265 Reinforced Concrete Box and Three-Sided Culverts

265.1 General

The Department recognizes three types of culverts;

- Round and elliptical reinforced concrete pipe,
- Concrete box culverts (four-sided), and
- Three-sided concrete culverts.

This chapter presents the minimum requirements for concrete box culverts and three-sided concrete culverts, both of which are classified as Category 1 structures in accordance with ***FDM 121***. It is not possible to provide prescriptive requirements for all conditions so guidance provided in this chapter is for typical designs. Each location will usually have some unique character (e.g., floods, scour, surroundings, salt water, historic character). Unique environments need to be thoroughly evaluated and all environmental requirements satisfied.

The procedure for the hydraulic analysis of culverts differs based on whether the culvert is located at a riverine or tidal crossing. Refer to ***Chapter 4*** of the ***Drainage Manual*** for the appropriate hydraulic analysis and documentation requirements.

Definitions of terms used in this chapter include the following:

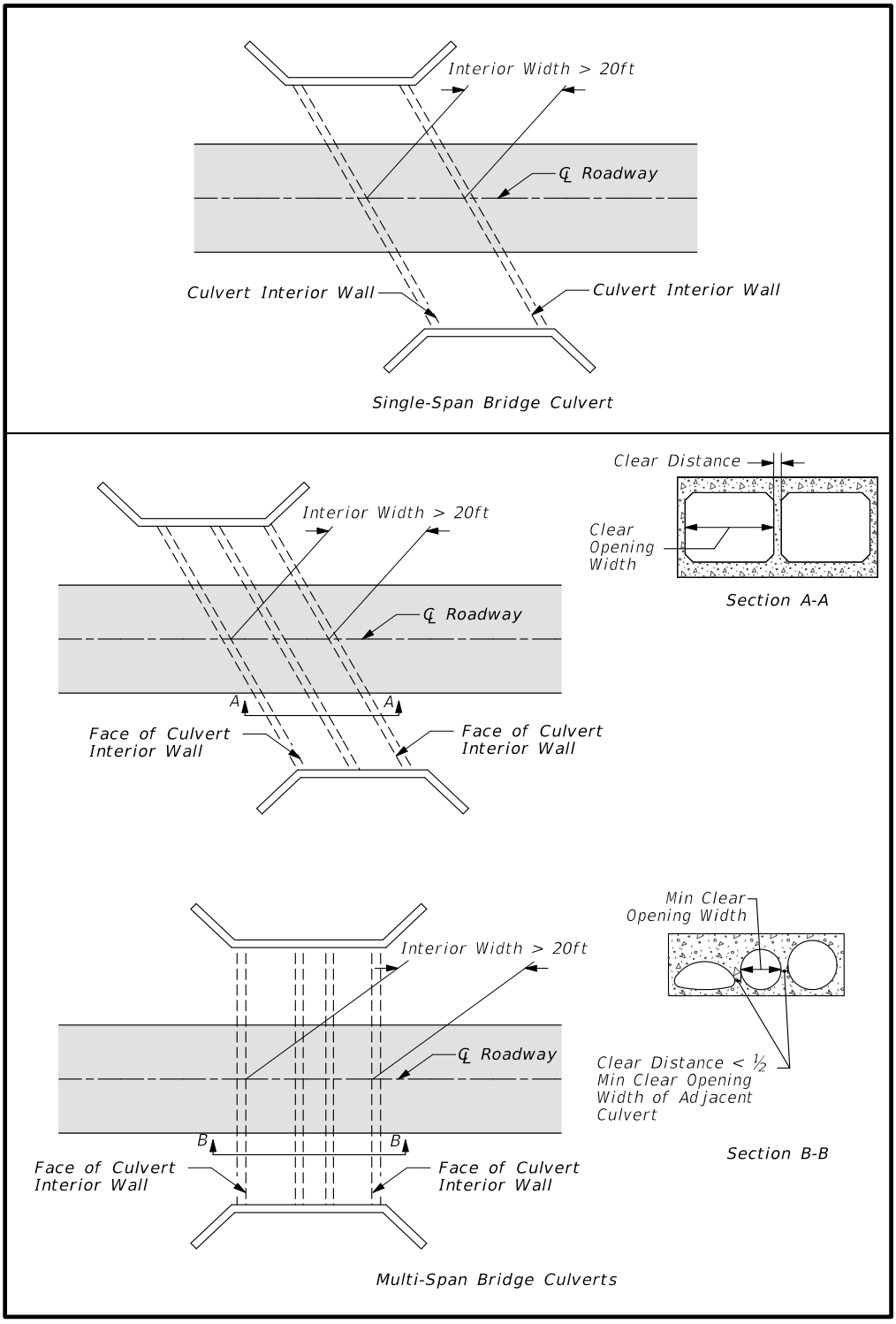
Culverts are structures under the roadway with an interior width of less than or equal to 20 feet. The interior width is measured along the centerline of the roadway from face-to-face (inside) of the extreme abutments or sidewalls.

