size, 0-degree skew

- Use Standard Sheets 1043s1 and 1043s2 for front sheet.
- Use Standard Sheet 1047 for detailing concrete transition details.
- If additional barrels are required, modify the appropriate barrel standard sheet, deleting all data and details that do not apply to the project, and include the sheet in the plans.
- Modify the appropriate headwall details sheet, and include the sheet in the plans, or detail appropriate inlet.

Case 7: Culvert extension, standard size, standard fill height, skewed

- Use Standard Sheets 1043s1 and 1043s2 for front sheet.
- Use Standard Sheet 1044 for detailing existing culvert junction section.
- Use Standard Sheet 1047 for detailing concrete transition details.
- Refer to RCB Culvert Standards for remaining barrel details, if applicable.
- Refer to RCB Culvert Standards for headwall details, or detail appropriate inlet.

Case 8: Culvert extension, standard size, non-standard fill height, skewed

- Use Standard Sheets 1043s1 and 1043s2 for front sheet.
- Use Standard Sheet 1044 for detailing existing culvert junction section.
- Use Standard Sheet 1047 for detailing concrete transition details.
- If additional barrels are required, modify the appropriate barrel standard sheet, deleting all data and details that do not apply to the project, and include the sheet in the plans.
- Refer to RCB Culvert Standards for headwall details, or detail appropriate inlet.

Case 9: Culvert extension, non-standard size, skewed

- Use Standard Sheets 1043s1 and 1043s2 for front sheet.
- Use Standard Sheet 1044 for detailing existing culvert junction section.
- Use Standard Sheet 1047 for detailing concrete transition details.
- If additional barrels are required, modify the appropriate barrel standard sheet, deleting all data and details that do not apply to the project, and include the sheet in the plans.
- Modify RCB Culvert Standards for headwall details, or detail appropriate inlet.

The designer or detailer shall discuss all unusual situations with the supervising Unit Leader.

7.2.4.2 Software

The standard plans have been designed with CulvertCalc IA, LRFD software that follows the design and detailing policies of the Bureau. For design of a nonstandard reinforced concrete box culvert the Bureau requires that the designer use CulvertCalc IA, unless the nonstandard condition does not fit within the parameters of the software. The designer shall discuss unusual design conditions with the supervising Unit Leader.

7.2.4.3 Plan preparation

When preparing plans for RCBs, the designer and detailer should set culvert lengths to the nearest one foot.

For new and replacement RCB culverts, the designer shall determine the NBIS structure length and provide an appropriate note on the TS&L stating the length. Refer to BDM 3.2.1 for guidance on calculating NBIS structure length. The cast-in-place and precast alternates for a site could have different NBIS structure lengths and each shall be noted on the TS&L for that alternate.

7.2.4.4 General

7.2.4.4.1 Excavation

Excavation quantities for culverts are determined differently depending on whether the culvert is new or is an extension and whether there are low areas along the culvert that require fill. If the culvert is new, the Iowa DOT Standard Specifications require that Class 20 excavation be computed using a width 4 feet greater than the inside width of the culvert and using side slopes of 1:1 horizontal to vertical [IDOT SS 2402.04, B, 4]. When concrete curtain walls are present additional Class 20 excavation shall be computed for each curtain wall assuming the culvert excavation extends 2 feet forward from the back of the curtain wall at its base and extends upward on a vertical plane.

For culvert extensions, the quantity of Class 20 excavation is to be computed using a width 4 feet greater than the inside width of the culvert and using vertical planes parallel with the boundaries of the structure. For long extensions where additional lanes are added and the amount of Class 20 excavation would be similar to the amount for new culverts, the excavation should be calculated with side slopes of 1:1 horizontal to vertical as for new culverts. For long culvert extensions the designer shall include notes or details in the plans describing how the Class 20 excavation was calculated.

Any Class 10 channel excavation associated with revetment installation at culvert inlets and outlets shall be included in Road Design’s quantities based on items shown in the preliminary TS&L. See BDM Article 4.5.8 for additional information.

Occasionally low areas will exist along the proposed culvert. If these areas are large, usually the road contractor is required to place Class 10 fill before the culvert contractor is allowed to begin construction.

If areas to be filled are relatively small, the designer shall place a note on the plans requiring the culvert contractor to fill and compact the areas. When this work is performed by the culvert contractor it can be designated as being incidental to the bid item "Class 20 Excavation", if there is adequate suitable Class 20 excavation available. If there is inadequate suitable Class 20, the bid item “Class 24 Excavation” is required to provide the fill material. See Figure 7.2.4.4.1 for a culvert section with fill provided by the culvert contractor.

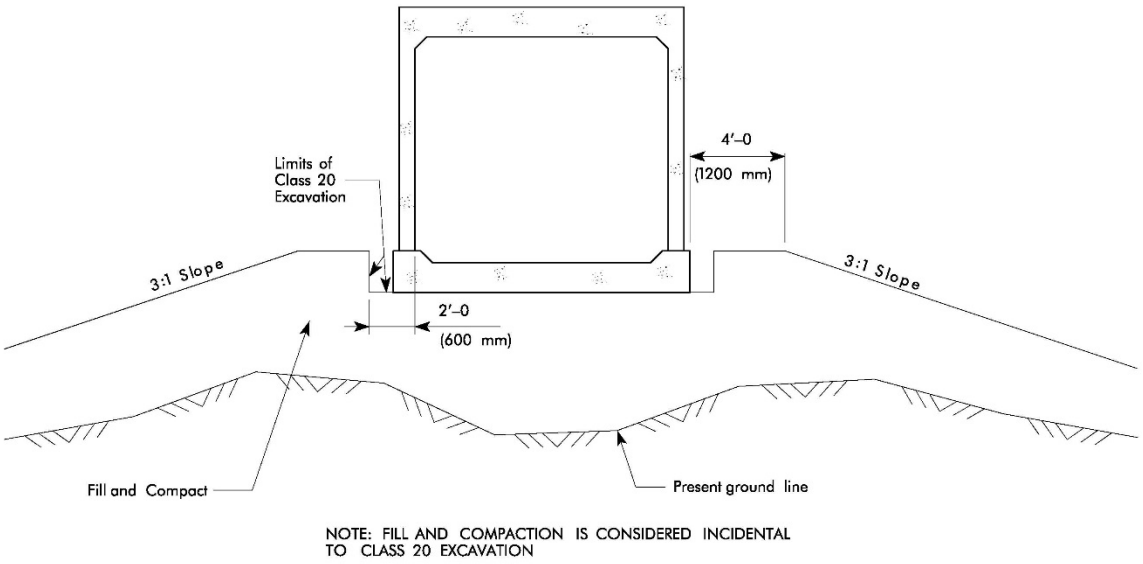


Figure 7.2.4.4.1. Fill and compaction section for fill placed by culvert contractor

The excavation limits discussed above may not be applicable for special situations such as rock excavation or granular blankets.

In some cases, additional excavation, commonly referred to as a core-out, is required below the culvert to remove unsuitable or compressible subsurface materials. The width, length, and depth of the core-out shall be determined by the Soils Design Unit. Unless otherwise specified, the excavation shall be considered Class 20 excavation with quantities being computed as described previously in this section.

7.2.4.4.2 Granular blankets and working blankets

Depending on site soil conditions, the Soils Design Unit will determine when it is necessary to place granular material below a reinforced concrete box culvert. The Soils Design Unit will use the term granular blanket for material which the contractor is required to install, however when the site soil conditions are uncertain, the Soils Design Unit will commonly use the term working blanket for the material. This indicates the material may be eliminated from the project if determined to be unnecessary at the time of construction. If bedrock is directly below a culvert, a granular blanket is always required.

If a granular blanket or working blanket is not specified by the Soils Design Unit, the Bureau's policy is to provide material for a 1’-0” thick working blanket at the bottom of the culvert excavation described in BDM 7.2.4.4.1, on all RCB projects including extensions.

Unless otherwise specified, the bid item “Granular Material for Blanket” shall be used for granular blankets and working blankets. Refer to IDOT SS 4118 for material requirements. For a working blanket, the designer shall provide an appropriate bid item reference note stating that the material is optional for construction and the contractor may request the material be eliminated from the project per contractor means and methods.

When a blanket is necessary, the Soils Design Unit will comment and provide dimensions on the geotechnical design sheets which are part of the soils package for the project. A general section through a granular blanket is shown in the commentary of this section.

The preferred policy is to have the culvert contractor install the granular blanket, in which case the detailer shall provide the details and quantities in the culvert plans. However, if the granular blanket is to be installed by the road contractor, the detailer should only add a granular blanket detail to the culvert plans for reference.

When a core-out has been specified, the Soils Design Unit will provide the backfill material requirements which typically include Macadam Stone Base or a similar gradation.

Refer to Section 7.3.4.3 for additional granular material requirements for precast RCB culverts.

7.2.4.4.3 Keyways

At construction joints, such as those shown in Figures 7.2.4.5.3-1 7.2.4.5.2.2, the detailer shall provide keyways to link the two components together. The sides of the keyway form shall be beveled about 10 degrees so that the form is easier to remove. The bevel dimensions for a typical dimension lumber keyway form are shown in Figure 7.2.4.4.3.

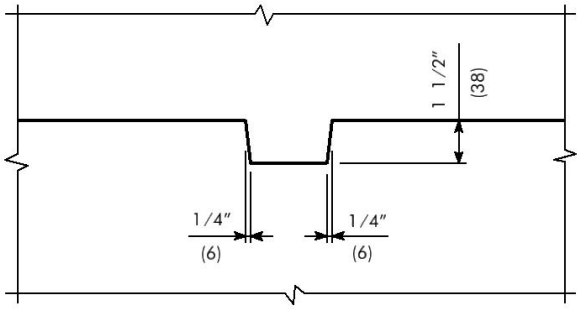


Figure 7.2.4.4.3. Typical keyway detail

7.2.4.4.4 Reinforcement

[AASHTO-LRFD 5.6.3.3, 5.10.1, 5.10.3.1.1, 5.10.3.2, 5.10.6, 9.7.3.2]

For barrels and headwalls the minimum concrete cover over reinforcing steel shall be as shown in Table 7.2.4.4.4-1. The cover amounts in the table meet or exceed the cover required in the AASHTO LRFD Specifications [AASHTO-LRFD 5.10.1].

Table 7.2.4.4.4-1. Minimum clear cover

Location		Clear cover
Rebar edge to concrete surface	Typical minimum	2 inches
	Bottom of floor	3½ inches
	Top of floor	2¼ inches
	Roadway on top slab	2½ inches
Rebar end to concrete surface	Typical horizontal bar	2 inches
	Top of vertical bar	2 inches
	Bottom of vertical bar	3 inches, or 3½ inches if overall height of culvert barrel is not to a full inch

In culvert barrel plans, uniform symbols make reinforcing bar groups easier for the contractor, fabricator, and detailer to identify. Therefore, use the symbols given in Table 7.2.4.4.4-2.

Table 7.2.4.4.4-2. Reinforcing bar group symbols

Location	Symbol
Slab transverse	k
Slab longitudinal	e
Wall vertical	a
Wall horizontal	b
Floor transverse	m
Floor longitudinal	f

Except for large culverts and deep fills, the designer shall limit the maximum bar size to #9. The minimum spacing for non-alternating bars shall be 6 inches. For alternating bars there should be no more than a three-bar-size change between adjacent bars, and for alternating bars with cutoffs not exceeding 50% there should be no more than a one-bar-size change between adjacent bars.

The minimum area of reinforcing in each exposed face of slab, walls, and floor shall meet the AASHTO requirements for shrinkage and temperature [AASHTO-LRFD 5.10.6]. Minimum bar size shall be #4. Spacing shall not exceed three times the slab, wall, or effective floor thickness, 18 inches, or 12 inches for any component more than 18 inches thick.

The minimum area of reinforcement designed for flexure shall meet the AASHTO LRFD Specifications [AASHTO-LRFD 5.6.3.3]. Reinforcement designed for flexure also shall be spaced no farther apart than 1.5 times the slab, wall, or effective floor thickness, 18 inches [AASHTO-LRFD 5.10.3.2], or 12 inches for any component more than 18 inches thick.

In slabs, walls, and floors, parallel reinforcement designed for flexure shall be spaced no closer than 6 inches for non-alternating bars or 4.5 inches for alternating bars. In typical cases these minimums are larger than required by the AASHTO guidelines [AASHTO-LRFD 5.10.3.1.1].

For radial placement the reinforcement spacing may be a minimum of 3 inches. More information for radial placement is given in the article for transverse reinforcement [BDM 7.2.4.5.4.2].

When the height of fill above the top slab is 2 feet or less, the designer shall provide distribution steel in the bottom of the top slab according to the AASHTO guidelines [AASHTO-LRFD 9.7.3.2]. Maximum spacing of the reinforcement shall not exceed 18 inches.

7.2.4.5 Barrels

7.2.4.5.1 Roadway on slab

For reinforced concrete box culverts with no fill, the slab is essentially a bridge deck and requires special detailing as described below.

- The top slab surface shall be finished with macro texture parallel with the centerline of roadway except within 2 feet of the parapet [Iowa DOT SS 2301.03, H, 3]. Use CADD Note E624/M624 [BDM 13.7.2].
- The approach slab shall be tied to the culvert with #5 deformed stainless steel bars at 2 feet on center as shown in Figure 7.2.4.5.1. Cost for the bars is to be incidental to the price for bid item “Reinforcing steel – epoxy coated”. Use CADD Note E634/M634 [BDM 13.7.2].
- The joint between the culvert and approach slab shall be an ‘E’ joint [DB SRP PV-101].
- Depending on construction scheduling it may be necessary for the contractor to protect the edge of the top slab at the approach pavement. In order to require the necessary protection use CADD Note E625/M625 [BDM 13.7.2].
- Provide 2.5 inches cover over the top slab reinforcement by increasing the thickness of the top slab by 0.5 inch.
- All reinforcement in the slab and corbel and all wall reinforcement extending into the slab shall be epoxy coated. Vertical wall reinforcement needs to be spliced to allow for variable thickness of the slab. Provide Class B lap lengths for the epoxy coated vertical bars as given in Table 7.2.4.5.1.

Table 7.2.4.5.1. Minimum lap for vertical epoxy coated bars

Bar size	Class B Lap length, feet-inches
#4	2’-0”
#5	2’-5”
#6	3’-7”
#7	4’-2”
#8	4’-10”
#9	5’-11”

Table note:

Lap length is based on a Class B splice with material strengths of f'_c = 4 ksi and f_y = 60 ksi, an epoxy bar condition, and center-to-center bar spacing of at least 6 inches and

clear cover of at least 2 inches measured in the direction of the spacing. Higher material strengths, smaller spacing, or less clear cover will require longer lap lengths.

- Spacing of the #4 bent corbel reinforcement shall be the same as the spacing of the vertical wall reinforcement so that it can be tied efficiently. Maximum spacing shall be 15 inches.
- Add the approach pavement joint detail in Figure 7.2.4.5.1 to the plans.

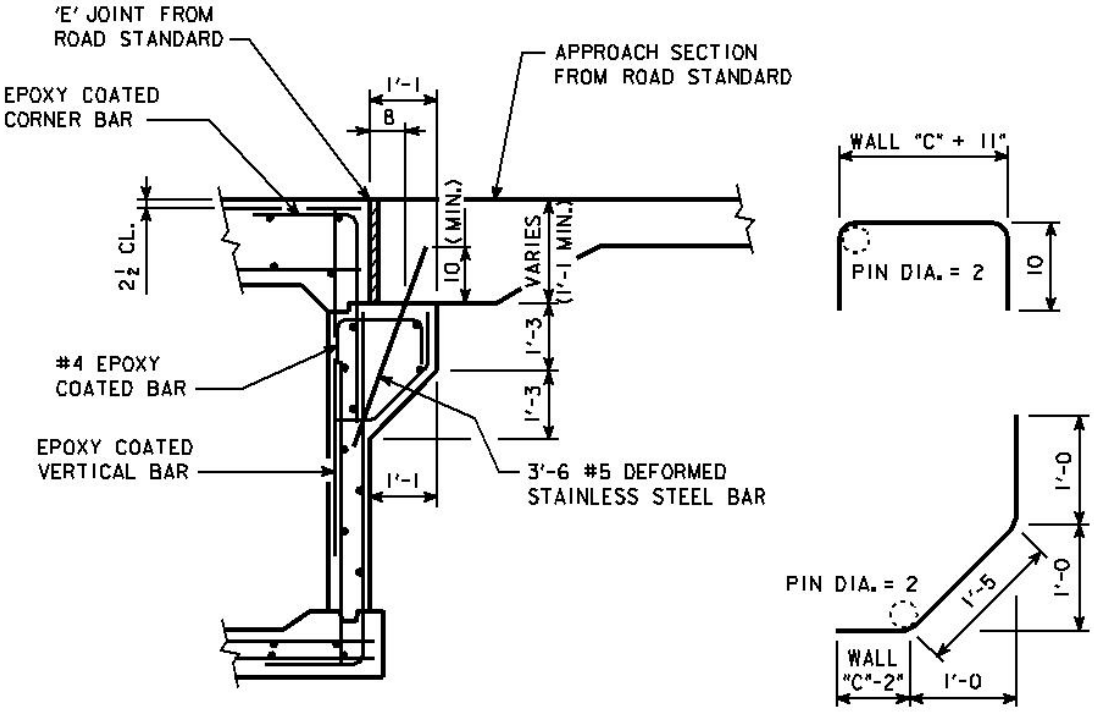


Figure 7.2.4.5.1. Approach pavement joint detail

7.2.4.5.2 Construction joints

7.2.4.5.2.1 Transverse

Whenever possible, construction joints for intermediate culvert barrel sections should be placed at equal intervals and should be a maximum of 38 feet apart. Because the current single, twin, and triple barrel culvert standard plans are detailed on a repeating 3-foot module it is preferable that the intermediate barrel sections be of a compatible length such as 38 feet, 35 feet, 32 feet, etc.

When the fill height above the culvert is 5 feet or less, if at all possible, locate culvert joints outside of the pavement boundaries. Uneven settlement of single barrel joints can cause damage in the pavement above. The location of barrel joints is more critical for multiple barrels because wide culverts tend to settle more unevenly than narrow culverts. Fill heights of 6 feet and more provide better distribution of pavement loads, thereby decreasing uneven settlement and pavement damage.

If a culvert joint must be inside the pavement boundaries, do not place the joint at the centerline of roadway. With the off-center joint, if the pavement were damaged by culvert settlement, one lane could be kept open during repairs.

End barrel sections next to the headwalls should have a minimum length of 10 feet. This minimum length helps with the distribution of settlement and secures the end section in the earth slope. The summation of the lengths of the frost troughs for the headwall and end barrel section should be a maximum of 38 feet. This maximum length is based on the length of the frost trough formwork available to most contractors.

When working with larger skewed culverts, it may not be possible to keep the length of the end barrel sections within the limits specified above. In this case it is desirable to keep the short wall, measured along inside face, a minimum of 5 feet long from back of parapet to construction joint.

7.2.4.5.2.2 Longitudinal

The standard detail at the top of each culvert wall is a permissible construction joint, with the option of lowering the joint with the engineer's approval.

For situations where water flow may make the construction of a large multiple box culvert difficult, provide a permissible longitudinal construction joint so that the floor can be constructed in two stages, as shown in Figure 7.2.4.5.2.2. Guidelines for locating the joint are as follows.

- Place the construction joint outside the short m7 bars.
- Place the construction joint between the longitudinal bars.

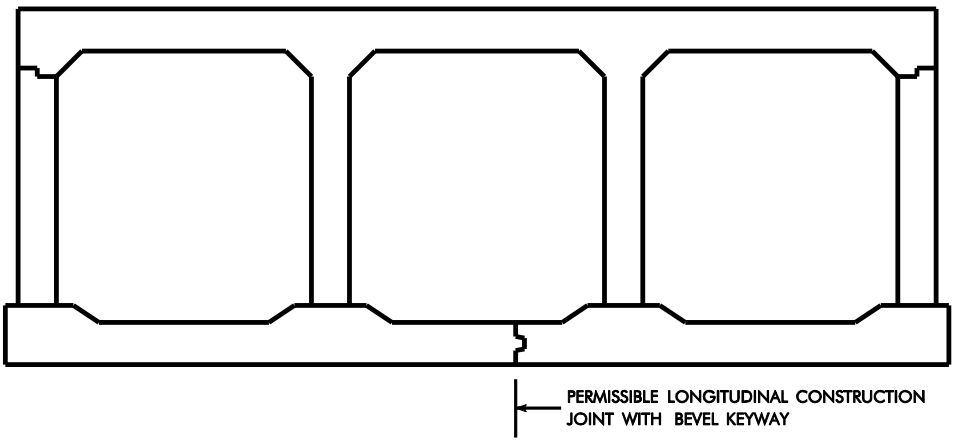


Figure 7.2.4.5.2.2. Permissible Longitudinal Construction Joint

7.2.4.5.3 Bell joints

In cases where large culvert settlements or other significant soil movements may occur, ordinary box culvert joints can open and cause erosion and related distress. A design feature to prevent such problems is a bell joint. The designer shall provide culvert barrel bell joints wherever any of the following conditions occur.

- The Soils Design Unit anticipates settlement of 12 inches or greater for single box culverts and 6 inches or greater for twin and triple box culverts. If such large settlements occur in the area where the culvert is constructed, the culvert construction joints tend to open up in the floor and walls. This allows the fill to erode through the open joints and cause increased settlement.
- Design fill heights are 35 feet or more. If embankments with such large fill heights are built on incompressible soil or bedrock, settlement may not be a problem, but some subsidence may occur within the fill itself. This subsidence will cause longitudinal forces to develop and pull the barrel construction joints apart.
- When estimated settlements are not available from the Soils Design Unit, the designer should use bell joints for single barrel culverts with 25 feet or more of fill and for multiple barrel culverts with 15 feet or more of fill.
- In cases where extensions are being added to an existing box culvert with bell joints, the designer should strongly consider providing bell joints on the extensions as well. Additional information and details for the extension are given in the bell joints article for extensions [BDM 7.2.4.9.3].

If the need for bell joints is uncertain, it is best to use them to ensure against possible culvert joint deterioration.

If bell joints are locked into bedrock they will not rotate and function as designed. Therefore, if bedrock is present in the streambed, the designer should adjust the flowline elevation so that the entire bell joint is above the surface of the rock, or the designer should require the rock to be excavated and backfilled with suitable material. Generally bell joints would not be used in this situation. The designer shall verify any decision with the Soils Design Unit.

With culvert settlement, a bell joint will open, thus reducing bearing length within the joint. As a rule of thumb, the designer should provide a minimum bearing length of 9 inches. This minimum will allow a maximum opening of 1 inch for a standard 10-inch bell joint [BSB SS CBJ 1-20] 3 inches for a standard 12-inch bell joint [BSB SS CBJ 2-20, TWCBJ 1-20] and 6 inches for a standard 15-inch bell joint [BSB SS CBJ 3-20, CBJ 4-20, TWCBJ 2-20, TRCBJ 1-20, TRCBJ 2-20], as shown in Figure 7.2.4.5.3-1.

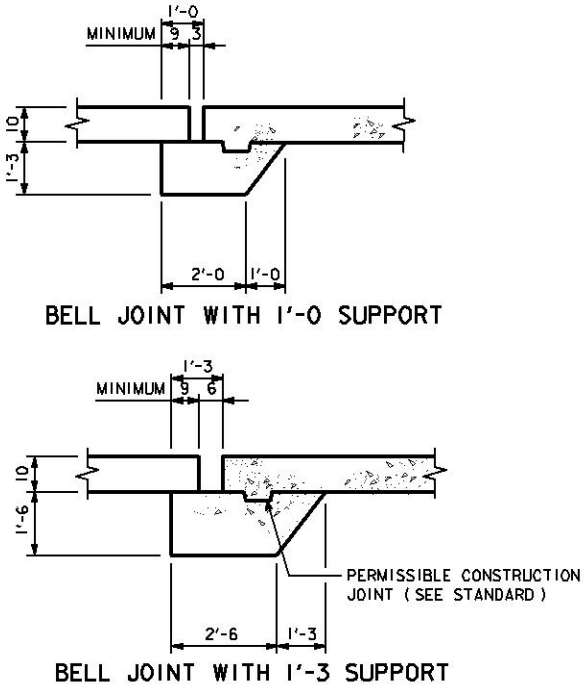


Figure 7.2.4.5.3-1. Allowable bell joint openings with standard details

The designer shall consult with the Bridge Project Development Engineer if bearing at a bell joint will be less than 9 inches. It may be necessary also to consult with the Soils Design Unit regarding alternatives such as over-excavation, geopiers, or non-standard bell joints.