The National Bridge Inspection Standards classify the following culverts as bridge-sized (a.k.a., bridge culverts):

- Box and three-sided culverts with a clear opening measured along the center of the roadway > 20 feet, or between the extreme ends of openings for multiple boxes;
- Also includes multiple pipes where the clear distance between openings is less than ½ of the smaller adjacent opening.

Figure 265.1.1 provides an illustration of a single-span and a multi-span bridge culvert.

Figure 265.1.1 Examples of Bridge Culverts



Concrete box culverts (four-sided) typically have rectangular cross sections. An arch or arch-topped culvert is considered a box culvert if the “sidewalls” are built monolithic with the bottom (invert) slab. Two-piece (four-sided) box culverts are permitted with a simply supported top slab, which is keyed into a monolithic three-sided bottom section. Concrete box culverts are typically used where the streambed is earth or granular soil and rock is not close enough to the streambed to directly support the structure.

Three-sided concrete culverts may be rectangular in shape or a frame with varying wall and slab thickness or an arched or arch-topped structure. These structures have separate foundations with spread footings supported by earth, rock or piles. The largest culverts are typically not boxes; rather they are frames or arches. Use of three-sided concrete culverts where rock is not at or near the streambed requires pile support for the footings or some other form of positive scour protection. Three-sided concrete culverts on spread footings may be used for railroads, wildlife crossings, bicycle/pedestrian/ equestrian/golf cart paths, and other uses that do not convey water or have scour vulnerability.

Clear span is the perpendicular distance between the inside face of the sidewalls. The maximum clear span recommended for a concrete box culvert is 24 feet.

Design span for non-skewed culverts is the perpendicular distance between the centerline of the sidewalls. For culvert units with skewed ends, the design span of end sections is the distance between the centerlines of the sidewalls measured parallel to the skewed end.

265.2 Structure Type Selection

Determine the most appropriate type of short-span structure. The basic choices are a corrugated metal structure, concrete box culvert, concrete frame or arch, and a short-span bridge. While the site conditions are the primary deciding factor for structure selection, aesthetics, constructability and economics are also very important.

Proper selection of the feasible structure alternatives is based on site and project-specific parameters, including but not limited to:

(1) Vertical and horizontal clearance requirements

(2) Available “beam” (top slab) depth

(3) Maintenance and protection of traffic requirements (e.g., phase construction)

(4) Construction constraints (e.g., water diversion requirements)

(5) Foundation requirements

(6) Environmental concerns (e.g., natural streambed)

(7) Desired aesthetic treatments (e.g., arch appearance)

(8) Geometric limitations (e.g., skew angle, right of way restrictions, utilities)

Concrete culverts are usually more expensive in initial cost than corrugated metal structures. However, concrete culverts are the preferred alternative when considering suitability to the site and life-cycle cost estimates. The advantages of concrete culverts are superior durability for most environmental conditions, greater resistance to corrosion and damage due to debris, greater hydraulic efficiency, and typically longer service life.

Concrete culverts are typically the least expensive option at sites with limited headroom. Smaller corrugated metal structures typically require a minimum height of soil cover of 2 feet and for some structures the soil cover increases to 4 feet or more depending on size and shape. Concrete culverts, frames, and arches can have the least amount of cover by placing a minimum of 3 inches of asphalt pavement directly on the top slab. Corrugated metal structures will also typically require taller structures than concrete box culverts, to provide adequate waterway area below design high water due to their arched shapes. If a corrugated metal structure is a viable option, an engineering evaluation and cost analysis should be performed in consultation with the District Drainage Engineer.

Single-cell and multi-cell concrete box culverts with barrel spans less than 15 feet, are often the most cost effective structural solution where debris collection and aesthetics are not a major concern. Three-sided culverts may be appropriate for single spans exceeding 20 feet where scour is not a concern.

The use of a short-span bridge should be investigated before a final determination is made to use a large concrete culvert. Possible advantages of a bridge may be minimized work in the stream, speed of erection, minimized interference with the existing structure foundation, and easier phased construction. See ***FDM 121*** for procedural steps on planning short-span bridges.

265.2.1 Precast Concrete Culverts

Precasting permits efficient mass production of concrete units. The advantages often offset the cost of handling and transporting the units to the site. Precast units are often limited to certain sizes and skews due to forms, transportation and handling concerns. Skewed units typically need more reinforcement and thicker slabs and/or sidewalls. The use of skewed units will increase the cost of the culvert due to increased fabrication costs.

Skewed end units are sometimes required to satisfy right of way constraints and/or phased construction requirements for skewed alignments. In the event they are necessary, skewed

precast culvert units must be designed for the skewed-end design span. Precast manufacturers should be contacted for information on maximum skews available.

Precast culverts may occasionally need to be placed on moderate or steep grades. No maximum slope is recommended for box culverts because of the need to match the slope of the streambed. Three-sided box culverts and the frames and arches should be limited to a maximum slope of 2%. Precast manufacturers should be contacted for the maximum grade that can be fabricated if a grade larger than 2% is proposed. If matching a steeper slope is necessary, the ends of the precast units must be beveled to create vertical joints and the footings may be stepped or the length of the sidewall varied.

Provide a 2 to 4 inch gap between the walls of adjacent cells when two or more single-cell, precast concrete culverts are placed side-by-side. Fill this gap with Class I (non-structural) concrete, non-excavatable, flowable fill or non-shrink grout.

All manufacturers must have approved precast drainage product facilities in accordance with ***Section 6.3*** of the ***Materials Manual***.

265.2.2 Concrete Box Culverts

A cast-in-place culvert must be designed and detailed in the contract plans when a concrete box culvert is selected as the appropriate structure for the site. A precast concrete box culvert alternative is permitted during construction unless specifically excluded in the contract plans. Speed of erection, maintenance of traffic, stream diversion problems, and site constraints can be minimized when utilizing precast culverts.

265.2.3 Three-Sided Concrete Culverts

There are various types of proprietary, precast concrete frames, arch topped units, and arches available. These units are typically used when larger culverts (spans ≥ 20 feet) are required. They can only be considered when scour protection is adequately provided or aesthetics are a consideration. They may be placed on spread footings with an invert slab, footings on rock, or pile-supported footings. The advantages of the precast concrete arches and frames are the same as for the precast concrete box culverts, except that longer spans (up to 48 feet) are possible.

A precast culvert should be the preferred option when a three-sided concrete culvert is selected as the appropriate structure for the site. A cast-in-place reinforced concrete foundation and the channel lining must be designed and detailed in the contract plans. The final design of the precast three-sided culvert structure and any necessary foundation

modifications must be completed by the Contractor's Engineer of Record (usually the manufacturer).

Sizes of precast units that are common to more than one manufacturer should be selected. Dimensions of the sidewalls and top slab, reinforcement size and spacing should not be shown on the plans, unless necessary. If sidewall or top slab dimensions are dictated by site conditions, only show the affected dimensions and indicate if they are minimums, maximums, or specifically required dimensions. The assumed top slab dimension used to determine fill limits should be shown in the contract plans.

Include a note in the contract plans requiring the Contractor to provide all design details not included in the contract plans. This method should result in the most economical culvert design.

265.2.3.1 Precast Arch and Arch-Topped Units

Consider the following when selecting a precast arch or arch-topped culvert:

(1) Aesthetics concerns may make the use of arch-shaped units desirable. The use of arch-shaped facade panels is not recommended, especially for hydraulic openings due to snagging of debris.