Longitudinal reinforcing is not permitted through bell joints. The "m1" and “m9” floor bars, in the area of the bell joints, must be shortened on the design plan or by field cutting to prevent them from locking up the bell joint.

The designer should include a detail similar to Figure 7.2.4.5.3-2 in the plans showing the correct orientation of the bell joint with flow and the permissible construction joint to simplify construction [BSB SS CBJ 4-20]. For reference and use on typical reinforced concrete box culvert projects, bell joint details are provided in standard plans [BSB SS CBJ 1-20 to CBJ 4-20].

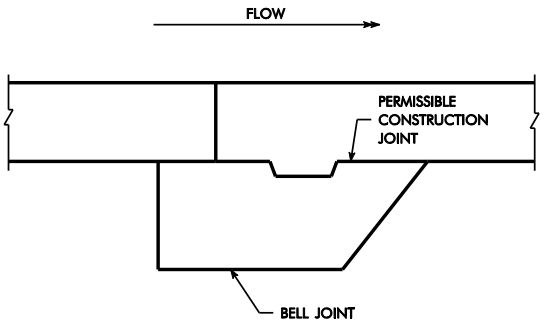


Figure 7.2.4.5.3-2. Typical barrel bell joint with flow orientation

If the top slab, wall, or floor thickness for a specific project changes from the bell joint standard sheets [BSB SS CBJ 1-20 to CBJ 4-20], the designer shall modify the standard. The changes shall reflect the new slab, wall, and floor thicknesses and new concrete quantities. The modified bill of reinforcing steel should reflect the corrected bar lengths and weight, and the bent bar details should be corrected. All information for other culvert sizes should be deleted from the sheet. The designer should replace the standard sheet title block with the one used for the design and should include this modified bell joint sheet as a design sheet in the plans.

When the culvert is designed for varying fill heights, the bell joint details must address the change in floor and slab thickness, but the designer shall not reduce the thickness of the designed culvert section. Figure 7.2.4.5.3-3 shows details for changes in thickness in barrel walls.

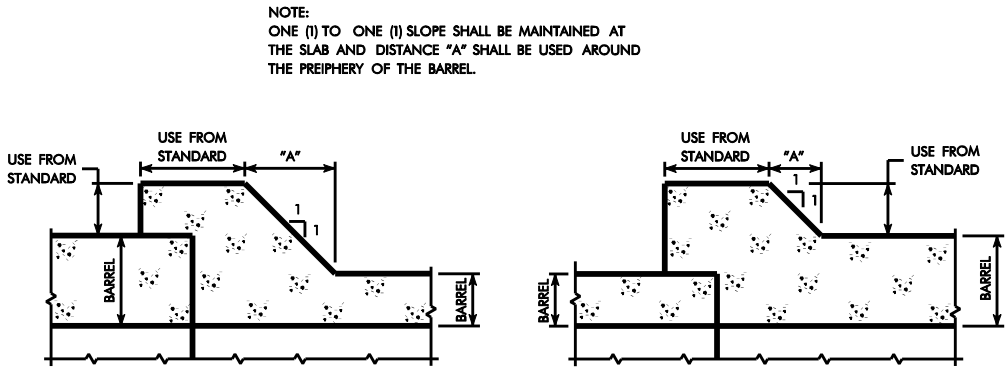


Figure 7.2.4.5.3-3. Barrel bell joint details for change in floor, wall, and slab thickness from thick to thin and from thin to thick

When both the width and height of reinforcing bars in the transverse direction exceed 6 feet the bent bars will be difficult to ship. Therefore, in those cases, the designer shall provide U-bars and straight bars with laps as shown in Figure 7.2.4.8.1-3 and as sized in Table 7.2.4.8.1 [BSB SS CBJ 1-20 to BSB SS CBJ 5-20].

7.2.4.5.4 Horizontally curved alignments

7.2.4.5.4.1 Layout

For ease of cast-in-place construction on curved alignments, culvert contractors prefer straight segments. The AASHTO publication, *Highway Drainage Guidelines* [BDM 7.1.5.2], notes that bends up to 15 degrees do not affect flow significantly and thus are acceptable when needed. For these reasons the

Bureau designs horizontally curved culverts as straight segments with a maximum centerline barrel section length of 38 feet and with maximum bends of 15 degrees, unless permission is granted for sharper bends.

The following are additional guidelines:

- All bent sections shall have equal lengths between bends. Also, to make detailing and construction easier, the Bureau prefers that the distance between the bend locations and the joint locations be symmetrical for each barrel section as shown in Figure 7.2.4.5.4.1.
- A bend shall be 5, 10, or 15 degrees. Bends greater than 15 degrees are allowed only when approved by the Preliminary Bridge Engineer.
- For barrel spans of 6 feet or less, the shortest barrel wall shall have a minimum length of 3 feet from the bend, as shown in Figure 7.2.4.5.4.3-1. The minimum length should be increased slightly so that the barrel length at the centerline of the culvert is dimensioned to the nearest whole inch in foot-inch format.
- For barrel spans of 8 feet or more, the shortest barrel wall shall have a minimum length of 5 feet from the bend, as shown in Figures 7.2.4.5.4.3-2, 7.2.4.5.4.4-1, and 7.2.4.5.4.4-2. The minimum length should be increased so that the barrel length at the centerline of the culvert is dimensioned to the nearest whole foot in foot-inch format.

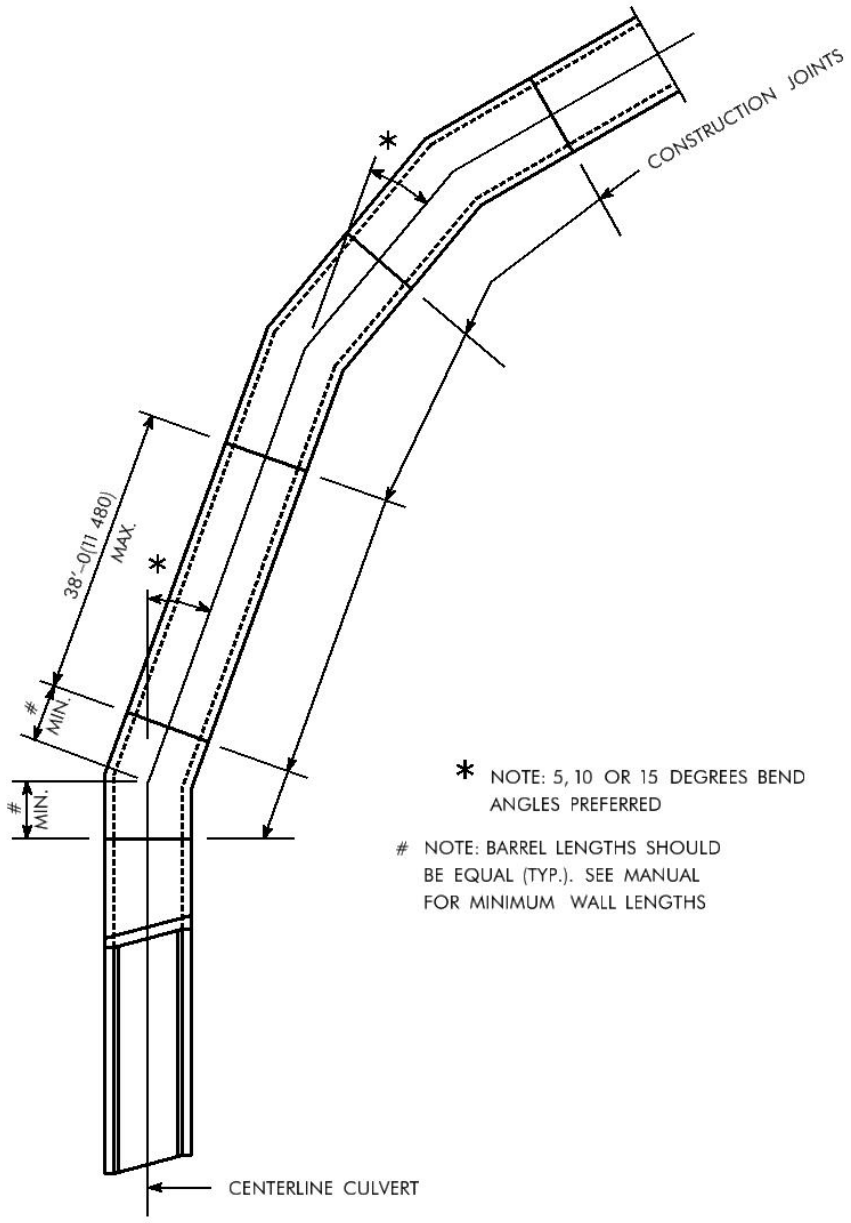


Figure note:

- Bends greater than 15 degrees require the approval of the Preliminary Bridge Engineer.

Figure 7.2.4.5.4.1. Example layout for a straight segment culvert on a horizontally curved alignment

7.2.4.5.4.2 Transverse reinforcement

The Bureau has the following guidelines for detailing transverse reinforcement at culvert bends.

- Maintain normal transverse reinforcing steel patterns to the front face of the shortest barrel wall for each barrel. Add flared bars to maintain design spacing at the wall joints and mid-span of the barrel.

- Whenever possible, keep the bar spacing and length pattern through the bend. Bar spacing should be a minimum of 3 inches center-to-center and a maximum of one-and-one-half times the design bar spacing.
- When the pattern cannot be maintained through the bend, drop the pattern and make the bar lengths as long as possible following the guidelines for minimum and maximum spacing given above.
- For ease of construction, keep the number of bars to a minimum and the reinforcing layout as simple as possible. Draw different bar arrangements to determine the best layout.
- Check to ensure that at maximum bending moment locations, such as midspan for positive bending and above interior wall for negative bending, the spacing of the reinforcing steel does not exceed the spacing required for strength.

The transverse reinforcing layouts for twin barrel culverts in Figures 7.2.4.5.4.2-1 through 7.2.4.5.4.2-4 were developed to minimize the number of variable bars and should be used in detailing the slabs and floors of single and multiple bent barrel sections.

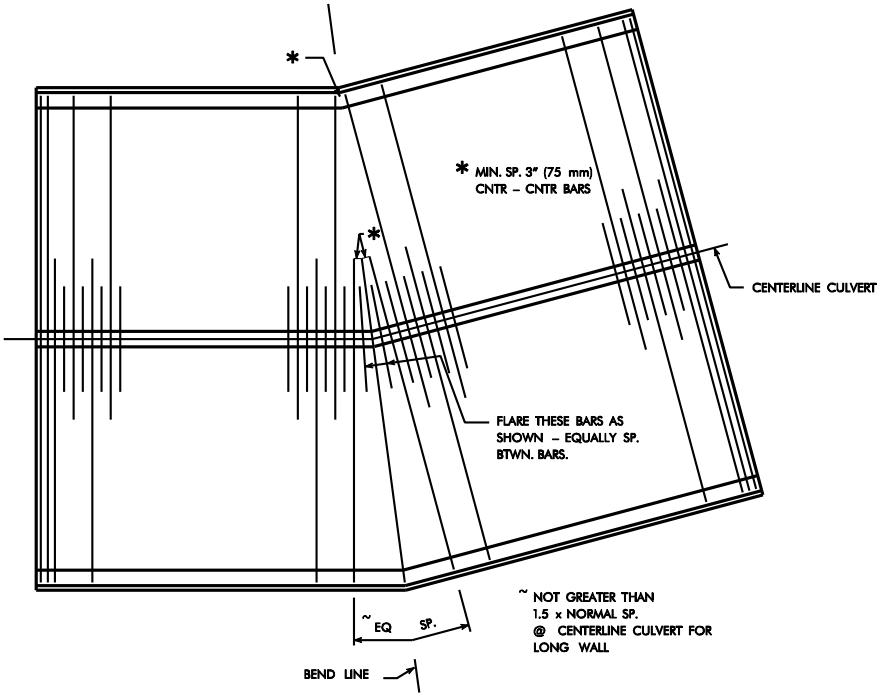


Figure 7.2.4.5.4.2-1. Transverse reinforcing layout for top of slab

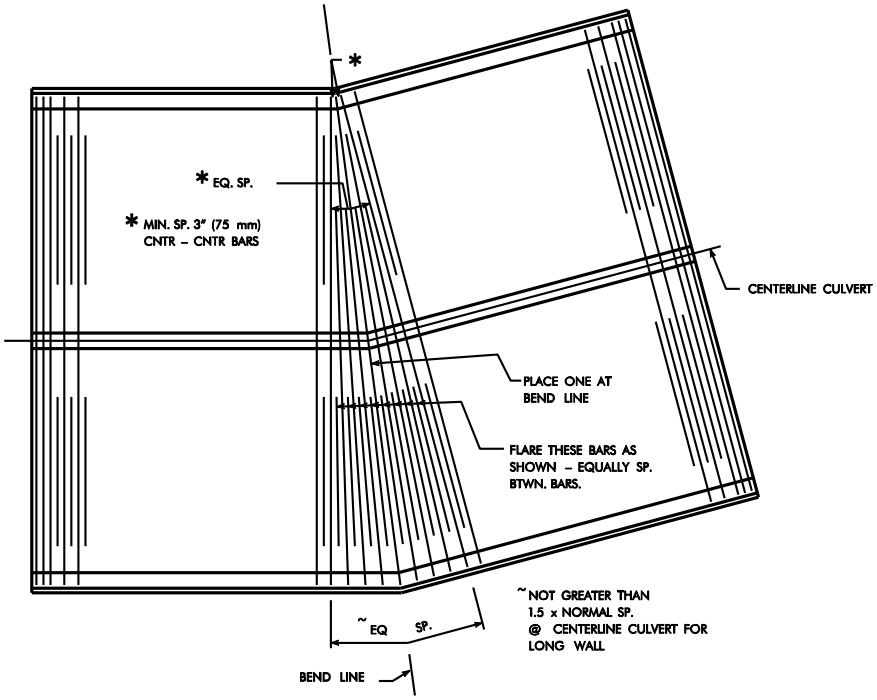


Figure 7.2.4.5.4.2-2. Transverse reinforcing layout for bottom of slab

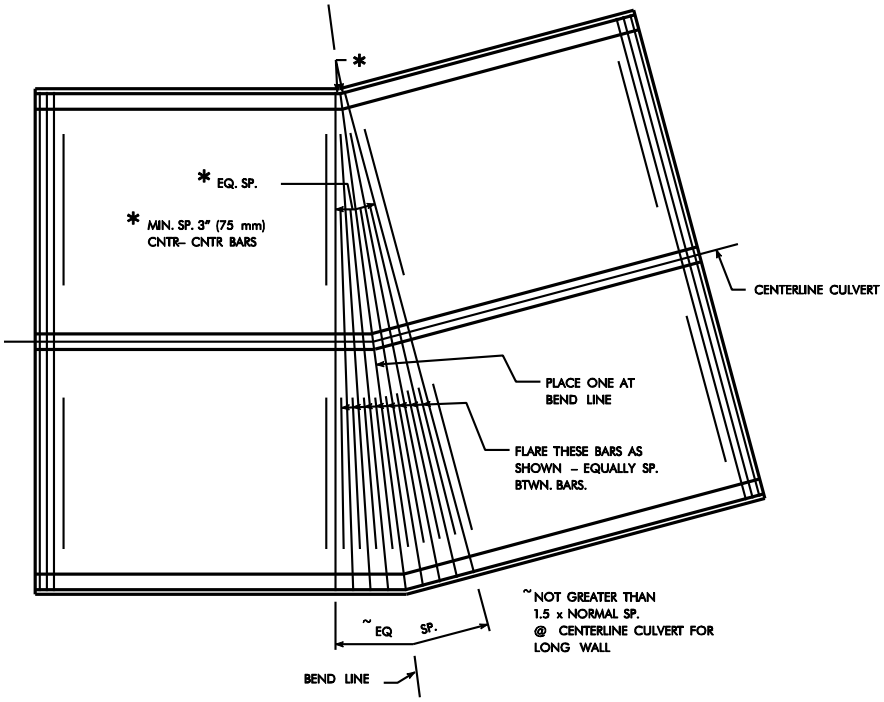


Figure 7.2.4.5.4.2-3. Transverse reinforcing layout for top of floor

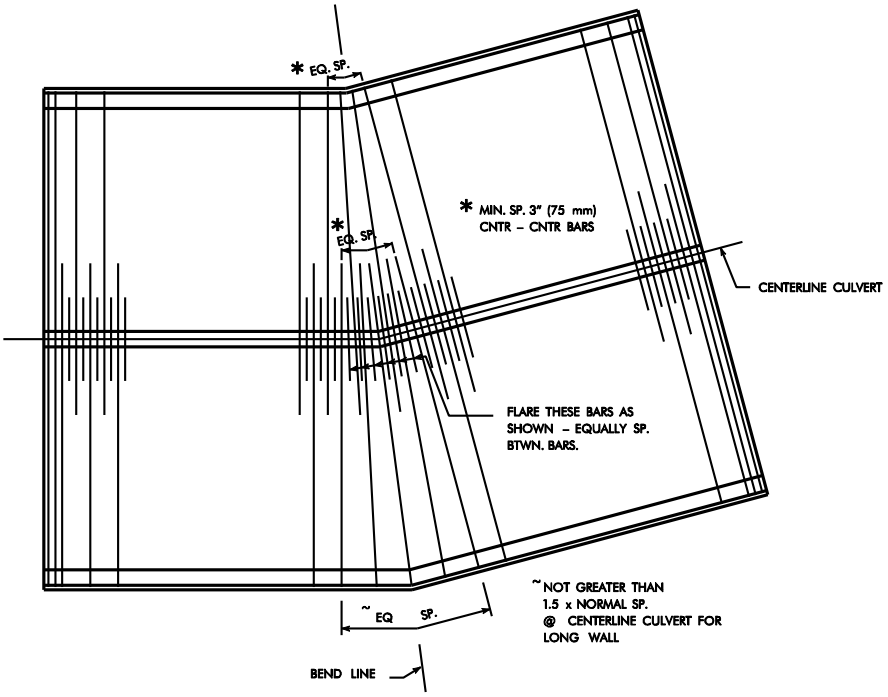


Figure 7.2.4.5.4.2-4. Transverse reinforcing layout for bottom of floor

7.2.4.5.4.3 Longitudinal reinforcement for single barrels

When detailing longitudinal bars for single barrel bends, follow the bar bend layouts shown in Figures 7.2.4.5.4.3-1 and 7.2.4.5.4.3-2. See also the guidelines for multiple barrels [BDM 7.2.4.5.4.4].

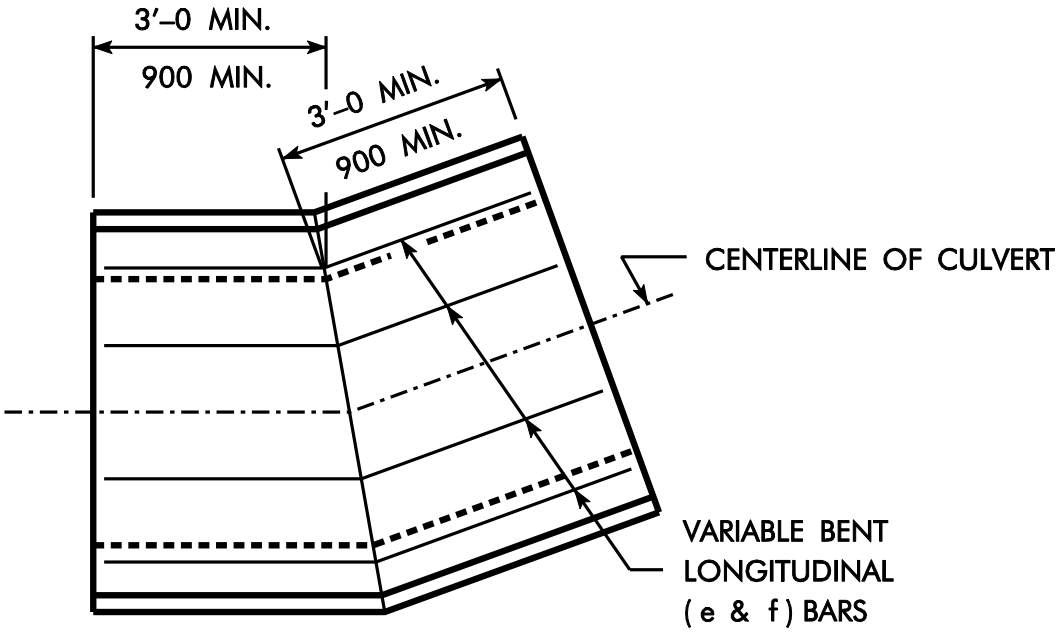


Figure 7.2.4.5.4.3-1. Longitudinal bar bends for 4-foot to 6-foot spans

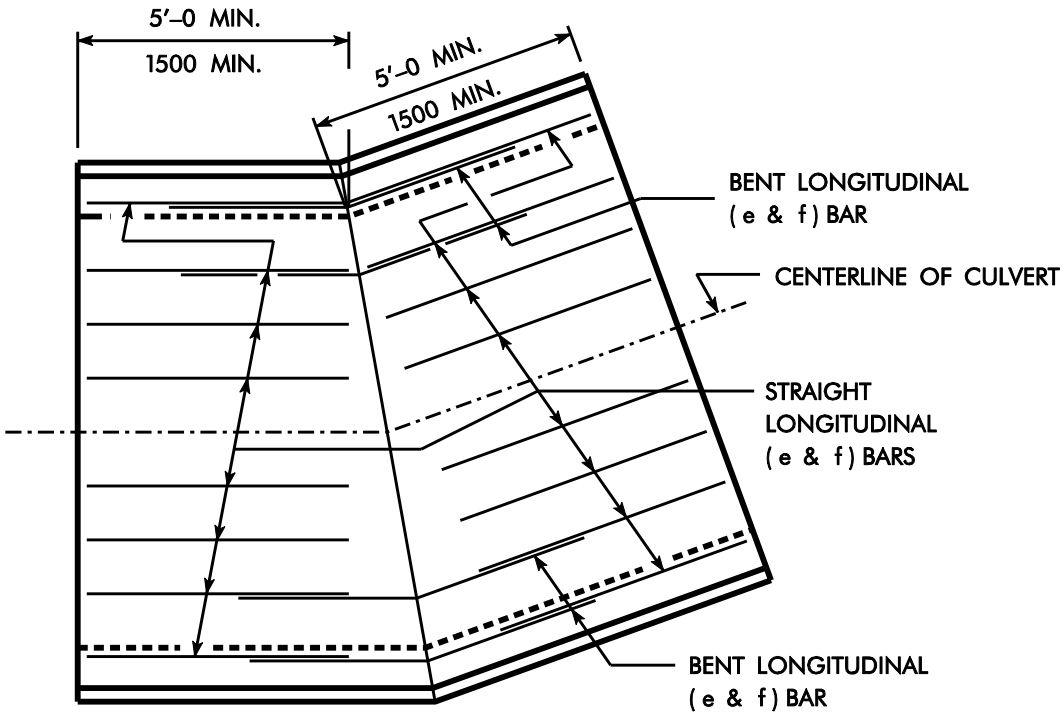


Figure 7.2.4.5.4.3-2. Longitudinal bar bends for 8-foot to 12-foot spans

7.2.4.5.4.4 Longitudinal reinforcement for multiple barrels

Longitudinal wall reinforcement for multiple barrel culverts is detailed differently from longitudinal slab and floor reinforcement. The barrel wall horizontal (b) bars are to be made up of single bent bars and are not to be spliced with bent bars. For the bars placed in each face, the bar lengths are determined using the centerline wall length. The horizontal bars in each wall will have a different length and bar designation.