(2) The amount of skew that can be fabricated varies. Some manufacturers prefer to produce only 0° skew units. The maximum skew at which a precast unit should be fabricated is 45°. The culvert orientation to the centerline of the highway may be at a skew greater than 45°.

(3) An arch unit is preferable for a grade separation for highway vehicles or railroads, when a dry conveyance environment is necessary. The arch shape eliminates any ponding problems above the culvert without special fabrication or field adjustments that would be required for flat-topped culverts.

(4) Arch units are preferred in cases where fills above the precast units exceed 20 feet.

(5) Precast arch-topped units are currently available in spans up to 48 feet.

(6) Arched units have been used as liners for old masonry or concrete arches in other States. After the construction of a pedestal wall at the base, the units are slid into place. The void between the existing arch and the liner is filled with grout installed through fittings cast into the liner units.

(7) Large arch units may be shipped in two pieces and assembled on site. Three-piece units are not permitted.

265.2.3.2 Precast Frame Units

Consider the following when selecting a precast frame (rectangular) culvert:

(1) Many of precast frame-type units can be fabricated with skew angles up to 45°. This characteristic is useful when phased construction is proposed. When used for phased construction with shallow highway pavements, no temporary shoring is needed at the phase construction joint to support the fill or pavement.

(2) Frame units provide a simpler traffic railing/headwall connection than arch-topped units.

(3) Frame units provide a hydraulic opening greater than arches of equivalent clear span when flowing full.

(4) Precast frame units can be fabricated by some manufacturers with any increment of span length up to 40 feet, although typical span length increments are 2 feet.

(5) Maximum rise of the units is normally limited to 10 feet due to shipping and handling considerations. Investigate the need for a pedestal wall when a larger rise is necessary.

265.3 Foundation Design

All structures discussed in this chapter, regardless of span and height of fill, are considered buried structures in regard to foundation design. There is no requirement for seismic analysis; however, this may change in the future as more research is completed.

For culverts with spans greater than or equal to 20 feet, foundation recommendations are provided in the Bridge Geotechnical Report (Phase I) and included in the Bridge Development Report (BDR). Foundation design parameters for culverts with spans less than 20 feet are provided by the District Geotechnical Engineer or the Department's Geotechnical Engineering consultant. Foundation recommendations and design parameters must include factored bearing resistance, predicted total and differential settlements, and any required excavation and replacement to ensure proper behavior of the foundation.

The District Geotechnical Engineer or the District Structures Design Office should be consulted to determine the proper foundation treatment.

Modification for Non-Conventional Projects:

Delete ***FDM 265.3*** above and replace with the following:

265.3 Foundation Design

All structures discussed in this chapter, regardless of span and height of fill, are considered buried structures in regard to foundation design. There is no requirement for seismic analysis. The EOR will coordinate the foundation recommendations with the geotechnical engineer for the project. Foundation design parameters must be shown in the contract plan set and will include factored bearing resistance, predicted total and differential settlements, and any required excavation and replacement to ensure proper behavior of the foundation.

265.3.1 Rock Foundations

In the unusual case where sound rock is at or near the surface of a streambed, an invert slab is not required and a three-sided culvert would generally be the appropriate structure selected. Concrete footings are either keyed or doweled into rock based on consultation with an Engineering Geologist and the District Geotechnical Engineer.

The wall height should be constant and the footing height varied when the elevation of the rock surface varies by 2 feet or less. If the variation in rock surface elevation exceeds 2 feet, the height of the culvert wall may be varied at a construction joint or at a precast segment joint. In some cases, it may be necessary to use walls of unequal heights in the same segment, but this should generally be avoided.

265.3.2 Earth or Granular Soil Foundations

In most cases a concrete culvert will not be founded on rock, so a box culvert (four-sided) with an integral invert slab should be the preferred foundation treatment. In areas of compact soil and low stream velocities, three-sided concrete culverts may be used if they have positive scour protection such as piles or channel lining with concrete-filled mattresses, gabions or riprap rubble, and spread footings founded below the calculated scour depth. Three-sided concrete culverts located in stream beds, with spans equal to or exceeding 20 feet, must have pile supported footings when the structure is not founded on sound rock.