For culvert barrel spans of 6 feet or less the longitudinal (e & f) bars in the slab and floor should be bent and of variable length.

For culvert barrel spans of 8 feet or more the longitudinal (e & f) bars in the slab and floor should be straight bars of constant length for each barrel and bent bars with variable lap lengths as shown in Figures 7.2.4.5.4.4-1 and 7.2.4.5.4.4-2. The following are additional guidelines:

- The length for the straight longitudinal (e & f) bars in the slab and floor should allow 2 inches clear at the barrel joint end and extend to where the front face of the short barrel wall bends.
- The bent longitudinal (e & f) bars in the slab and floor are to lap the straight longitudinal bars with the lap shown for the bar size in Table 7.2.4.5.4.4. If the concrete thickness below the bar exceeds 12 inches, use the Top Bar lap from the table. There will be one bent bar length for each of the bar sets: top slab, bottom slab, top floor, and bottom floor reinforcement. (This also will be the case for single barrel culverts.)
- The straight longitudinal bars will change length in each barrel as shown in Figures 7.2.4.5.4.4-1 and 7.2.4.5.4.4-2. The bent longitudinal bars will remain one length for all barrels.

Table 7.2.4.5.4.4. Minimum longitudinal (e & f) bar laps

Bar size	Top Bar Lap (1) Feet-inches	Other Bar Lap (1) Feet-inches
#4	1’-7”	1’-3”
#5	2’-0”	1’-6”
#6	2’-5”	1’-10”

Table notes:

(1) Lap length is based on a Class A splice with material strengths of f'_c = 4 ksi and f_y = 60 ksi, a black bar condition, center-to-center bar spacing of at least 6 inches, and clear cover of at least 2 inches measured in the direction of the spacing. Higher material strengths, epoxy coating, smaller spacing, or less clear cover will require longer lap lengths.

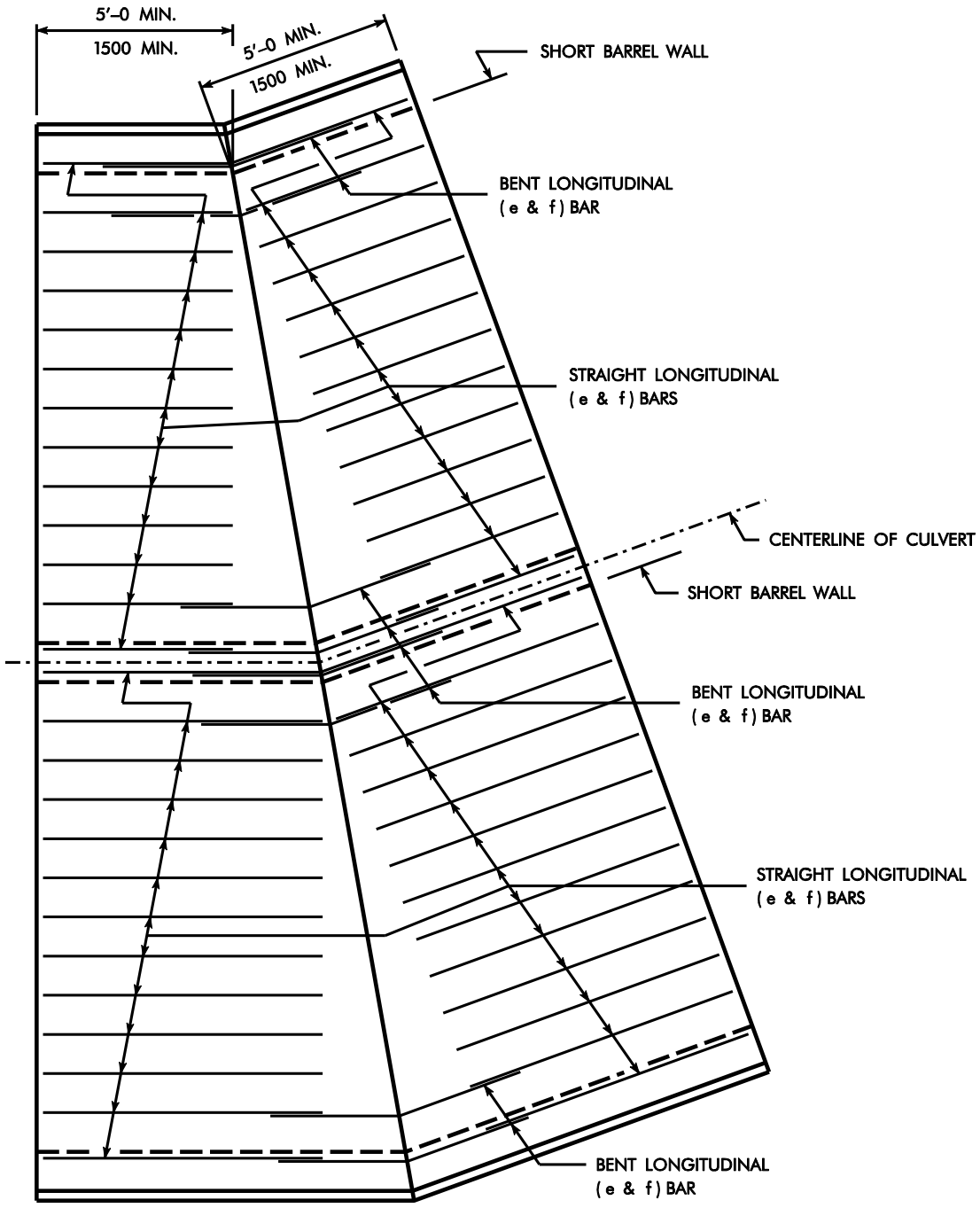


Figure 7.2.4.5.4.4-1. Longitudinal bar bends for 12-foot span twin culvert

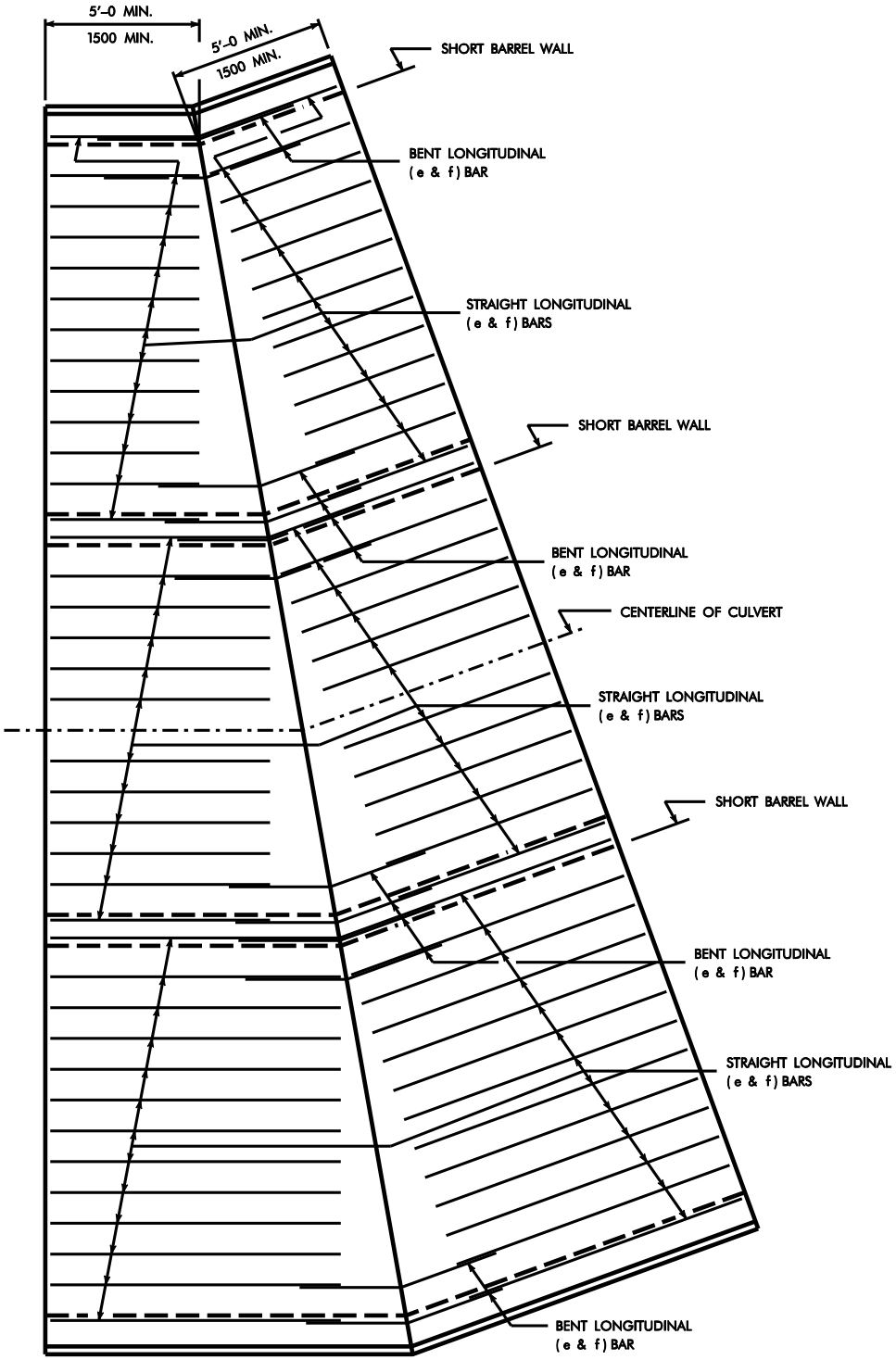


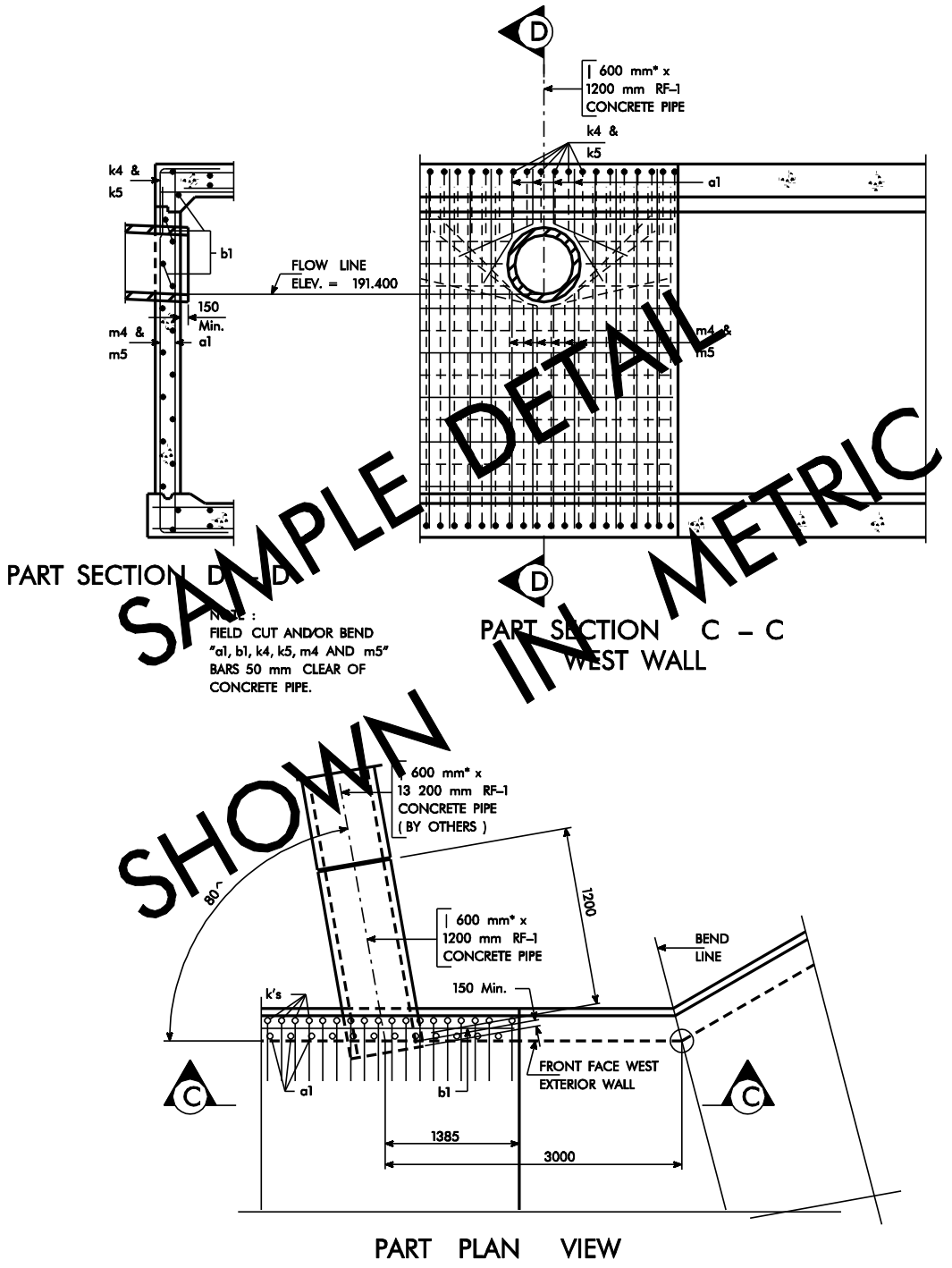
Figure 7.2.4.5.4.4-2. Longitudinal bar bends for 12-foot span triple culvert

7.2.4.5.5 Wall penetrations

7.2.4.5.5.1 Pipes

As needed, the preliminary designer will designate locations where openings for reinforced concrete pipes (RCPs) are to be provided in the reinforced concrete box culvert walls or top slab. Bureau policy is for the pipe sections to be cast in the wall or slab during the box culvert construction.

For pipes in walls, give the flow line elevation of the proposed pipe, and reference its location with respect to the back face of the parapet. For pipes in the slab, reference the location with respect to the back face of the parapet and the centerline of the culvert. The end of the pipe shall extend a minimum of 6 inches past the inside face of the culvert wall. The maximum length of pipe to be cast into the wall should be 4 feet. See Figure 7.2.4.5.5.1 for a sample detail.



SAMPLE DETAIL SHOWN IN METRIC

Figure notes:

- For pipes 48 inches and larger, use reinforcing shown in Figure 7.4.4.8.1.
- Place a note on the plans similar to CADD note E633 or M633 [BDM 13.7.2].

Figure 7.2.4.5.5.1. Sample detail for a concrete pipe through a culvert wall

The portion of the pipe that is cast into the culvert wall or slab shall be incidental to the cost of structural concrete. The item reference list should include the size and length of the pipe.

7.2.4.5.5.2 Weep holes

In cases such as a nearby natural spring, high water table, or use of a drainage blanket where it is advisable to reduce hydraulic pressure on a reinforced concrete box culvert, the Soils Design Unit or preliminary designer will recommend that weep holes be placed in exterior walls. The 4-inch diameter weep holes normally are placed in pairs, with the bottom hole one foot above the flow line. The top hole is placed one foot above the bottom hole and offset one foot, as shown in Figure 7.2.4.5.5.2-1. Typically, there will be one set of weep holes per 38-foot barrel section.

Each hole is covered with a rodent screen consisting of a 24-inch square by ¼-inch galvanized hardware cloth centered on the weep hole. Normally the culvert contractor is required to place porous backfill over the weep holes, as shown in Figure 7.2.4.5.5.2-2, and also to furnish and place special backfill material when completing the Class 20 excavation.

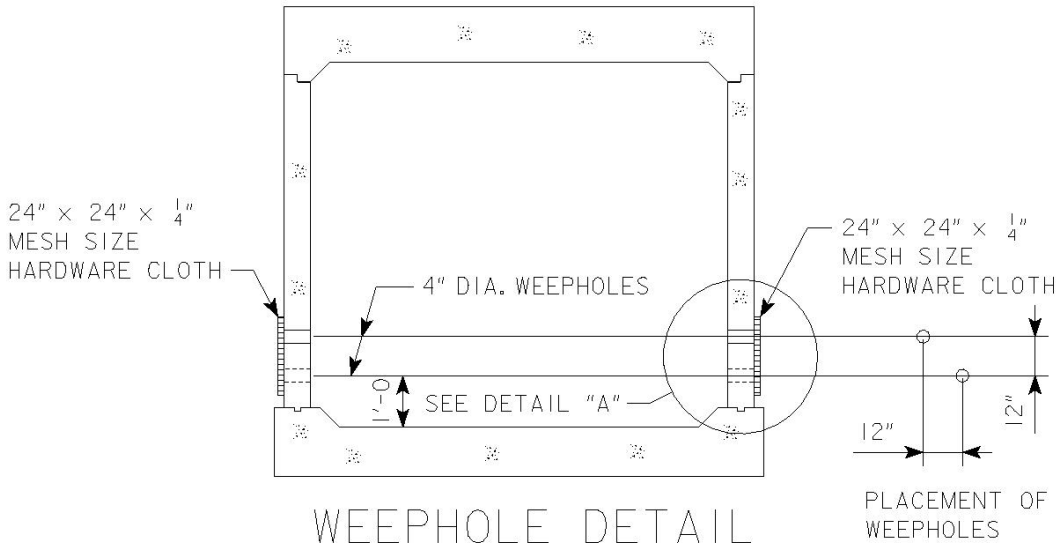


Figure 7.2.4.5.5.2-1. Exterior wall weep hole detail

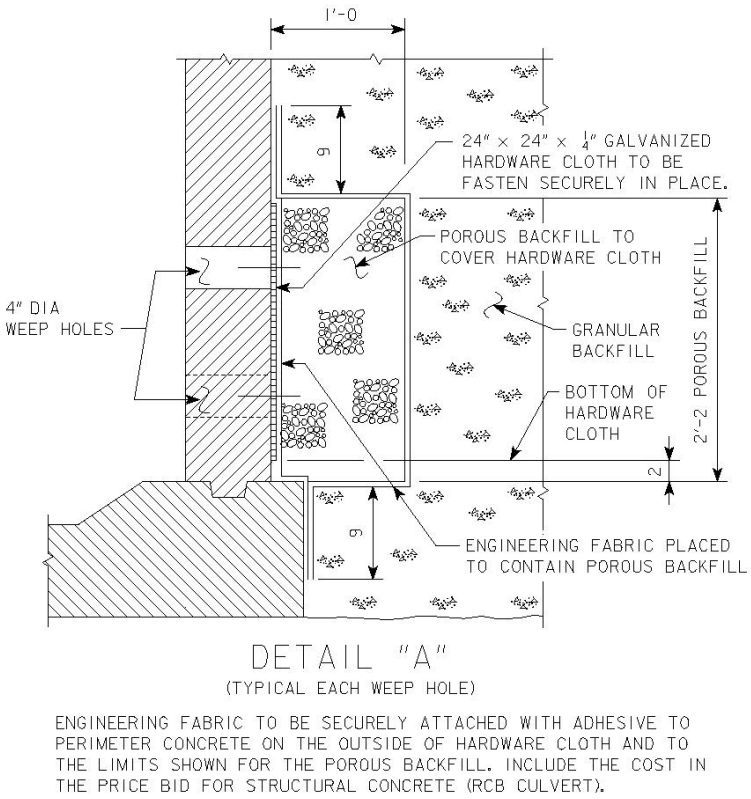


Figure 7.2.4.5.5.2-2. Typical individual weep hole detail

7.2.4.5.6 Settlement and camber

Reinforced concrete box culverts often are placed in embankments that will settle as new loads compress existing soil and/or embankment fill. The Soils Design Unit will provide the culvert settlement estimates needed for final design.

If the anticipated settlement is zero, the designer should provide the note “Anticipated Settlement = Negligible” under the longitudinal section along the centerline of the culvert.

If the estimated settlement for a culvert is 6 inches or more, the designer shall camber the culvert. Settlement is considered to be zero at the toes of the fill slopes and maximum at the roadway shoulder lines. Therefore, the camber should be set as zero at the inlet and outlet flow lines and as the maximum settlement at the shoulder lines, with linear interpolation between any set of two points. The designer should give the flow line elevation at each cambered bell joint and provide a note under the longitudinal section along the centerline of the culvert, “Anticipated Settlement = ___ feet”, for the maximum settlement. See BDM 7.2.4.5.3 regarding the need for bell joints.

7.2.4.6 Headwalls

Transitions between different wing and adjacent barrel wall thicknesses are handled differently for single, twin, and triple RCB culverts. The Single-, Twin-, and Triple Reinforced Concrete Box Culvert Standards include transition wall details on sheets RCB G3-20, TWRCB G3-20, and TRRCB G3-20, respectively.

7.2.4.7 Inlets

7.2.4.7.1 Trash racks

As necessary for unusual site conditions, the preliminary designer will add a steel pile trash rack to the situation plan for a reinforced concrete box culvert. The trash rack is placed across the streambed upstream from the culvert and is intended to prevent large trees or other large debris from plugging the culvert inlet.

The length of the trash rack is governed by the size of the culvert and the width of the stream. A typical trash rack is made from HP 10 x 42 piles spaced about 10 feet apart in a line across the stream. The piles normally are driven to a specified elevation, the tops are prepared by drilling or burning and reaming holes for bolts, and a pile section is then bolted horizontally to the upstream side of each driven pile with four galvanized 7/8 inch diameter high strength bolts, nuts, and washers.

Designers and detailers should check all available soil borings for the elevation of bedrock below the stream bed elevation. The piles must be driven deep enough in soil to develop lateral strength to resist the debris load.

For an example of a typical trash rack see the plans for Montgomery 285 on Iowa Highway 48.

7.2.4.7.2 Debris racks

When necessary, Preliminary Bridge Design Unit will add a debris rack to the inlet end of a culvert. A debris rack is relatively lightweight and intended to prevent plugging of a culvert by ordinary trash and debris. The designer shall contact the Preliminary Bridge Design Unit to discuss design criteria.

The Construction and Materials Bureau recommends that debris racks be made with smooth ½-inch or 5/8-inch diameter steel bars meeting the requirements of commercial grade, low carbon steel, AASHTO M1020. The designer shall note on the plans that the racks are to be fabricated before galvanizing.

When detailing debris racks the designer should be aware of the size limitations of available galvanizing kettles. The table below gives usable medium and large kettle sizes for galvanizers in Iowa and adjacent states.

Table 7.2.4.7.2. Usable sizes of galvanizing kettles in Iowa and adjacent states[1]

General Kettle Size Category	Number of Kettles Available in 2009	Length, feet	Width, feet	Depth, feet
Medium	2	29.00	5.50	4.00
Large	6	50.00	6.17	7.00

Table note:

(1) The usable sizes were determined from *GalvaSource*, a publication available from the American Galvanizers Association web site: http://www.galvanizeit.org/images/uploads/publicationPDFs/North_American_Galvanizers_Listing.pdf. The usable sizes are the least published sizes for the arbitrary categories in the table less clearances of 1.00 foot on length and depth and 0.50 foot on width.

For an example of a debris rack see the plans for Clayton 483 on US 18.

7.2.4.7.3 Safety grates

When a box culvert inlet or outlet will be in the clear zone and otherwise unprotected, Preliminary Bridge Design Unit in consultation with the Design Bureau will add a safety grate. A safety grate is heavier than a debris rack [BDM 7.2.4.7.2] and is intended to prevent serious injury to occupants of an errant vehicle traversing the end of a box culvert.

Safety grate design guidelines originally were developed by the Texas Transportation Institute [BDM 7.1.5.2] and then were included with minor modifications in AASHTO's Roadside Design Guide [BDM

7.1.5.2]. Recent testing of a grate that met the guidelines and NCHRP Report 350, TL-3 standards verified the grate's safety performance on roadside slopes as steep as 3:1 horizontal to vertical [BDM 7.1.5.2]. The Design Bureau has developed standard safety grate designs for box culverts [DB SRP DR-503] that meet the Roadside Design Guide guidelines, and the designer should use the standard designs.

In unusual cases when a standard design is not appropriate, the designer shall provide a grate that meets the Roadside Design Guide standards and generally follows the Design Bureau's standard details and notes. The grate members should be designed for yield under a traversing 1.8-kip load. The pipe members should be fabricated from ASTM A53, Grade B steel pipe [IDOT SS 4153.05]. It is important that the designer note on the plans that the members and brackets are to be fabricated before galvanizing.

7.2.4.7.4 End walls

When necessary to elevate the inlet for a multiple barrel reinforced concrete box culvert, the preliminary designer will add an end wall to the basic culvert headwall configuration. The end wall weir will set the elevation of the upstream flow, and therefore the end wall height shall be determined by the Preliminary Bridge Design Unit.

Figures 7.2.4.7.4-1 and 7.2.4.7.4-2 show typical details for an end wall applied to a standard twin or triple box culvert. For end walls the designer should follow these guidelines:

- The additional quantities for the modification of the interior wall of the headwall are to be included with the end wall quantities.
- The interior wall reinforcing steel from the standard culvert plan is not to be modified. The displaced concrete area from the interior wall is to be subtracted from the end wall concrete quantity.
- The additional vertical hoops shall match bar size with the vertical "c" headwall bars. The additional horizontal bars shall match bar size with "s" bars from the standard flared wing

headwall plan.

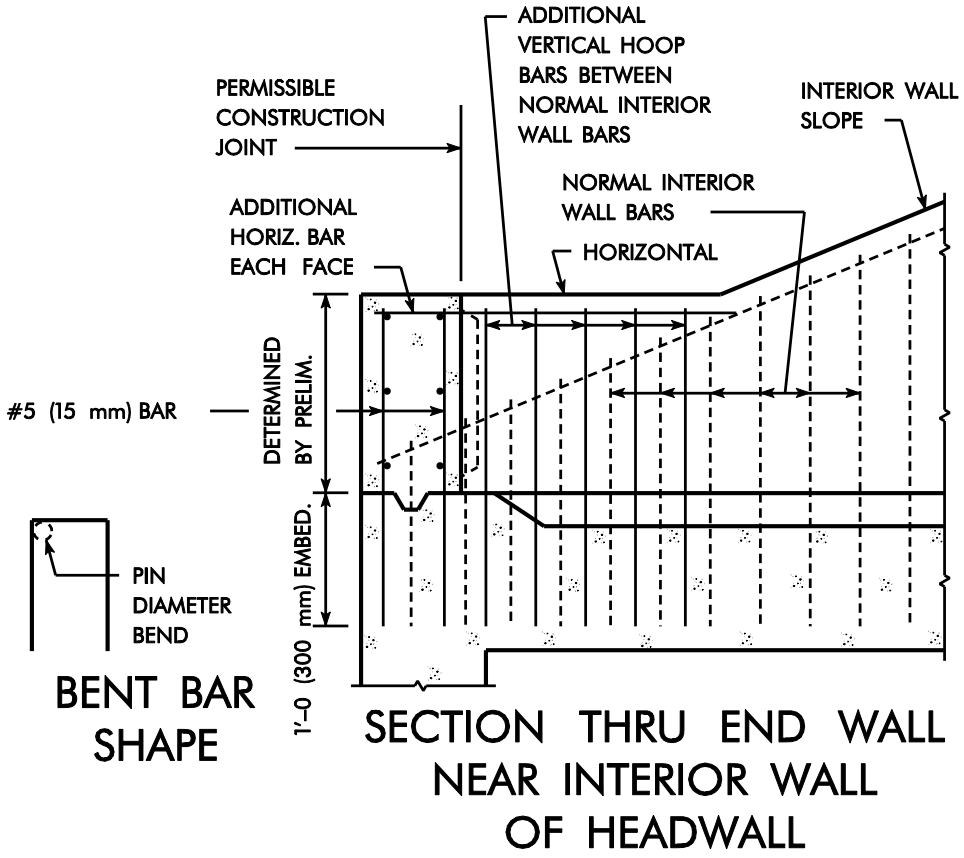


Figure 7.2.4.7.4-1. End wall details for a multiple box culvert

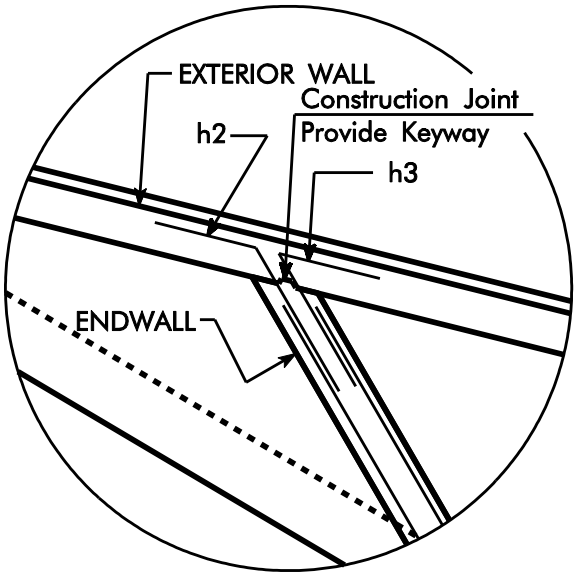


Figure note:

- Exterior wall bar leg is to be tied to exterior headwall steel.

Figure 7.2.4.7.4-2. Detail of end wall to exterior wall connection

7.2.4.7.5 Slope tapered inlets

A slope tapered inlet is intended to reduce construction costs by reducing the size of a culvert barrel and still provide acceptable hydraulic capacity and upstream headwater. The culvert site must have enough elevation difference for the overall culvert design to function properly. Usually the culvert outlet will have a flume and basin to dissipate energy.

Bell joints are placed between the slope tapered inlet and the culvert. For a reinforced concrete box culvert, the designer shall provide 1.50 feet of normal barrel length at the inlet-culvert joint to accommodate placement of the bell joint. See Figure 7.2.4.7.5 for sample slope tapered inlet details.

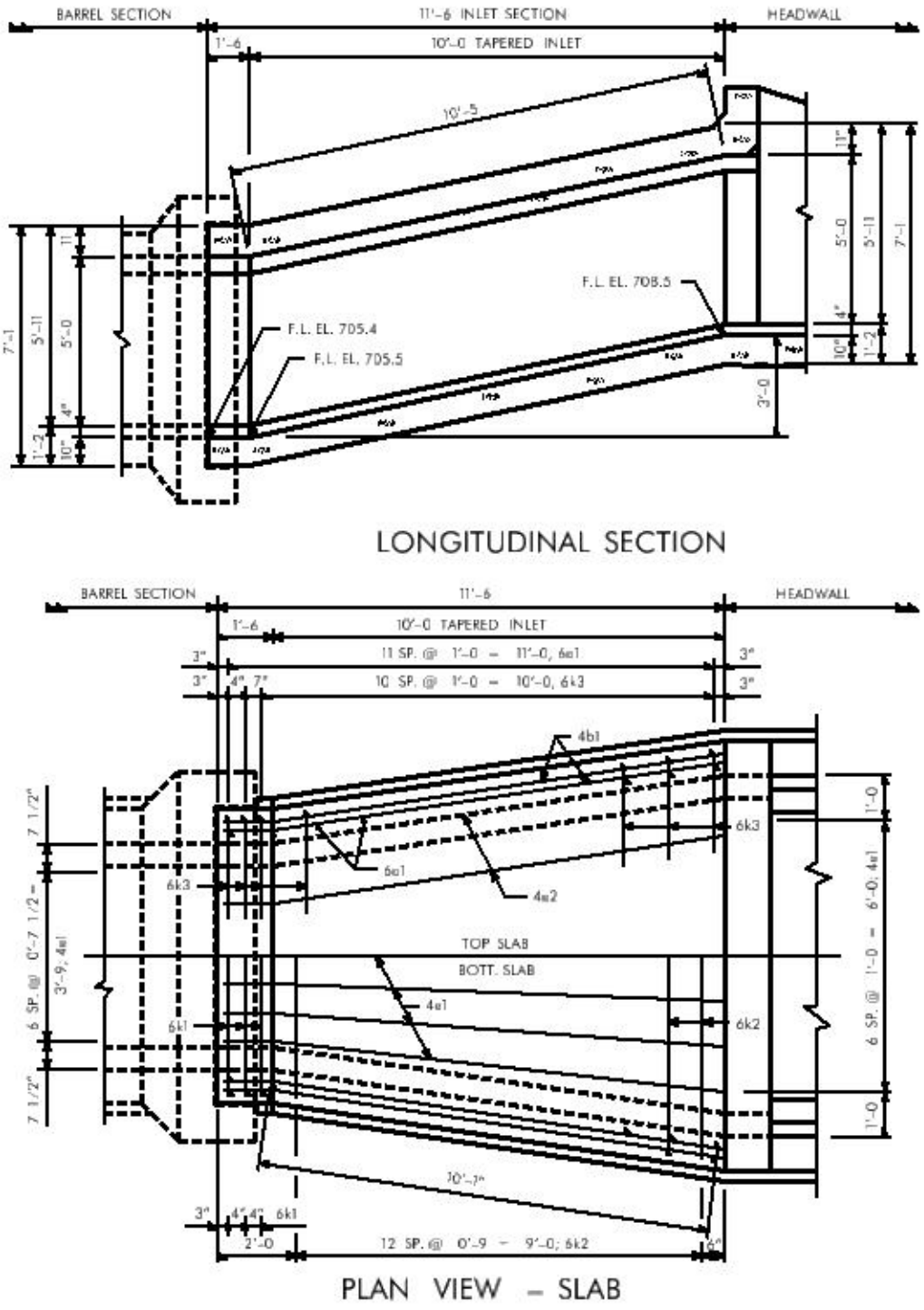


Figure 7.2.4.7.5. Sample reinforced concrete box culvert slope tapered inlet details

7.2.4.7.6 Drop inlets

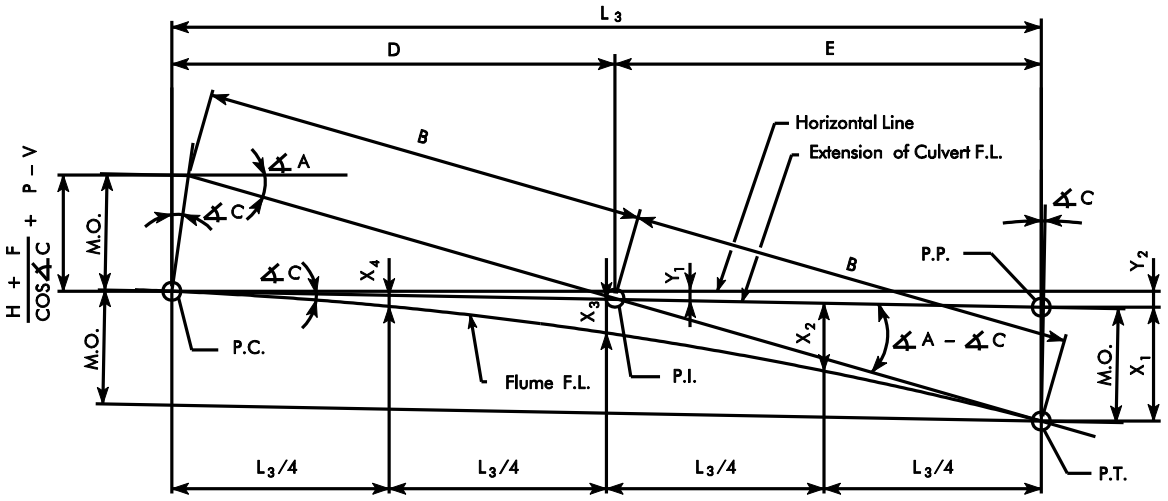
Reserved.

7.2.4.8 Outlets

7.2.4.8.1 Flumes

For a site with considerable elevation difference the preliminary designer may add a flume to conduct water from the reinforced concrete box culvert outlet down to streambed elevation. Flume length and outlet elevation are dependent on the configuration of the site. The flume length will be determined by the preliminary designer and generally rounded to the nearest one foot. Other, calculated flume dimensions determined by the final designer or detailer, however, should be given to the nearest 1/8-inch.

The typical flume floor begins at its top with an L3 length that fits a parabolic curve and continues with a straight length to its bottom. Curve equations are given in Figure 7.2.4.8.1-1, and area equations are given in Figure 7.2.4.8.1-2. Standard flume dimensions for 3:1 and 4:1 horizontal to vertical slopes are given on a standard sheet with slightly different notation [BSB SS RCF-03-20].



PARABOLIC CURVE

$$M.O. = \left[\frac{H + F}{\cos \angle C} + P - V\right] \frac{\sin \angle (90 \text{ deg} - A)}{\sin \angle (90 \text{ deg} - C + A)}$$

$$B = \frac{M.O.}{\sin \angle (A - C)}$$

$$E = B \cos \angle A$$

$$D = \frac{M.O.}{\tan \angle (A - C)} \cos \angle C$$

$$L_3 = E + D$$

$$X_1 = M.O. \cos \angle C$$

$$X_2 = 9/16\ X_1$$

$$X_3 = 1/4\ X_1$$

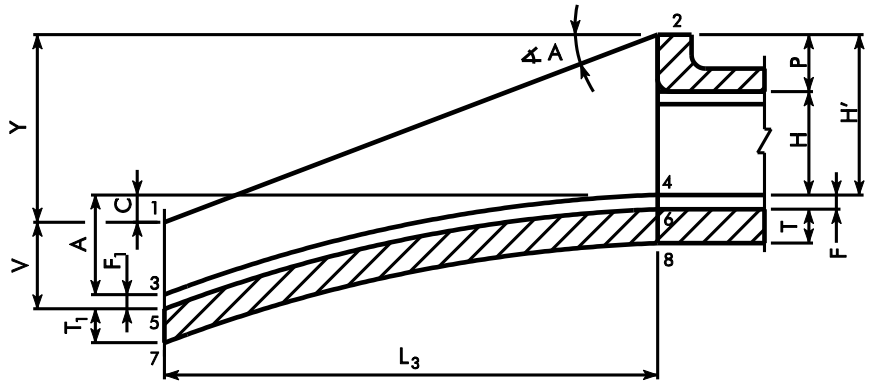
$$X_4 = 1/16\ X_1$$

$$Y_1 = \frac{M.O. \sin \angle C}{\tan \angle (A - C)}$$

$$Y_2 = L_3 \tan \angle C$$

H = Height of RCB
P = Depth of Parapet
F = Depth of Frost Trough
V = M (1/COS∠A) (Vertical Height of Chute)
M = 3/4 H

Figure 7.2.4.8.1-1. Variables and equations for a parabolic flume curve



$T_1 = T (1 / COS \measuredangle A)$	AREA 1 = 1-2-4-3, sidewall
$F_1 = F (1 / COS \measuredangle A)$	AREA 2 = 3-4-6-5, floor above frost trough
$V = M (1 / COS \measuredangle A)$	AREA 3 = 5-6-8-7, floor at frost trough
$Y = L_3 (TAN \measuredangle A)$	AREA 1 = $L_3 (H' + A/3 + Y/2)$
$C = Y - H'$	AREA 2 = $(L_3 / 3) (F_1 + 2F)$
$A = V + C - F_1$	AREA 3 = $(L_3 / 3) (T_1 + 2T)$
	AREA = SQ. FT. ONLY

Figure note:

- $L_3 > H'$
- See standard sheet for M dimension [BSB SS RCF-02-20]

Figure 7.2.4.8.1-2. Dimensions and estimated areas for the curved flume floor length

For typical projects the Bureau prefers that the designer use standard flume chute detail sheets for heights of 3 to 12 feet [BSB SS 1070-03 to 1070-14].

A flume usually is built on an embankment where settlement can be expected. Therefore, Bureau practice is to place a bell joint at the junction of the culvert end barrel section and the flume [BSB SS FBJ-01-20 to FBJ-09-20]. For a flume over 40 feet in length, the designer also shall provide a bell joint at the mid-point of the flume, located on the straight L_2 length below the L_3 curved length.

Typical flumes have a basin at the bottom, but stub flumes end with a cut-off wall at the bottom.

Bent U-bars placed transverse to a flume, for which the length of the bottom and vertical legs are both greater than 6 feet, are difficult to ship because of the limited width of a truck bed, 8 feet or less. Therefore, if both the bottom and vertical legs of a bent bar would exceed 6 feet in length, break the bar into three pieces and lap as shown in Figure 7.2.4.8.1-3.

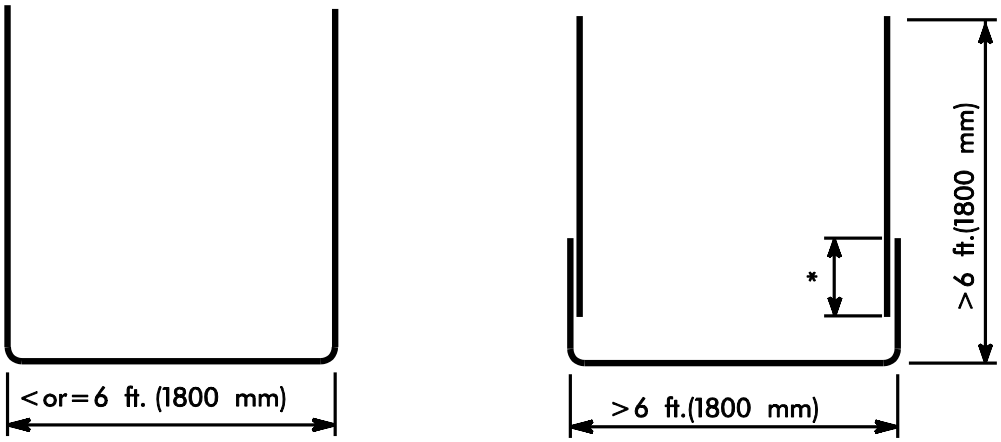


Figure note:

- See Table 7.2.4.8.1 for lap lengths

Figure 7.2.4.8.1-3. Length limits for transverse bent bars

Table 7.2.4.8.1. Lap lengths for transverse bent bars

Bar size	Minimum lap length (1)
#5	2’-0”
#6	2’-5”
#7	2’-10”
#8	3’-2”

Table note:

(1) Lap length is based on a Class B splice with material strengths of f'_c = 4 ksi and f_y = 60 ksi, a black bar condition, center-to-center bar spacing of at least 6 inches, and clear cover of at least 2 inches measured in the direction of the spacing. Higher material strengths, epoxy coating, smaller spacing, or less clear cover will require longer lap lengths.

7.2.4.8.2 Scour Floors

When appropriate for site conditions the preliminary designer will add a scour floor between the wing walls beyond the usual apron and curtain. See Figure 7.2.4.8.2 for an example.

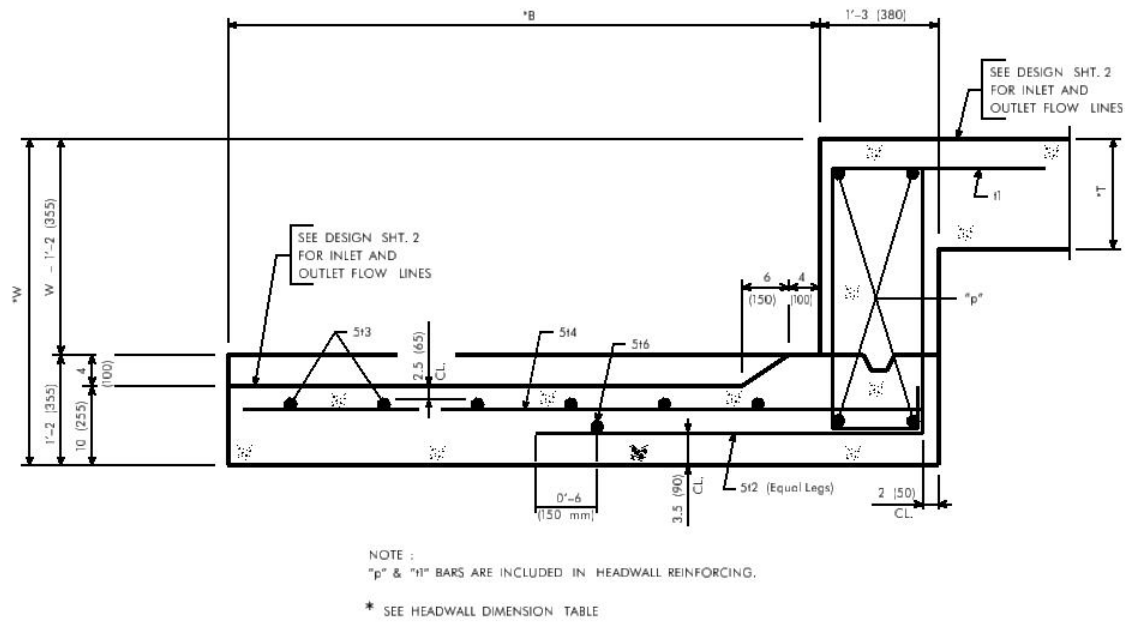


Figure note:

- The headwall dimension table and design sheet 2 would be in the plan set for the culvert and are not given in this manual.
- The scour floor is on the left.

Figure 7.2.4.8.2. Section through curtain wall and scour floor

7.2.4.8.3 Basins

Standard flume basin dimensions and reinforcement are given on standard sheets [BSB SS RCFB-01-20 to RCFB-11-20]. The lengths of the standard basins are based on a 4:1 horizontal to vertical slope, which is hydraulically sufficient based on a review by the Preliminary Bridge Design Unit using methodology established by the Saint Anthony Falls stilling basin.

The preliminary designer normally will set the flume basin floor elevation approximately 5 feet below the existing streambed. Thus the streambed typically will be one to three feet below the end of the flume. Detailers should check all available soil borings to be sure there is no bedrock at the elevation of the proposed basin.

7.2.4.9 Extensions

7.2.4.9.1 Connections

In order to initiate a clean break line, removals of culvert ends for culvert extensions require a 2.5-inch deep saw cut on the top slab, both sides of the walls, and top of the floor. Because these saw cuts will sever most reinforcing steel, the existing longitudinal reinforcing will not be incorporated into new work. Dowels, #5 x 2'-6, with a minimum embedment of 10 inches are required to connect the culvert extension to the existing culvert slab, walls, and floor. Typical locations of the dowels are given for single barrels in Figure 7.2.4.9.1-1 and for multiple barrels in Figure 7.2.4.9.1-2.

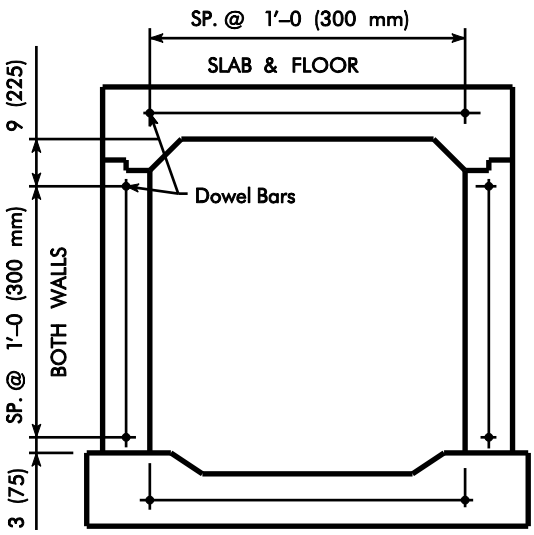


Figure 7.2.4.9.1-1. Cross section at dowels for single barrel extensions

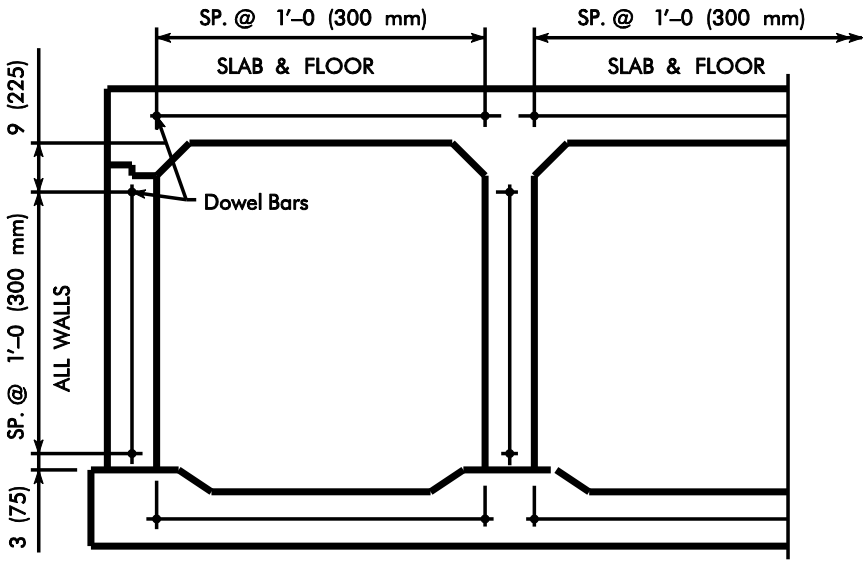


Figure 7.2.4.9.1-2. Cross section at dowels for multiple barrel extensions

The details shown in Figures 7.2.4.9.1-3 through 7.2.4.9.1-5 shall be used for connecting culvert extensions to existing culverts. The flow lines shall match at the joint between the existing culvert and the extension. A section view and plan view similar to those shown below will be required on the plans when transitions are used for the top slab, walls, or floor. The walls should be used to set the transition length, and the same transition length should be used for the slab and floor.