Concrete box culverts should never be founded partially on rock and partially on earth to avoid differential settlement. If rock is encountered in a limited area, it should be removed to a minimum depth of 12 inches below the bottom of the bottom slab and backfilled with

either select granular material or crushed stone. Concrete culverts are rigid frames and do not perform well when subjected to significant differential settlement due to a redistribution of moments. All concrete box culverts should have a designed undercut and backfill. Consult the District Geotechnical Engineer to determine the depth of the undercut and type of backfill material required to prevent excessive differential settlement. Any required undercut and backfill must be shown on the plans.

Modification for Non-Conventional Projects:
Delete the above paragraph and replace with the following: The EOR will coordinate the depth of undercut and type of backfill with the geotechnical engineer for the project and include the details in the contract plans.

A concrete box culvert can be considered if settlement is expected and the foundation material is fairly uniform. The culvert should be designed to accommodate additional dead load due to subsequent wearing surface(s) which may be needed to accommodate the settlement of the box. Precast culverts require mechanical connections between units when significant differential settlement is anticipated. ***Standard Plans***, ***Index 400-291*** provides criteria for cast-in-place link slab to satisfy this requirement when joint openings are expected to exceed 1/8 inch. The District Geotechnical Engineer or the Department's Geotechnical Engineering consultant should provide the anticipated differential settlement, which should be included in the contract plans.

If the foundation material is extremely poor and it is desirable to limit settlement, coordinate with the District Geotechnical Engineer to determine the best course of action. A typical remedy might be removal of unsuitable or unstable material and replacement with suitable material. All required remedies must be shown on the plans.

265.3.3 Three-sided Culvert Foundation Design

Provide a cast-in-place footing design in the contract plans when a three-sided structure is selected for a site. There are several types of culverts that may meet the project specifications. Determine which specific type of unit would best fit that particular application and use those vertical and horizontal reactions for design of the foundations. Consider contacting known fabricators for design reactions. If no specific type of unit is determined as most appropriate, a conservative estimate of the design reactions for all types should be used and the reactions included in the contract plans.

Modification for Non-Conventional Projects:
Delete ***FDM 265.3.3*** and replace with the following: **265.3.3 Three-sided Culvert Foundation Design** When a three-sided structure is selected for a site, the specific culvert details including the cast-in-place footing design must be included in the contract plans.

265.4 Wingwalls

A wingwall is a retaining wall placed adjacent to a culvert to retain fill and to a lesser extent direct water. Wingwalls are preferably cast-in-place, but precast wingwalls may be considered on a project by project basis. Wingwalls are generally designed as cantilevered retaining walls. Precast counterfort and binwalls may also be considered for design of wingwalls. Cast-in-place wingwall designs are provided by the Department's standard box culvert computer program.

Wingwall alignment is highly dependent on site conditions and should be evaluated on a case-by-case basis. The angle(s) of the wall(s) on the upstream end should direct the water into the culvert. It is also desirable to have the top of the wall elevation above the design high water elevation to prevent overtopping of the wall.

Consider potential conflicts with R/W limits and utilities when precast wingwalls are permitted. The footprint of the footing and excavation, especially for bin type walls, can be extensive. Notes should be placed on the plans alerting the Contractor to these requirements when they exist. Due to skew or grade differences between the cast-in-place or precast culvert units and precast wingwalls, it is necessary to provide a cast-in-place closure pour between the culvert end unit and precast wingwalls. A closure pour is not required if cast-in-place wingwalls are used.

When precast wingwalls are permitted, the cost is included in the cost of the culvert barrel. No separate item is required but the estimated concrete and reinforcing steel quantities for a cast-in-place design should be included in the contract plans.

Modification for Non-Conventional Projects:
Delete ***FDM 265.4*** above and replace with the following: **265.4 Wingwalls** Precast wingwalls will only be permitted when specifically allowed in the RFP. The specific culvert details must be included in the contract plans.

265.5 Headwalls/Edge Beams

Headwalls are normally used on all culverts. In deep fills a headwall helps retain the embankment. In shallow fills the headwall may retain the roadway and provide the anchorage area for the railing system.