Any dimensional transition required between the existing structure and the extension should be a minimum of 1'-0. For transition differences between existing sections and new sections greater than 2 inches, make the transition with a 1:6 slope or shallower. For transitions over 3 feet consult with the supervising Unit Leader. The outside faces of the exterior wall transitions shall be stepped.

For metric projects the designer shall convert existing English culvert dimensions to metric with a soft conversion.

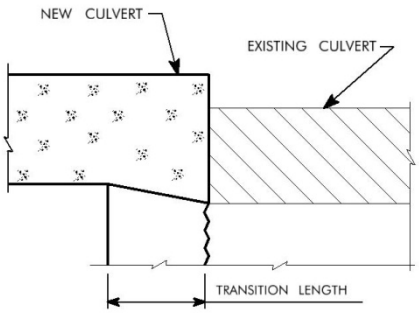


Figure 7.2.4.9.1-3. Section through top slab at extension connection

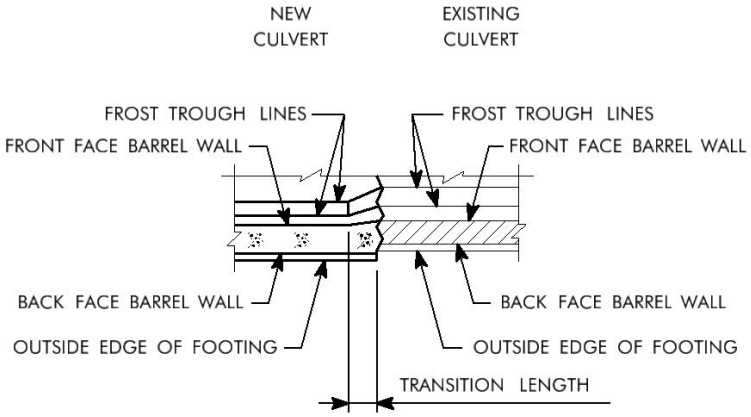


Figure 7.2.4.9.1-4. Plan of frost trough at extension connection to existing frost trough

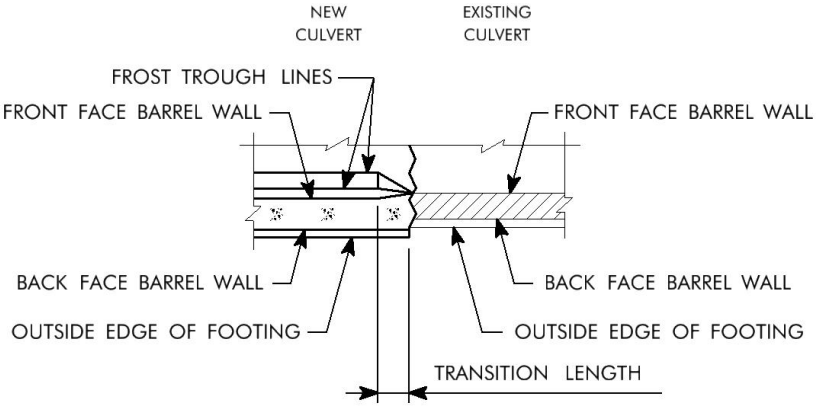


Figure 7.2.4.9.1-5. Plan of frost trough at extension connection to barrel without frost trough

When detailing extension barrel bends adjacent to skewed headwalls, follow the details shown in Figures 7.2.4.9.1-6 and 7.2.4.9.1-7. Use the minimum dimension to the bend, unless the bend occurs some distance away from the headwall, in which case the centerline barrel length shall not exceed 38 feet.

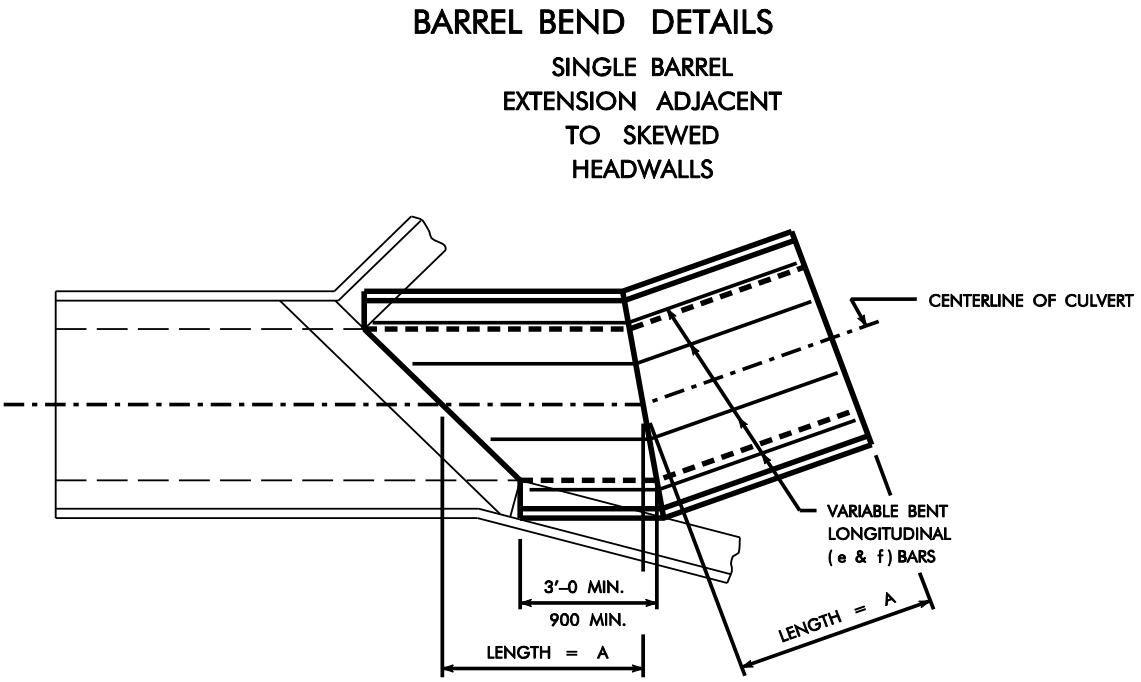


Figure 7.2.4.9.1-6. Barrel bend example for 4-foot (1.200-m) culvert span

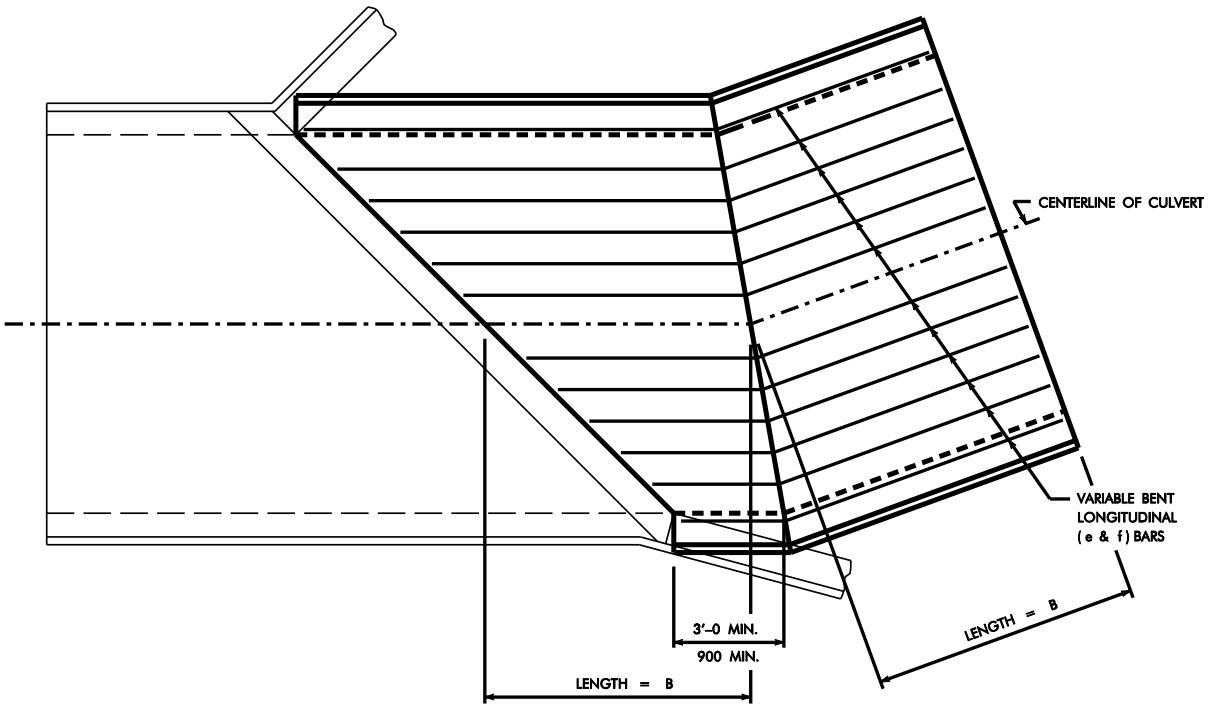


Figure 7.2.4.9.1-7. Barrel bend example for 12-foot (2.400-m) culvert span

At barrel bends, transverse bars shall be flared according to the minimum and maximum spacings specified for barrels on horizontally curved alignments [BDM 7.2.4.5.4.2].

7.2.4.9.2 Skewed reinforcement

For skewed cast-in-place single culvert extensions, the transverse bars shall be placed parallel with the skew angle of the existing parapet and flared as necessary to meet the skew of the new parapet. The designer shall not use this skewed bar placement for twin or triple culvert extensions, as discussed near the end of this article.

Placing the transverse reinforcement at the skew requires that the reinforcement be increased because it will not be parallel with the direction of the span. The increase may be achieved with larger bars and/or closer spacing. Two specific culvert barrel bars need to be adjusted: transverse bars k1 and m1. Also, with certain designs two additional bars will need to be adjusted. These are the k9 and m9 bars at the ends of a culvert section [BSB SS RCB-G3-20], which are used when the horizontal legs of corner bars do not lap across the span of the barrel. These k9 and m9 bars will be identical in bar size to their corresponding k2 and m2 counterparts and need to be adjusted for skewed placement. The adjustment for all of these bars is achieved by multiplying steel areas by the increase factor (1/cos of skew angle), by revising bar sizes and spacings accordingly, and by increasing skewed bar lengths as needed.

The following outlines the process of adjusting the bars for skew placement:

- Determine the area of steel per foot (A_s) for k1, k9, m1, and m9 from either the appropriate standard Culvert Barrel Details sheet (for the extension size and fill) or from CulvertCalc^{TM}$_{IA}$ output for the extension.
- Increase each area of steel by multiplying by the factor (1/cos of skew angle).
- For each increased area, select a bar size and spacing to the nearest conservative half inch. The spacing will be measured and dimensioned along the centerline of the culvert extension and, therefore, the perpendicular bar spacing will be less than the centerline dimension. Preferably the perpendicular spacing should be 6 inches or more to limit splice and development lengths.

- For bars k1, k9, m1, and m9, increase the bar length for the skew by multiplying the length by (1/cos of skew angle).
- See Figures 7.2.4.9.2-1 through 7.2.4.9.2-4 for typical single culvert skewed extension bar placement.

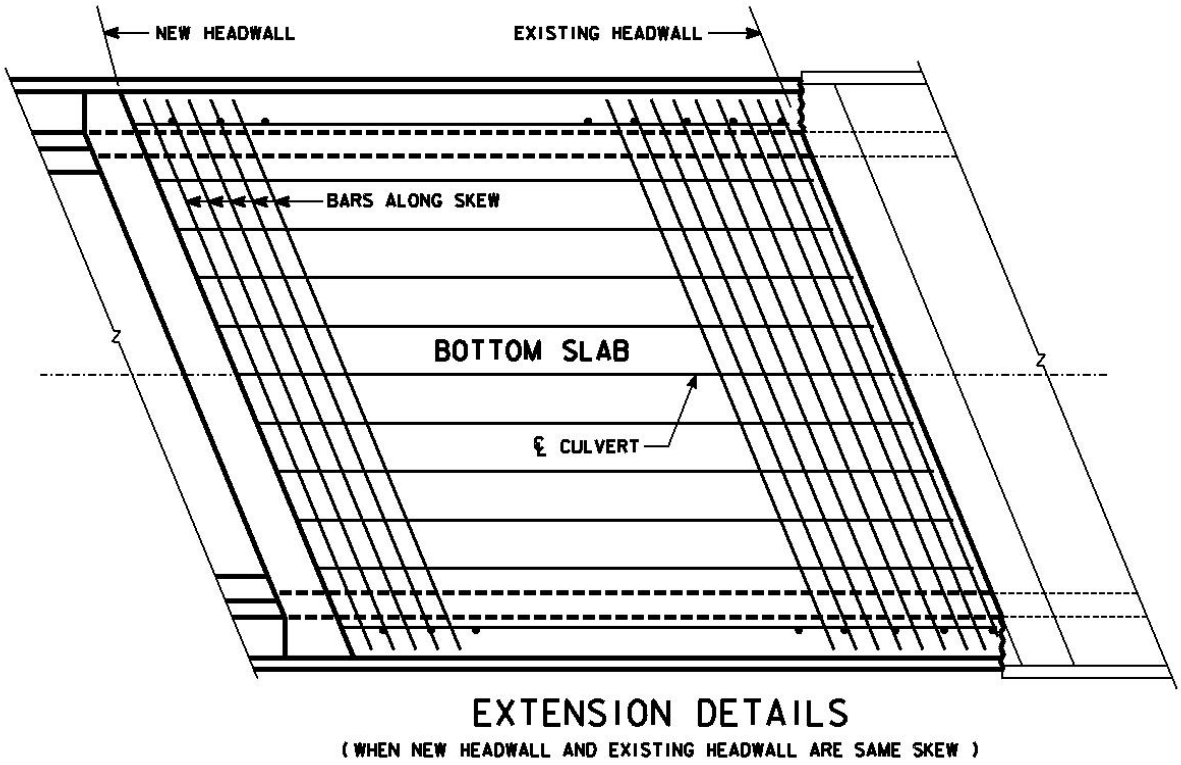


Figure 7.2.4.9.2-1. Bottom of slab skewed k1 bar layout when new headwall and existing headwall are the same skew

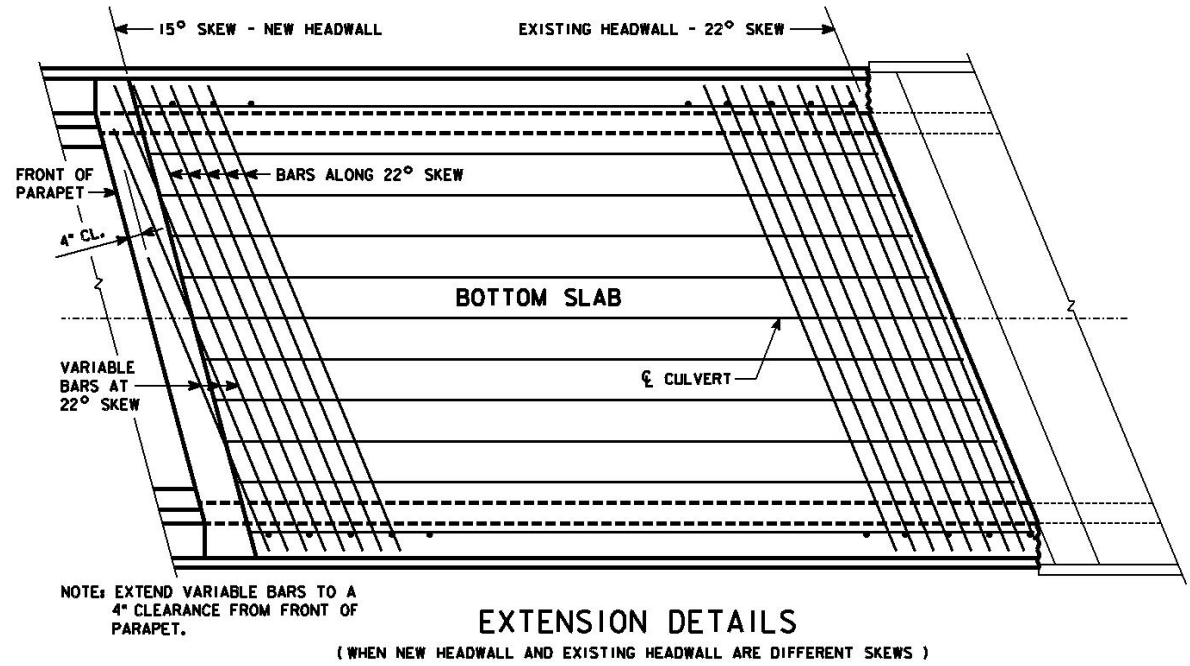


Figure 7.2.4.9.2-2. Bottom of slab skewed k1 bar layout when new headwall and existing headwall have different skews

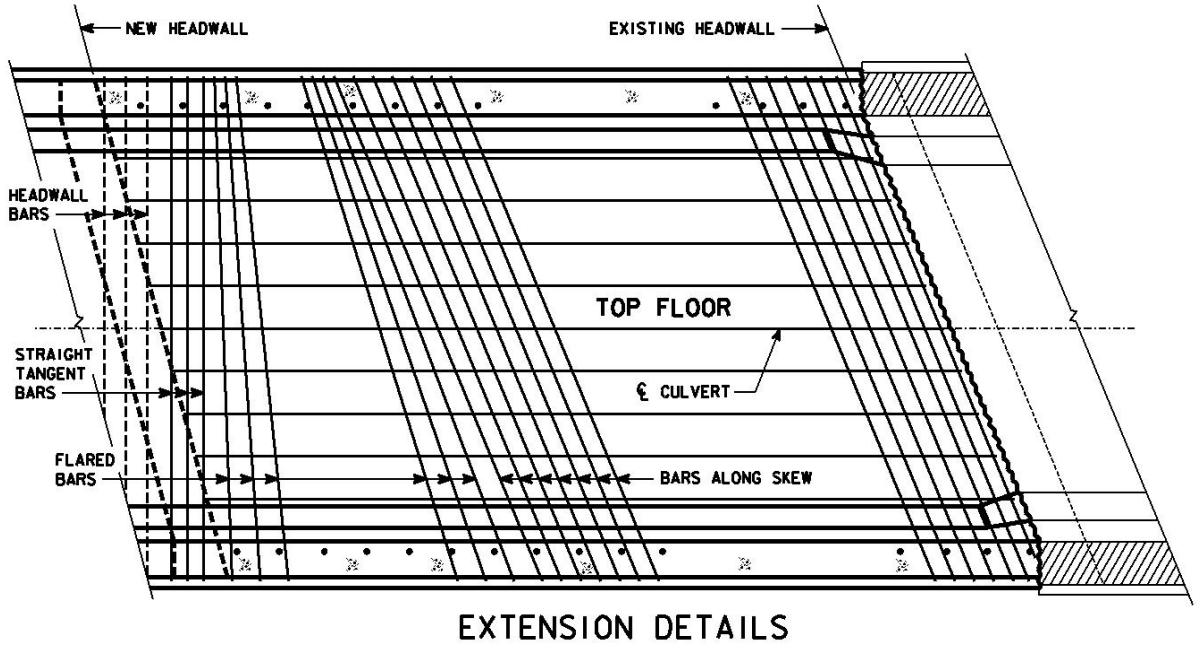


Figure 7.2.4.9.2-3. Top of floor skewed m1 bar layout

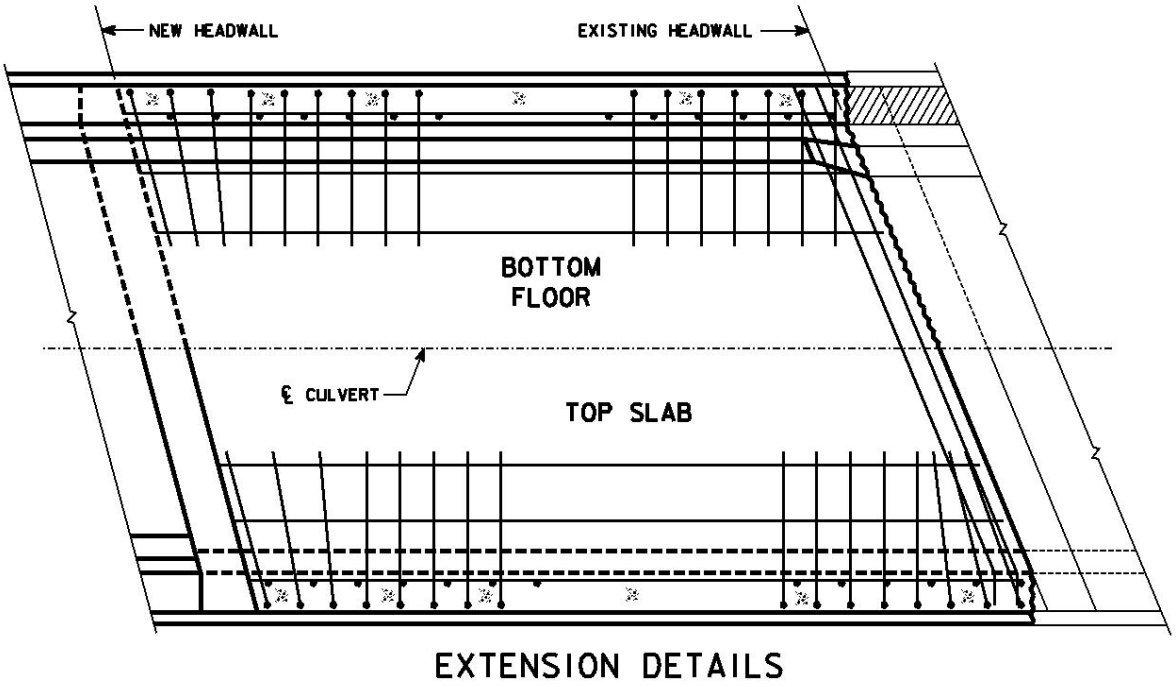


Figure 7.2.4.9.2-4. Bottom of floor and top of slab unskewed k2 and m2 corner bar layout

Skewed twin and triple culvert extensions shall be detailed with transverse and corner reinforcement placed perpendicular to the centerline of the extension as shown in Figure 7.2.4.9.2-5. Placing the reinforcement at the skew is not an option unless approved by the supervising Unit Leader.

Twin and triple transverse bars near the existing culvert headwall shall be cut off as shown in Figure 7.2.4.9.2-5. Pairs of additional bars spaced at 4.5 inches shall be provided and placed parallel with the extension connection and located in the top and bottom of the slab and floor to reinforce the edge of the barrel.

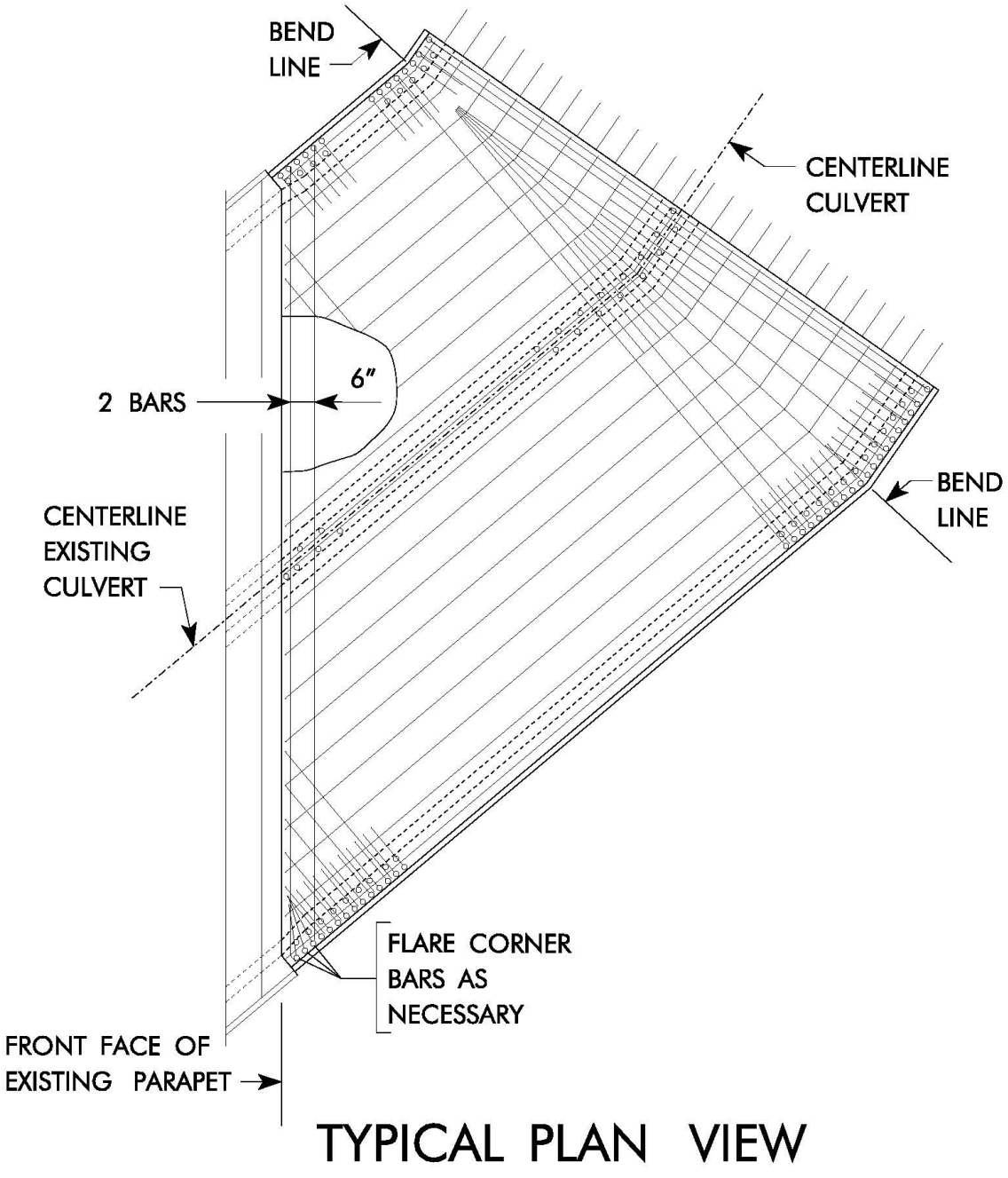


Figure 7.2.4.9.2-5. Reinforcement layout for a skewed twin culvert extension

7.2.4.9.3 Bell joints

When bell joints are to be used with an extension, a minimum of 5 feet extension along the centerline or 3 feet along the front face of the short wall shall be provided before the bell joint, as shown in Figure 7.2.4.9.3.

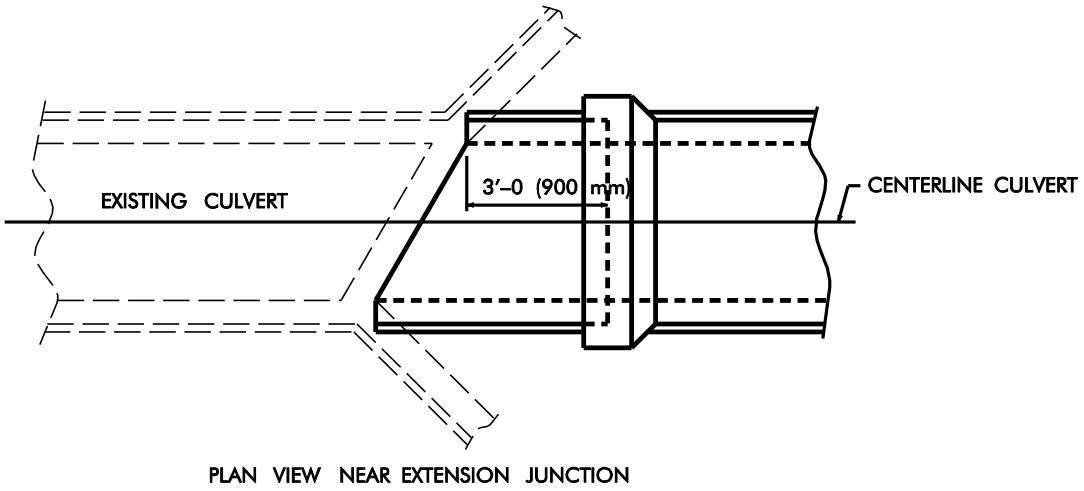


Figure 7.2.4.9.3. Single barrel extension with bell joints

7.2.4.9.4 Backfill

For culvert extensions on roads open to traffic, backfilling to the top of the culvert is to be completed within 14 working days after the curing period has expired [IDOT SS 2402.03, H, 13]. The Design Bureau will include the detail “Immediate placement of embankment at culvert extension” [DB RDD 4309] in plans for projects where a culvert extension and road work are to be accomplished at the same time.

When a culvert is to be extended with no simultaneous road work in progress, the detail [DB RDD 4309] must be included with the culvert plans. In this case the Design Bureau will provide the embankment detail and all other details and quantities required for incorporation into the Bridge Bureau’s culvert plans.

7.2.4.10 Bridge replacements

In some cases, a reinforced concrete box culvert (CIP or precast) is placed and buried under an existing bridge instead of replacing the bridge. If there is adequate height under the bridge, the space is filled first with flowable backfill and then flowable mortar [DB RDD 4317] or, if there is restricted height, the space is filled entirely with flowable mortar [DB RDD 4318]. In either case the space between the underside of the bridge and top of culvert is backfilled with flowable mortar. For this type of project the culvert contractor needs information about the space between the bridge and culvert. Therefore, the designer shall give on the plans the elevation of the lowest beam (or slab) on the existing structure and the top of slab elevation of the proposed culvert. The difference in elevations shall meet the following criteria:

- For slab bridges use a minimum clearance of 3 feet between the top of the culvert slab and the bottom of the bridge low slab.
- For beam bridges use a minimum clearance of 1 foot between the top of the culvert slab and the bottom of the lowest beam. For beam spacings of 3.5 feet or less, use a minimum clearance of 3 feet between the top of the culvert slab and the bottom of the lowest beam.

Also, the designer shall provide a minimum horizontal clearance of 1.5 feet between existing substructure components and the new culvert as shown in Figure 7.2.4.10-1. It should be noted that a precast multi-barrel RCB option takes up more horizontal space than CIP. The additional space for a precast multi-barrel option is needed due to adjacent box culvert walls and required minimum space between each barrel.

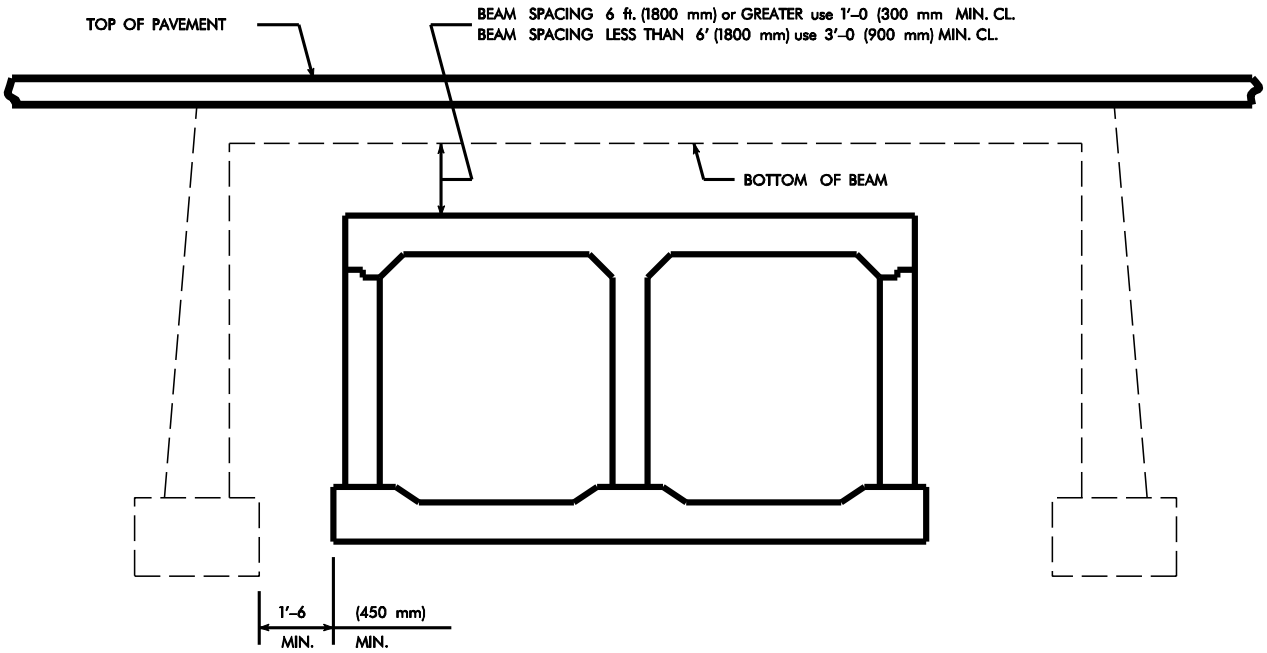


Figure 7.2.4.10-1. Clearances for a culvert backfilled with flowable mortar [Clearances in figure are incorrect.]

If any of the clearances would be less than the minimum shown above, the designer will need to consider other options such as:

- Burying the flowline of a reinforced concrete box culvert to meet vertical clearance,
- Eliminating an RCB design alternative (cast-in-place or precast) if guidance cannot be met.
- Removal of the bridge to allow an RCB.

The designer shall discuss these options with the Preliminary Bridge Design Unit. If a flowable mortar option is determined to meet clearance and constructability requirements, the designer shall refer to BDM 4.2.5 for additional requirements relative to potential settlement.

For a flowable mortar project, to ensure that all the voids under the existing bridge are filled, vent holes will be drilled in the existing bridge deck to facilitate the placement of the mortar. To assist the contractor with this type of project, the designer shall provide a vent hole layout in the culvert plans.

When developing the vent hole layout, use the following guidelines:

- Layout the existing bridge, showing the existing abutment and pier locations and dimensions. In addition, provide the location of the existing beam lines and concrete diaphragms that would restrict the flowable mortar placement.
- Locate any additional existing obstructions that would prevent the flow of mortar near the bottom of the bridge deck.
- Place vent holes along the width of the bridge deck at the same skew angle as the bridge. Along the length of the bridge place holes a minimum of 2 feet and a maximum of 8 feet away from the abutment. Across the width of the bridge the number of holes depends on beam placement and width of bridge. Place holes a minimum of 2 feet and a maximum of 8 feet on each side of all

beams. Adjacent hole spacing where there is no obstruction between holes shall be a maximum of 16 feet.

- When beams are not present, such as in a continuous concrete slab bridge, the distance from the side of the bridge to the nearest hole shall be a maximum of 8 feet. Adjacent hole spacing where there is no obstruction between holes shall be a maximum of 16 feet.
- Placement of holes along the length of the bridge should depend on existing diaphragm and pier locations and the overall length of the bridge. Locate holes a minimum of 2 feet and a maximum of 8 feet away from either side of diaphragms and piers. Each possible enclosed or restricted area shall have at least two vent holes. If possible, use a consistent spacing between holes. Adjacent hole spacing where there is no obstruction between holes shall be a maximum of 16 feet.
- When diaphragms are not present, adjacent hole spacing where there is no obstruction between holes shall be a maximum of 16 feet and a minimum of 10 feet.

Figure 7.2.4.10-2 shows a sample vent hole layout for a skewed bridge.

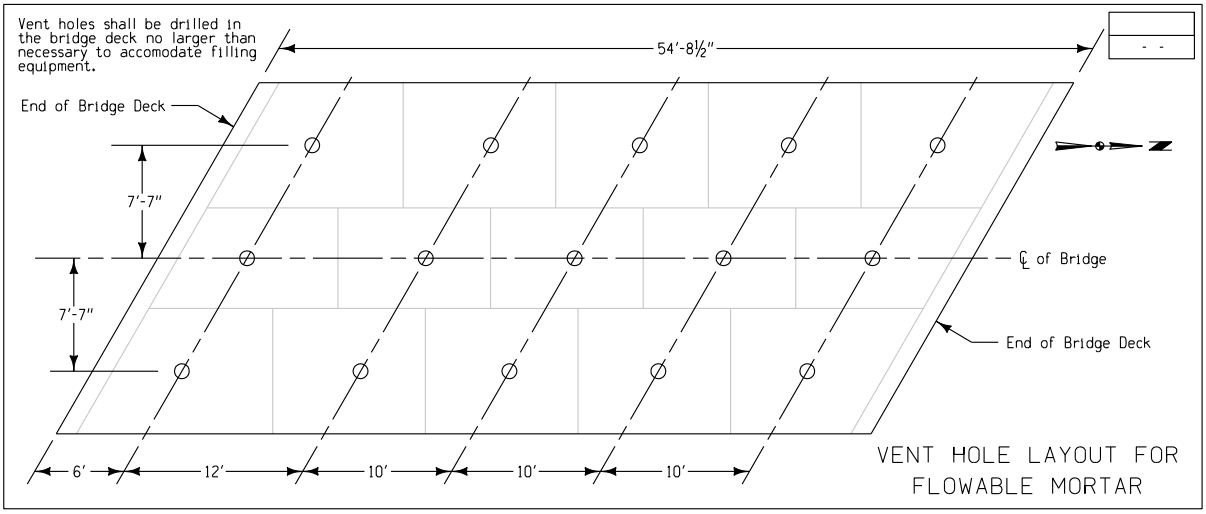


Figure 7.2.4.10-2. Example vent hole layout for a skewed bridge

If the depth of flowable mortar is greater than 5 ft, the designer shall consult with the Soils Design Unit for alternatives.

This type of project usually involves removing the bridge rail from the existing bridge structure after the new culvert has been put in place. If construction of the culvert is part of a paving project, then it is possible the paving contractor may subcontract the culvert work. In such cases, the work of removing the bridge rail may be performed by the paving contractor since this work is typically performed well after the installation of the culvert. In such cases, it is still preferred to include the rail removal bid item with the other culvert bid items since it is generally the responsibility of BSB to ensure that all items with respect to the culvert and bridge are appropriately addressed in the culvert plan sheets. Regardless of where the bridge rail removal item is placed, the designer shall coordinate with road design to ensure all bid items are addressed and not duplicated.

7.2.4.11 Miscellaneous

7.2.4.11.1 Fish baffles or weirs

In some cases the Iowa Department of Natural Resources (Iowa DNR) will require that a reinforced concrete box culvert be detailed for fish passage. Depending on fish characteristics and site conditions, fish passage will require an arrangement of baffles or weirs on the floor of a culvert. The Preliminary

Bridge Design Unit will determine the size, spacing, and arrangement, and the designer should follow the guidelines below and use the standard sheets noted:

- Baffles are placed part way across the culvert floor at an angle [BSB SS 1060].
- Weirs are placed completely across culvert openings [BSB SS 1061].
- Baffles or weirs shall not be placed across the culvert joints.
- When baffles or weirs are used, a rock splash basin shall be installed at the outlet end of the culvert as shown in Figure 7.2.4.11.1.

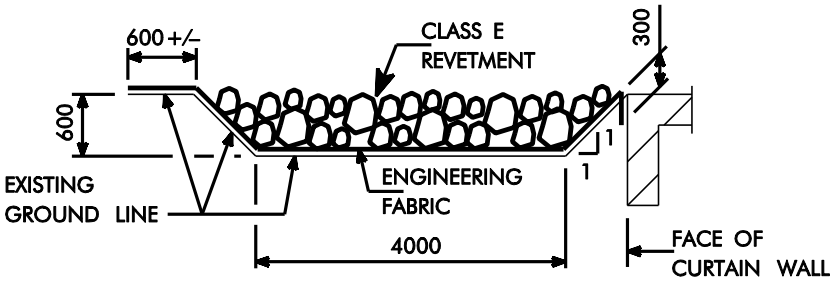


Figure note:

- All dimensions are in millimeters.

Figure 7.2.4.11.1. Rock splash basin at outlet end of culvert

7.2.4.11.2 Drain pipe anchors

In some cases corrugated metal pipe (CMP) or polyethylene pipe (PEP) drainage lines need to be anchored to the tops of wing walls or flumes. For each pipe, the designer shall include in the plans two bars similar to the 5fa fence anchors shown on the “Bill of Reinforcing” on standard flared wing headwall sheets. A detail for a pipe anchor bar is given in Figure 7.2.4.11.2.

The designer also shall require the contractor responsible for furnishing and placing the pipe to furnish and install a ¼-inch diameter galvanized cable over the pipe and clamps to secure the cables.

The designer should indicate on the plans the spacing between the pipe anchor bars and the centerline of the pipe with respect to the front face of the parapet. See Figure 7.2.4.11.2.

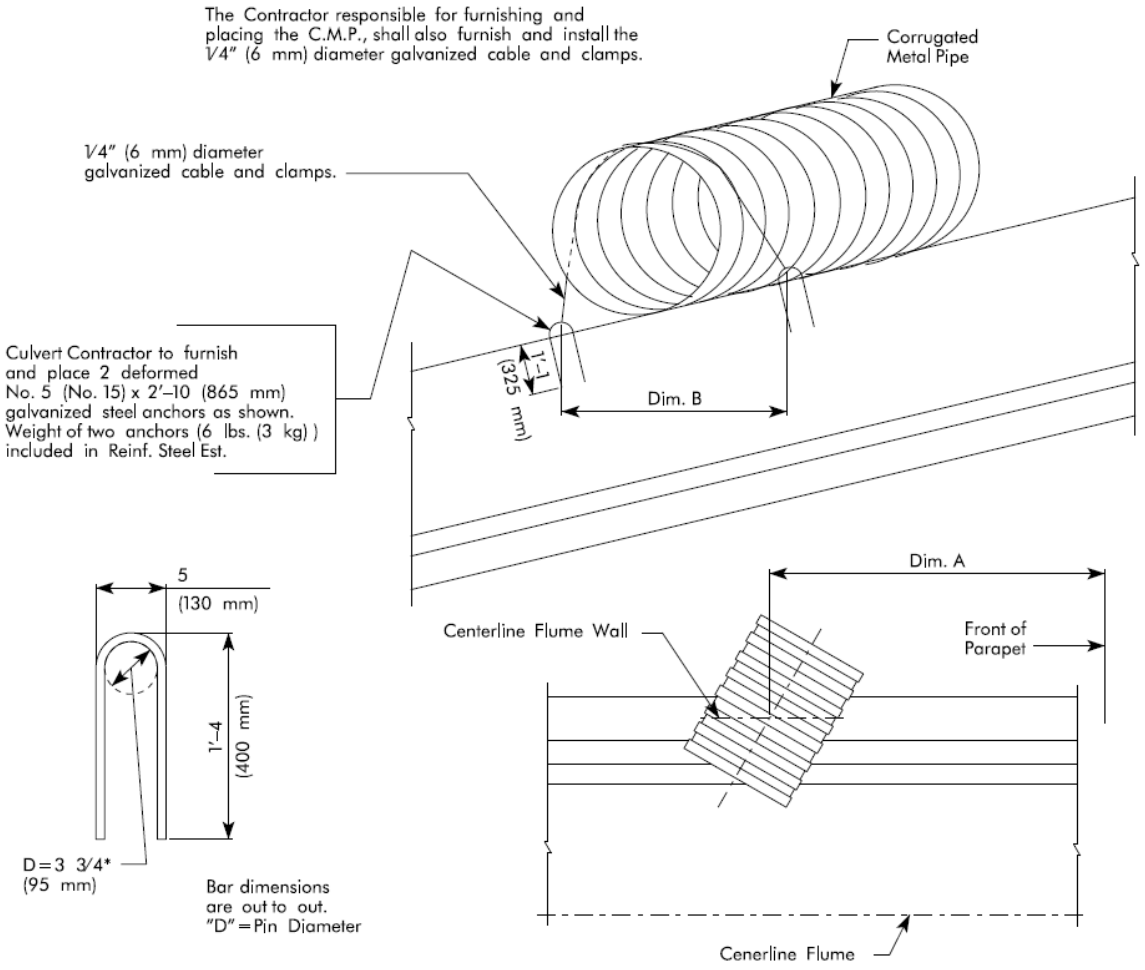


Figure 7.2.4.11.2. CMP anchorage at top of wing wall or flume

7.2.4.11.3 Pipe hand railings

For safety, where pedestrians or bike riders are likely to be near reinforced concrete box culvert inlets or outlets, the preliminary designer will require pipe hand railings at culvert parapets and drop inlets. The pipe hand railings should be detailed with the following considerations:

- Ease of handling and transporting and
- Size of galvanizing tanks [BDM 7.2.4.7.2].

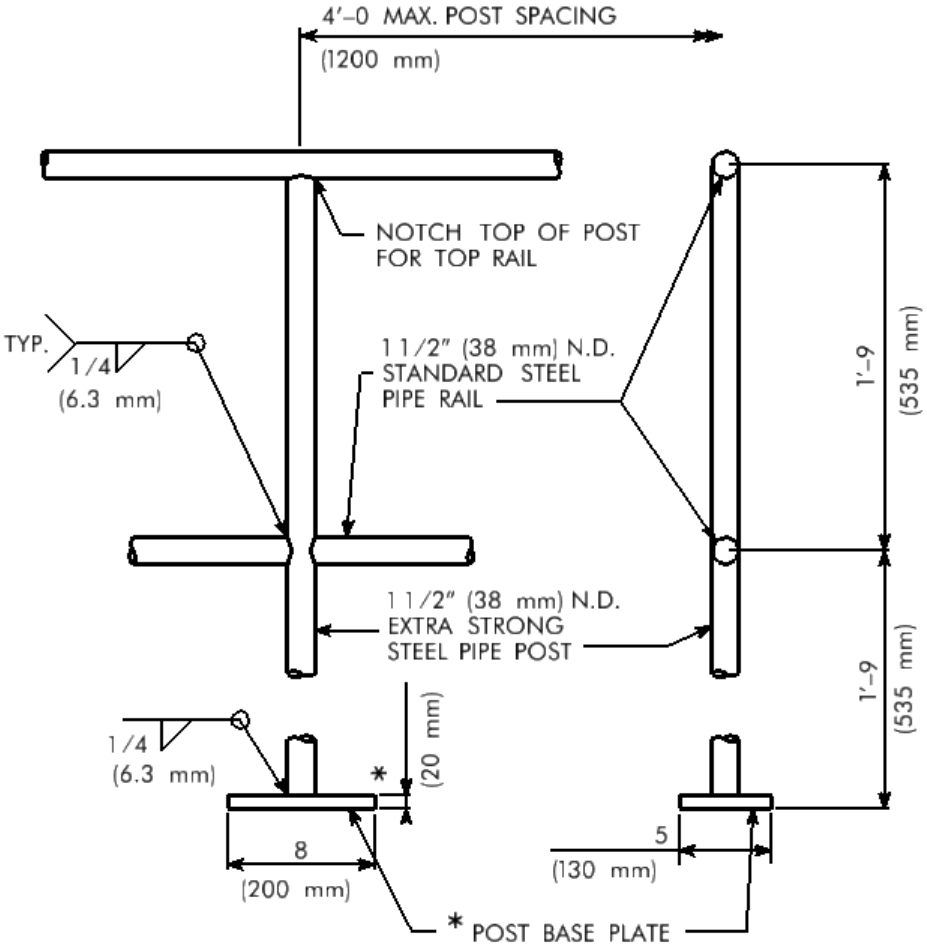
General pipe hand railing details are shown in Figures 7.2.4.11.3-1 to 7.2.4.11.3-3. All posts are to be set vertical. In rural areas the designer should use the horizontal rail spacings shown in Figure 7.2.4.11.3-1 and embed posts one foot into concrete walls. In urban areas the designer should use the horizontal rail spacing shown in Figure 7.4.4.10.1-2 and select the base plate detail so that the hand railing can be replaced easily.

The hand railing sections shall be galvanized after fabrication. Drain holes to facilitate the hot dip galvanizing process shall be shown on the railing shop drawings.

The method of measurement for pipe hand railing is the length from end to end of railing [IDOT SS 2414.05, B].

For drop inlets in rural and urban locations, the railings should be detailed to show the centerline of the top rail to be 3'-6 above the top of the drop inlet walls, which also should be 3'-10 above the flowline of the weir. In rural locations the centerline of the bottom rail is to be 1'-9 below the centerline of the top rail. In urban locations the horizontal rails shall be spaced at 7 inches as shown in Figure 7.4.4.10.1-2.

Parapet hand railings for rural locations are detailed the same as for drop inlets, as shown in Figure 7.2.4.11.3-4. However, parapet hand railings for urban locations need to be taller, 4’-8 as shown in Figure 7.4.4.10.1-2.



PIPE HANDRAIL DETAILS

* POST BASES ARE TO BE USED IN URBAN AREAS, OTHERWISE EXTEND POST 1′–0 (300 mm) INTO THE WALLS OF THE DROP INLET.

Figure 7.2.4.11.3-1. Typical pipe hand railing details

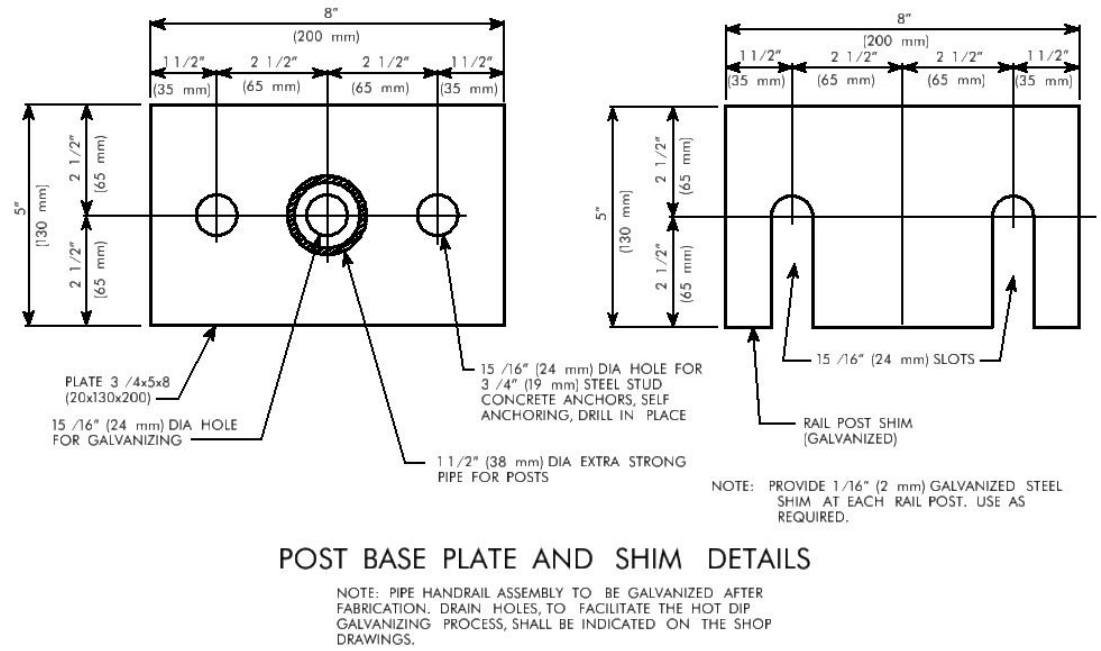


Figure 7.2.4.11.3-2. Typical urban post base plate and shim details

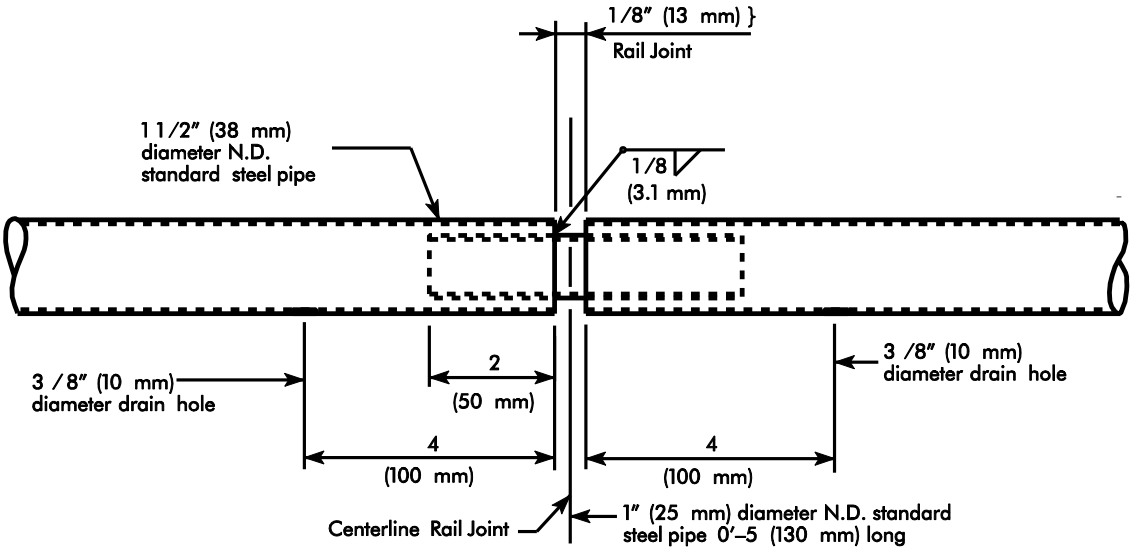


Figure 7.2.4.11.3-3. Typical rail joint detail

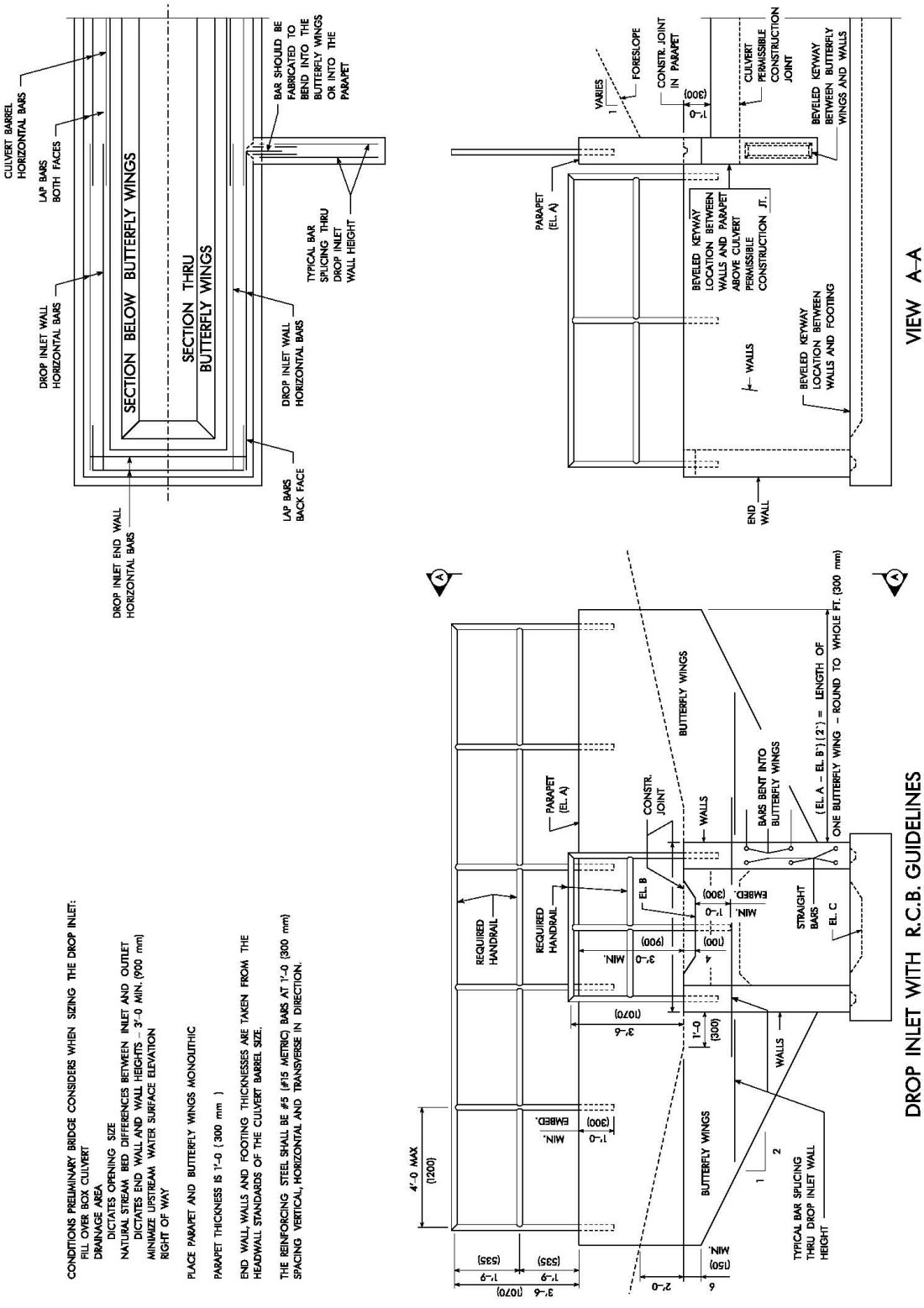


Figure 7.2.4.11.3-4. Rural reinforced concrete box culvert railings

7.2.4.11.4 Pedestrian Culverts

Culverts designed for pedestrian use, will typically have the following characteristics.

- A 12’ X 11’ minimum size.
- A minimum 0.5% longitudinal slope to prevent ponding.
- No frost troughs for CIP culverts because of ADA requirements.
- A one foot deep cutoff wall.
- Flared end sections.
- Railing on end sections to meet fall protection requirements.

See BDM 1.5.3 and 3.5 for additional information. A precast option shall normally be required (BDM 7.3.4.2.4).

Some culverts may require the following if requested by the local planning authority.

- Galvanized light fixture boxes and rigid steel conduit cast into the concrete for CIP boxes.
- A structural concrete coating of light color to accentuate the lighting followed by a compatible anti-graffiti coating. When used, coatings are only applied to ceiling and interior wall concrete surfaces as well as the exposed surfaces of the tunnel headwalls except for the top and back of parapet. Do not apply the coating to the walking surface.

These parameters may vary depending on the project and should be verified with BSB before starting a pedestrian culvert design.

7.3 Precast concrete box

Unless otherwise specified, for primary road projects the Bureau now allows both cast-in-place and precast box culvert alternates under the following project conditions:

- The culvert is an Iowa DOT standard size single, twin or triple box with standard size headwalls at both ends. For precast twin and triple box culverts use two or three side-by-side standard size precast single boxes, respectively [BSB SS 1082P],
- The barrel span or spans are each 6 to 16 feet,
- Design earth fill heights are in the range from 2 feet to 25 feet for 6’ to 12’ spans and 2 feet to 16 feet for 14’ and 16’ spans,
- The culvert is not placed directly on bedrock,
- Anticipated culvert settlement is less than 12 inches for a single line of single cell boxes and less than 6 inches for side-by-side single cell boxes and multiple cell boxes under these fill heights, and
- There are no conditions requiring bell joints.

Culverts with bends, drop inlets, scour floors, and other details which are only available with cast-in-place box culverts will only be approved on a case-by-case basis.

Projects meeting these requirements will require the designer to develop plans showing two alternate designs: one for cast-in-place, and one for precast. The designer shall prepare the plans with details and quantities that address both alternates. The Contracts and Specifications Bureau will prepare the bidding documents to allow the contractor to bid on either plan alternate.

For a precast alternate there are three options. Standard precast box designs and details from Option A or B are required when the box size, fill height, and skew meet the limits found in those options. Option C may only be utilized when non-standard box designs are required. Non-standard box designs are only required when box size, fill height or skew do not meet the criteria under Option A or B. Fabricators shall not substitute their own designs and details for any of the three options.

> Option A: ASTM C1577 with the end sections and associated details in Iowa DOT Single Precast Reinforced Concrete Box Culvert Standards

- The precast barrel sections shall meet the minimum requirements of ASTM C1577, Table 1.
- Skew shall not exceed 30 degrees.
- The box tie, end section, lintel beam, curtain wall, and embankment protection details shall be taken from Single Precast Reinforced Concrete Box Culvert Standards. General notes, specifications, and design stresses on Sheet PRCB G1-20 also shall apply.

Option B: Iowa DOT Single Precast Reinforced Concrete Box Culvert Standards

- The precast barrel sections, end sections, and details shall be taken from Single Precast Reinforced Concrete Box Culvert Standards.
- The standards may be used for skews of 45 degrees or less.

Option C: ETCulvert designs (or equivalent) for non-standard designs with the end sections and associated details in Iowa DOT Single Precast Reinforced Concrete Box Culvert Standards

- The precast barrel sections must be designed with ETCulvert (or equivalent) following design criteria used in the development of the standards under Option B which include some of the following conditions:
  - The live load distribution factor through fill shall be 1.00.
  - The minimum load factor for horizontal earth pressure shall be 0.90.
  - The maximum reinforcement ratio shall be set to $0.634\rho_b$ to ensure tension controlled sections for flexural design. The maximum reinforcement in the culvert walls shall not exceed 4% of the gross section.
  - See Single Precast Reinforced Concrete Box Culvert Standards for permissible reinforcement clearances and other design requirements.
- The box tie, end section, lintel beam, curtain wall, and embankment protection details shall be taken from Single Precast Reinforced Concrete Box Culvert Standards. General notes, specifications, and design stresses on Sheet PRCB G1-20 also shall apply.

The contractor shall submit shop drawings for review and documentation. The Contractor shall allow 30 working days for the Engineer's shop drawing review. The designer may only use Option C if barrel span and/or height dimensions are different from those in the standards or if fill heights exceed 25 feet, or if skews exceed 45 degrees.

For submission of shop drawings the contractor may download and use the precast box culvert submittal sheets available on the Bridges and Structures Bureau web page.

The Iowa DOT Single Precast Reinforced Concrete Box Culvert Standards were developed from Minnesota DOT precast concrete box culvert standards, but the Bridges and Structures Bureau has chosen to deviate from those standards based on past Iowa practice and other factors. Culvert fabricators that serve both states need to consider the differences carefully.

Following are the plan development guidelines for projects when precast concrete boxes are required or an alternate to cast-in-place culverts. Both the precast and cast-in-place culverts would be considered alternates.

- Preliminary Bridge shall prepare the preliminary design (TS&L) for a single, twin or triple precast culvert length when precast is required and cast-in-place is not an option.
- If a single, twin or triple culvert structure is a candidate for either a precast or cast-in-place culvert, Preliminary Bridge will prepare the preliminary design (TS&L) for a cast-in-place culvert length and will provide dual dimensions for the precast length left and right and total length back to back of parapet (including "G" dimension). The final detailer should copy the preliminary TS&L CADD file designed for the cast-in-place culvert and change the Situation Plan/Longitudinal Section to represent the precast culvert alternate, adjusting the length according to the dimensions given.
  The final detailer should note the following when determining the precast culvert length:
  - The foreslope for a precast culvert should intercept the bottom of the parapet (lintel beam) which would make the overall length longer than the alternate cast-in-place culvert

where the foreslope intercepts the top of the parapet. Compare Figure 7.3 below with Figure 7.2.

- The overall length for the precast culvert will include the end to end of barrel length plus the additional barrel length included with the headwalls at each end of the culvert. The end to end of barrel length should be adjusted so it is a whole foot length. The overall length for the precast culvert from back to back of parapet (lintel beam), the end to end barrel length and the additional barrel length as part of the headwalls, indicated as the 'G' dimension in the precast culvert standards, shall be dimensioned on the TS&L.

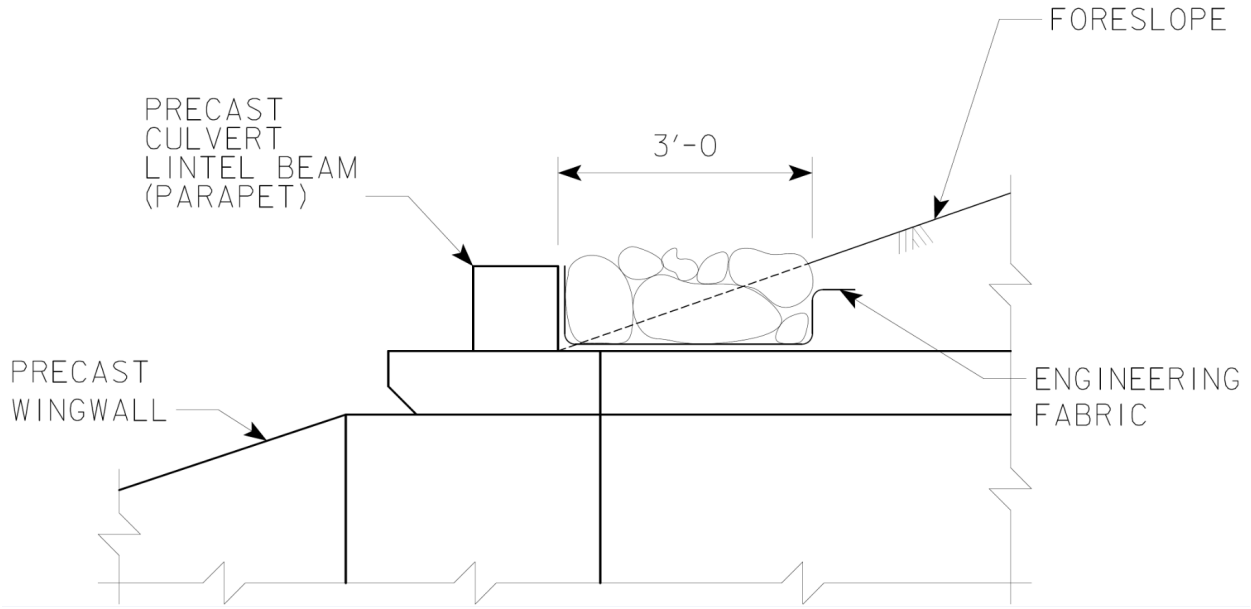


Figure 7.3. Foreslope-Lintel beam intersection diagram

- Show Class E revetment around both headwalls as on the standard sheet [BSB SS PEP 12-20].
- If the back to back dimensions for the precast alternate are not given, the Final Designer shall check with Preliminary Design for the appropriate dimensions before proceeding.

- The design earth fill height shown on the plans for the cast-in-place alternate should remain the same for the precast alternate.
- The final detailer shall prepare one title sheet with two alternate sets of detail plans, one for the cast-in-place culvert and one for the precast culvert. This will result in two sets of Estimated Quantities with notes on the Index of Sheets table on the title sheet. Cast-in-place and precast culvert details will be as normally shown with referral to the Iowa DOT Box Culvert Standards.
- Projects with multiple culvert designs shall include a culvert estimate sheet for each alternate design (precast and cast-in-place). The location of each Estimated Quantity table should be noted in the Index of Sheets on the Title Sheet.
- These are the V8 model naming conventions:

  The cast-in-place naming convention is CCDDDDSC01, CCDDDDSC02P, CCDDDDSC03, etc. The SC represents Sheet Cast-in-place models.

  Precast naming convention is CCDDDDSP01, CCDDDDSP02P, CCDDDDSP03, etc. The SP represents Sheet Precast model names.

  Both cast-in-place and precast V8 models are in the same V8 file because all details are for the same project.

  The CC which is County Number and DDDD is Design Number are the same for both cast-in-place and precast plans.

7.3.1 Loads

Design loads for a precast box culvert are generally the same as for a cast-in-place RCB of the same size, span, and height of fill. See the loads articles for reinforced concrete box culverts [BDM 7.2.1]. The standard precast designs are currently based on a fill interaction factor (i.e. live load distribution factor) of 1.00.

7.3.2 Load application

Load application for a precast box culvert generally is the same as for a cast-in-place RCB of the same size, span, and height of fill. See the precast Option C conditions [BDM 7.3] and load application articles for reinforced concrete box culverts [BDM 7.2.2].

7.3.3 Analysis and design

Precast concrete box culverts shall be designed structurally by the load and resistance factor design (LRFD) method. The LRFD analysis and design requirements for the ASTM C1577 barrel sections (Option A) are contained in the aforementioned document. The LRFD analysis and design requirements in this section specifically apply to Options B and C. Any designs performed under Option C [BDM 7.3] shall be based on the LRFD design criteria used in the development of the Option B standards. For design conditions that do not fit the available standard designs in Options A or B or if Option C [BDM 7.3] is chosen the Bureau prefers that the precast box culvert producer uses software endorsed by the American Concrete Pipe Association (ACPA): ETCulvert on which the Option B standards are based, or equivalent software. Options A and B generally require no analysis and design.

The minimum floor, slab, and wall thickness for culverts with 6-foot spans is 8.0 inches. For culverts with spans of 8-foot to 12-foot, the minimum thicknesses are 8.0 inches for walls, 9.0 inches for the slab, and 10.0 inches for the floor. For culverts with spans of 14-foot, the minimum thicknesses are 8.0 inches for walls, 10.0 inches for the slab, and 10.0 inches for the floor. For culverts with spans of 16-foot, the minimum thicknesses are 8.0 inches for walls, 10.0 inches for the slab, and 11.0 inches for the floor. The maximum desirable thickness for any member of any culvert size is 12.0 inches. If this requirement cannot be met when assuming a concrete compressive strength of f'c = 5 ksi without the addition of shear reinforcing, a concrete compressive strength of f'c = 6 ksi may be used.

The standard precast designs assume traffic is travelling parallel to the span. This assumption is considered to provide adequate designs for culverts skewed to a maximum of 45 degrees. The standard precast designs may need to be redesigned if skew angles exceed 45 degrees.

When the Soils Design Unit or geotechnical consultant does not provide site-specific information the designer should use the following cohesionless soil properties in design.

- Angle of internal friction (φ) 30 degrees
- Unit weight of saturated soil 0.135 kcf
- Unit weight of dry soil 0.120 kcf
- Unit weight of water 0.0624 kcf

In general, the designer should model components of box culverts using typical 12-inch wide strips for analysis and design.

7.3.4 Detailing

Reserved.

7.3.4.1 Extensions

On a case-by-case basis the Bureau allows precast culvert extensions of existing single cast-in-place or precast box culverts. For an extension the contractor has the same three design options as for new

precast culverts [BDM 7.3].

Except for the connection between the existing culvert and extension covered by standard sheets [BSB SS 1043P-1045P], precast box culvert extension projects are treated the same as new precast box culvert projects.

7.3.4.2 Miscellaneous

7.3.4.2.1 Fish baffles or weirs

In some cases the Iowa Department of Natural Resources (Iowa DNR) will require that a precast box culvert be detailed for fish passage. Depending on fish characteristics and site conditions, fish passage will require an arrangement of baffles or weirs on the floor of a culvert. The Preliminary Bridge Design Unit will determine the size, spacing, and arrangement, and the designer should follow the guidelines below and use the standard sheets noted:

- Baffles are placed part way across the culvert floor at an angle [BSB SS 1060P].
- Weirs are placed completely across culvert openings [BSB SS 1061P].
- Baffles or weirs shall not be placed across the culvert joints.
- When baffles or weirs are used, a rock splash basin shall be installed at the outlet end of the culvert as shown in Figure 7.2.4.11.1.

7.3.4.2.2 Weep holes

In cases such as a nearby natural spring, high water table, or use of a drainage blanket where it is advisable to reduce hydraulic pressure on a precast concrete box culvert, the Soils Design Unit or preliminary designer will recommend that weep holes be placed in exterior walls. The 4-inch diameter weep holes normally are placed in pairs, with the bottom hole one foot above the flow line. The top hole is placed one foot above the bottom hole and offset one foot, as shown in Figure 7.3.4.2.2-1. Weep hole spacing is typically 25 to 30 feet.

Each hole is covered with a rodent screen consisting of a 24-inch square by 1/4 inch galvanized hardware cloth centered on the weep hole. Normally the culvert contractor is required to place porous backfill over the weep holes, as shown in Figure 7.3.4.2.2-2, and also to furnish and place special backfill material when completing the Class 20 excavation.

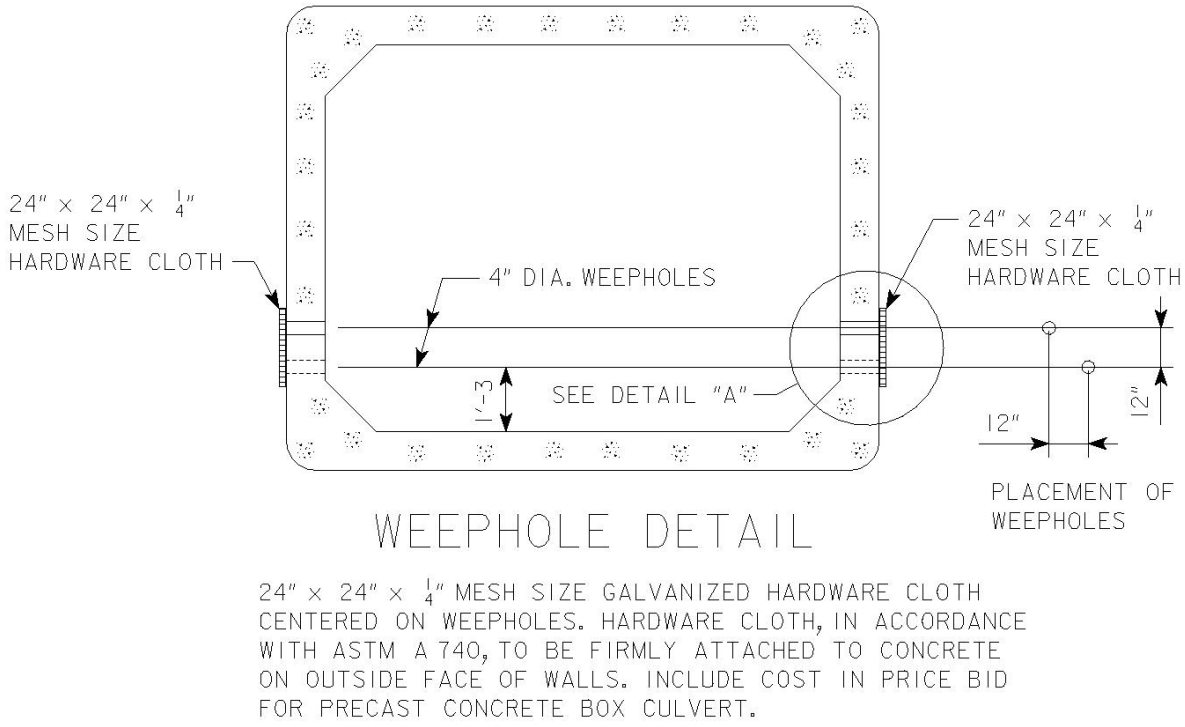


Figure 7.3.4.2.2-1. Exterior wall weep hole detail

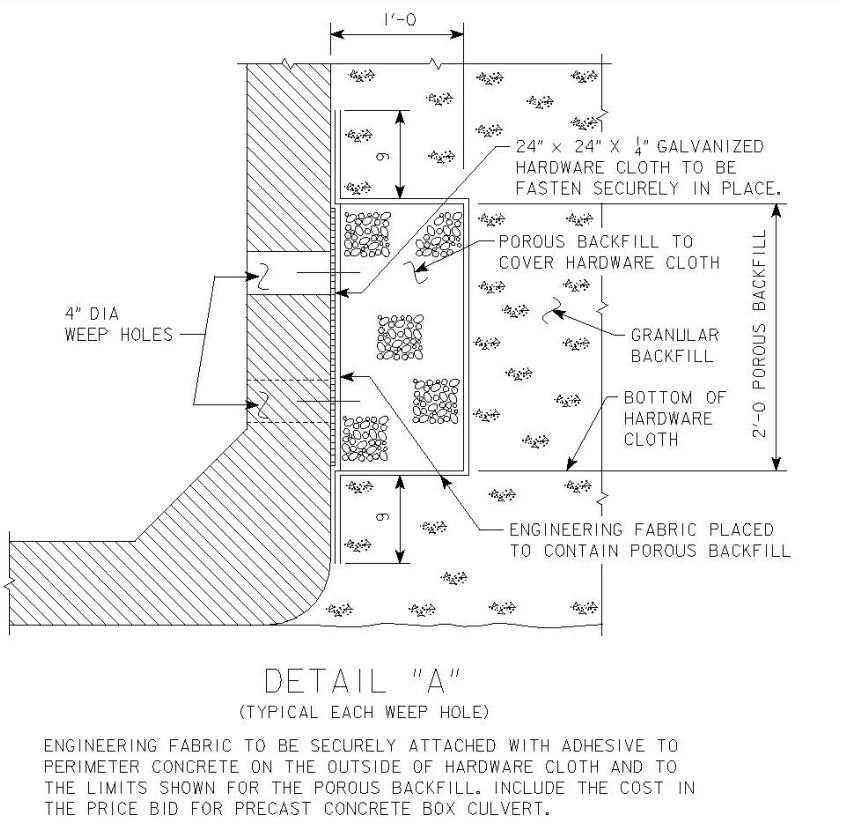


Figure 7.3.4.2.2-2. Typical individual weep hole detail

7.3.4.2.3 Bridge replacements

Reinforced concrete box culverts are sometimes placed and buried under an existing bridge instead of replacing the bridge. A precast box culvert should be included as an option for these types of projects. Refer to BDM 7.2.4.10 in addition to the guidelines given in this article.

In many cases, precast boxes cannot be lifted and set into place underneath a bridge due to low overhead clearance. Additionally, poor ground support conditions combined with the large construction equipment needed to lift and place the boxes under the bridge makes this method of placement difficult. As a result, contractors must often employ alternative installation approaches such as sliding boxes into place. While sliding is the most common alternative approach, the methods and materials used by different contractors to accomplish a sliding installation can be quite varied. The results of a sliding installation can also be quite varied with the following concerns being most prevalent: box damage particularly to the tongue and groove portions, final box support conditions which induce stress concentrations, and increased risk for piping. In order to mitigate the potential for these issues, project plans with precast boxes shall include CADD Note E685 which requires the contractor to submit a precast box installation plan for review and approval.

Acceptable methods and materials for a sliding installation might include the following. (Note that this list is only illustrative and is not intended to be exhaustive.)

- A full-width 8-inch thick unreinforced concrete pad as a sliding support surface. The concrete pad should typically terminate at least 18” from the end of any box in its final position. The top surface of the pad should be smooth. An approved lubricant may be applied to the concrete pad to reduce sliding friction.
- Construction equipment used in the sliding operation should not have direct contact with the precast box sections. Sliding operations should avoid quick, sharp, sudden movements. Typically, boxes should be pulled rather than pushed. Pulling devices may consist of high tension chains or

cables attached to a rigid cross beam spanning the width of the culvert. Attachment of the pulling devices to the cross beam should be close to each culvert wall. The cross-beam should typically be placed level at or near the height of the bottom haunches. Contact points between the cross beam and precast box should be made with a deformable material such as timber.

- For multiple lines of boxes, the 4 feet wide strip of engineering fabric beneath the bottom slabs of the two boxes in BSB SS 1082P may be omitted for any boxes resting on the concrete pad. Where the pad is omitted the fabric shall be included.

7.3.4.2.4 Pedestrian culverts

Precast culverts for pedestrian use shall consider the following items in addition to those listed in BDM 7.2.4.11.4.

- Culvert box ties shall not protrude beyond the interior wall surface since that will create a snagging hazard for pedestrians.
- For precast boxes, the 1'x1' corner haunches shall be omitted.
- The floor shall receive a minimum 2-inch thick unreinforced PC overlay after the culverts have been installed in order to provide an even walking surface from one end of the culvert to the other. The floor of the precast barrel shall be sand-blasted to facilitate bond between the floor concrete and PC overlay.
- Flared CIP end sections shall be used.
- Attach galvanized light fixture boxes and rigid steel conduit, if needed, to the culvert ceiling.
- Ensure interior culvert height provides intended clearance with consideration of overlay and light fixtures (BDM 3.5).

7.3.4.3 Granular leveling material

The excavation and granular blanket guidance in Sections 7.2.4.4.1 and 7.2.4.4.2 also applies to precast RCB culverts. In addition, all precast RCB culverts shall include a 6-inch thick layer of granular leveling material directly below the precast units. This allows the Contractor to establish the line and grade of the culvert prior to setting the precast units. The granular leveling material shall be considered incidental to culvert bid items. Refer to IDOT SS 4117 for material requirements. Special Backfill shall not be used for this material.

When the Soils Design Unit determines that a granular blanket or core-out is needed, the blanket or core-out shall be installed below the granular leveling material with engineering fabric separating the materials. A typical detail showing a precast RCB installation is provided in the commentary of this section.

7.4 Concrete pipe

In general, concrete pipe design and detailing is based on the Design Bureau's Standard Road Plans (DR series) and Road Design Details (1000 series). Only in unusual cases are pipe culverts custom designed.

7.4.1 Loads

Reserved.

7.4.2 Load application

Reserved.

7.4.3 Analysis and design

Reserved.

7.4.4 Detailing

7.4.4.1 Standard plans

See the Design Bureau's Standard Road Plans (DR series) and Road Design Details (1000 series).

7.4.4.2 Software

Reserved.

7.4.4.3 Plan preparation

Reserved.

7.4.4.4 General

Reserved.

7.4.4.5 Pipes

Reserved.

7.4.4.6 Headwalls

Reserved.

7.4.4.7 Inlets

Reserved.

7.4.4.8 Outlets

7.4.4.8.1 Flumes

For a site with considerable elevation difference the preliminary designer may add a flume at a pipe culvert outlet. In general the flume will be similar to a flume for a reinforced concrete box culvert, as indicated in the details in Figure 7.4.4.8.1.

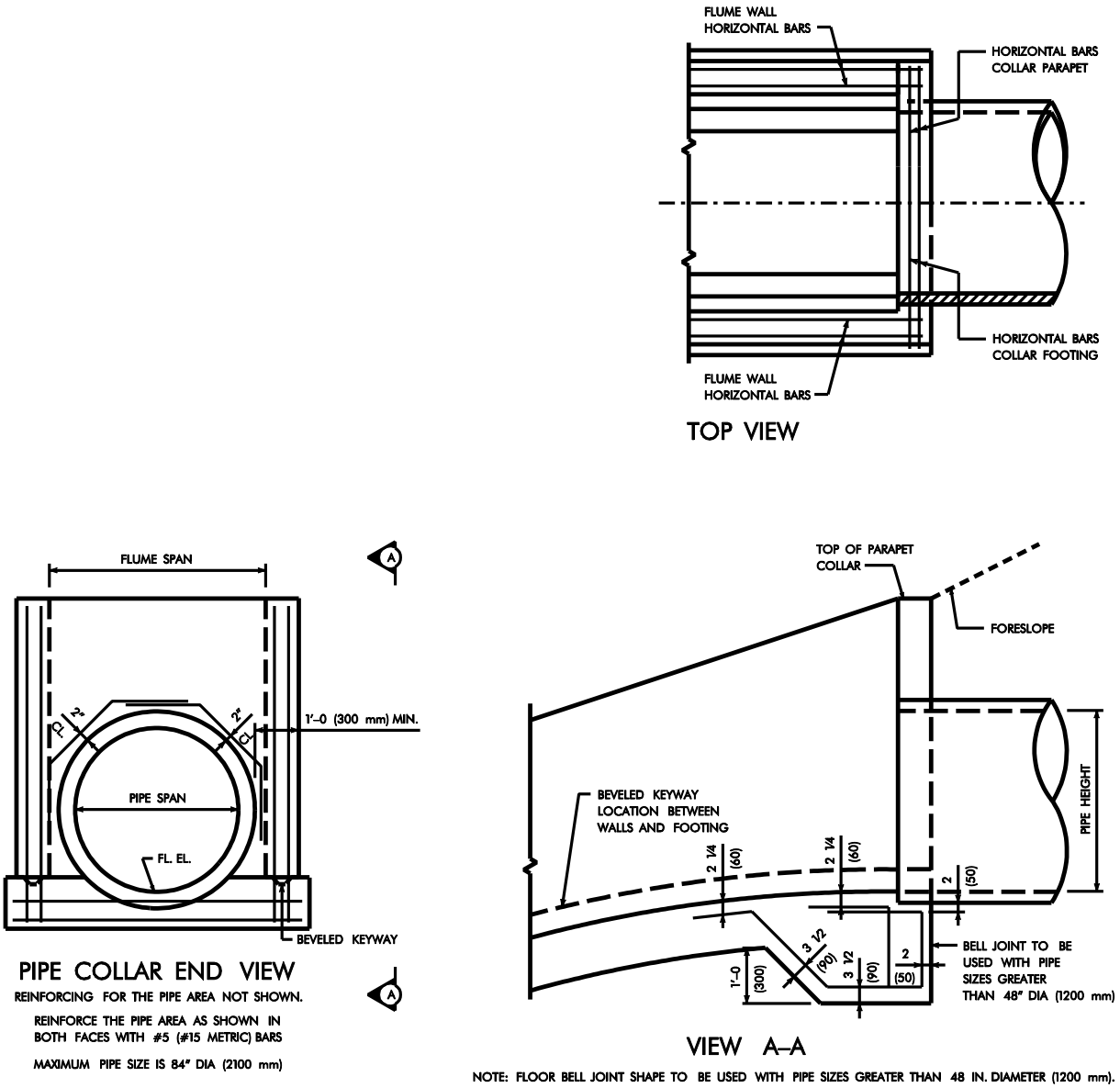


Figure 7.4.4.8.1. Flume details for standard reinforced concrete pipe

So that there is adequate wall thickness around the pipe for the cast-in-place, one-foot thick collar, the designer shall size the flume using Table 7.4.4.8.1.

Table 7.4.4.8.1. Flume size and height for standard reinforced concrete pipe

Reinforced Concrete Pipe Size (inches)	Flume Size (feet x feet)	Height from flowline to top of parapet (ft-in)
24	3 x 3	5’-4
30	4 x 4	6’-4
36	5 x 3	5’-4
42	5 x 4	6’-4
48	6 x 4	6’-4
54	6 x 5	7’-4
60	8 x 5	7’-4
66	8 x 6	8’-4
72	8 x 6	8’-4
84	10 x 8	10’-4

For skewed pipe culvert alignments 30° and greater with an embankment slope of 3:1, the slope of the top of the flume wall should be set at 4:1 to accommodate the skew.

7.4.4.9 Extensions

Reserved.

7.4.4.10 Miscellaneous

Reserved.

7.4.4.10.1 Pipe hand railings

For safety, where pedestrians or bicyclists are likely to be near pipe culvert inlets or outlets, the preliminary designer will require pipe hand railings at culvert parapets and drop inlets. The pipe hand railings should be detailed with the following considerations:

- Ease of handling and transporting and
- Size of galvanizing tanks [BDM 7.2.4.7.2].

General pipe hand railing details are shown in Figures 7.2.4.11.3-1 to 7.2.4.11.3-3. All posts are to be set vertical. In rural areas the designer should use the horizontal rail spacings shown in Figure 7.4.4.10.1-1 and embed posts one foot into concrete walls. In urban areas the designer should use the horizontal rail spacing shown in Figure 7.4.4.10.1-2 and select the base plate detail so that the hand railing can be replaced easily.

The hand railing sections shall be galvanized after fabrication. Drain holes to facilitate the hot dip galvanizing process shall be shown on the railing shop drawings.

The method of measurement for pipe hand railing is the length from end to end of railing [IDOT SS 2414.05, B].

For drop inlets in rural and urban locations, the railings should be detailed to show that the centerline of the top rail to be 3'-6 above the top of the drop inlet walls, which also should be 3'-10 above the flowline of the weir. In rural locations the centerline of the bottom rail is to be 1'-9 below the centerline of the top rail. In urban locations the horizontal rails shall be spaced at 7 inches as shown in Figure 7.4.4.10.1-2.

Parapet hand railings for rural locations are detailed the same as for drop inlets, as shown in Figure 7.4.4.10.1-1. However, parapet hand railings for urban locations need to be taller, 4’-8 as shown in Figure 7.4.4.10.1-2.

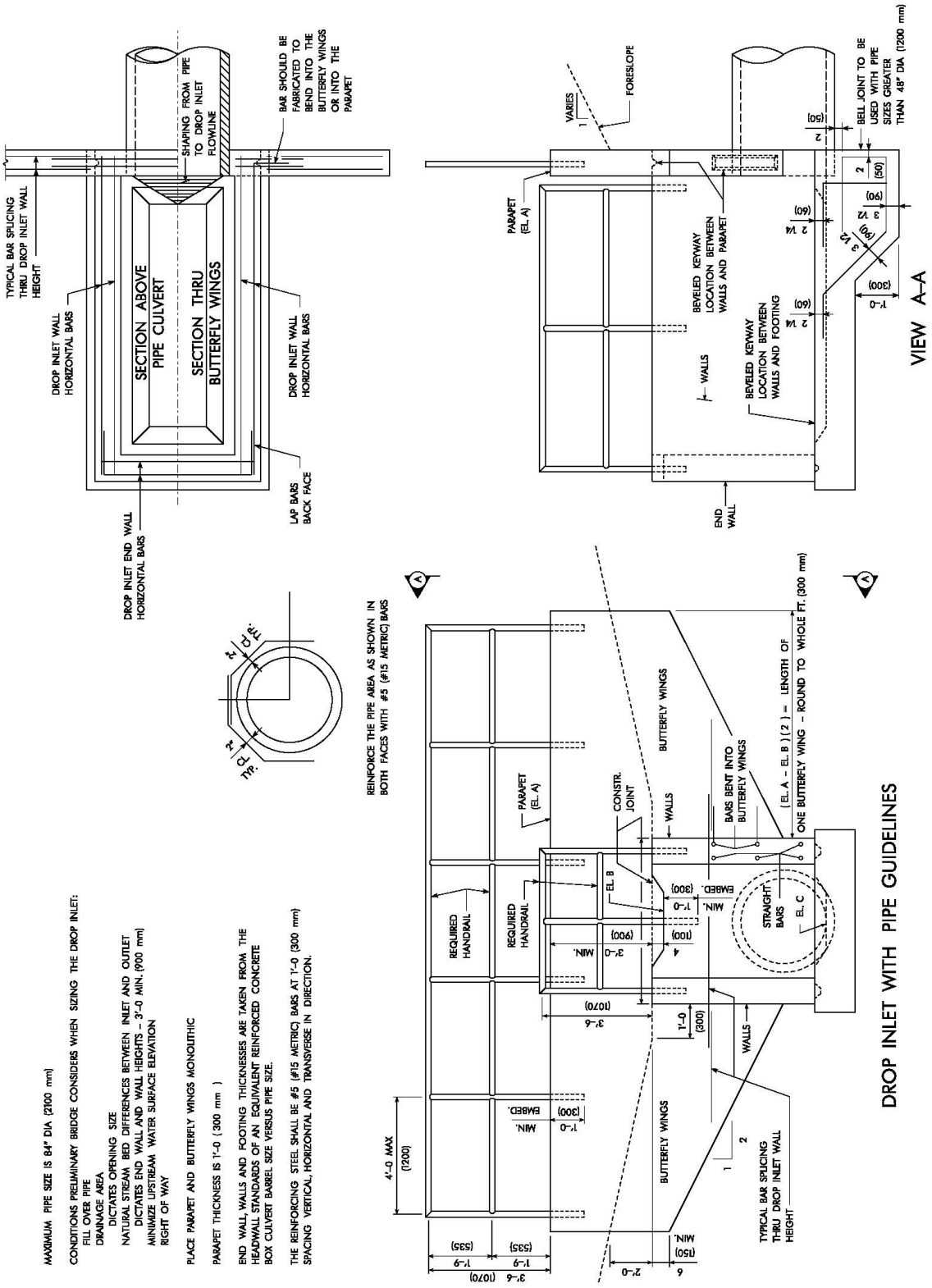


Figure 7.4.4.10.1-1. Rural pipe culvert railings

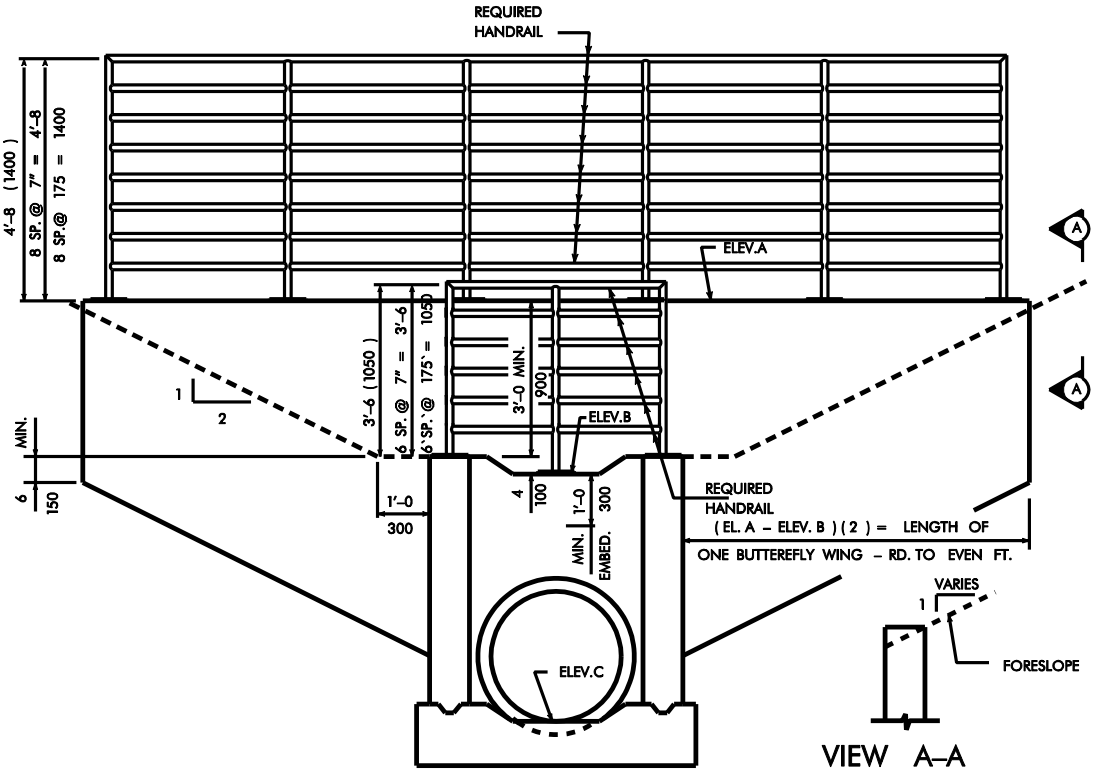


Figure 7.4.4.10.1-2. Urban pipe culvert railings