Headwalls should be cast-in-place and attached to precast culvert end segments in accordance with ***Standard Plans***, ***Index 400-291***. Headwalls one foot or less in height with no railing attachment for single barrel precast culverts may be precast. If a curb must be placed on a culvert without a sidewalk, the headwall must be cast-in-place to allow for the tie-in of the curb's anchor bar, unless the curb is also cast at the precast facility.

The typical maximum height of headwalls is 3 feet. Greater heights are attainable but are only used in special cases. Headwall heights greater than 2 feet above the top slab require an independent transverse analysis, which is not provided by the FDOT box culvert program.

Concrete culverts with skewed ends may require additional stiffening of the top and bottom slabs by what is most commonly called an "edge beam". An edge beam is similar to a headwall or cutoff wall. The headwall may be used to anchor metal traffic railing posts and traffic railings or retain earth fill, as well as stiffening the top slab of culverts that lose their rigid frame action as a result of having a skewed end.

When additional strength is required in the concrete edge beam, use the following criteria:

(1) If there is a 1-on-2 slope to the edge beam, it will be more economical to increase the depth of the edge beam in order to meet the required design.

(2) When the edge beam is at shoulder elevation (anchoring guard rail and traffic railing), the edge beam height should be maintained and the width of the edge beam should be increased.

265.6 Cutoff Walls

A cutoff wall is required in all culverts with invert slabs to prevent water from undermining the culvert. The cutoff wall should be a minimum 24 inches below the bottom of the invert slab or to the top of sound rock if the rock is closer. Investigate the need for deeper cutoff walls when culvert is founded on highly permeable soils or with significant hydraulic gradients. The cutoff wall may also act to stiffen the bottom slab for skewed box culverts.

Cutoff walls must always be specified at each end of the barrel. When a concrete apron is provided, show an additional cutoff wall at the end of the apron. For three-sided culverts, where the apron is made continuous with the barrel invert slab, the cutoff wall is only required at the end of the apron. The wingwall footings should have toe walls extending close to the bottom of the cutoff wall to prevent scour around the edges of the cutoff wall.

When a precast culvert is specified, the cutoff wall must be cast-in-place. The cost of the cutoff wall is included in the cost of the culvert barrel. No separate item is required but the estimated concrete and reinforcing steel quantities should be included in the contract plans.

265.7 Aprons

Box culverts can significantly increase the stream flow velocity because the concrete has a roughness coefficient significantly lower (i.e., smoother) than the streambed and banks. To dissipate this increase in energy and to prevent scour, a riprap rubble or other type of revetment apron may be required at the ends of some culverts. The District Drainage Engineer should be consulted to determine the appropriate apron requirements.

Modification for Non-Conventional Projects:
Delete the last sentence in above paragraph and see RFP for requirements.

The apron must be cast-in-place when a precast culvert is specified with a concrete apron. The cost of the apron is included in the cost of the culvert barrel. No separate item is required but the estimated concrete and reinforcing steel quantities should be included in the contract plans.

Modification for Non-Conventional Projects:
Delete the above paragraph and replace with the following: When a precast culvert is specified with a concrete apron, the apron must be cast-in-place.

265.8 Subbase Drainage

In some situations where there is low fill (< 12 inches below the base course) ***Standard Plans*, *Index 400-289*** requires additional friable base or coarse aggregate material above the top and along the sides of the culvert to eliminate maintenance problems.

265.9 Joint Waterproofing

Culverts will occasionally be used to allow the passage of things other than water, including but not limited to pedestrians, bicycles, trains, golf carts, wildlife, or farm animals. In cases where it is desirable to have a dry environment, a waterproof joint wrap should be used to cover the joints between precast culvert units or to cover the construction joints in cast-in-place culverts.

Even though a joint sealer is always placed between individual precast concrete culvert units and the units are pulled tightly together, water may seep through the joint. The minimum requirement for waterproofing these joints is to provide an external sealing band in accordance with ***ASTM C 877***, centered on the joints, covering the top slab, and then extending down the sidewalls to the footing. The purpose of the waterproofing membrane is to restrict seepage of water or migration of backfill material through the joints in the culverts and it is not intended to protect the concrete.

The external sealing band is mandatory for precast three-sided culverts under ***Section 407*** of the ***Standard Specifications*** but will need to be included as a note in the contract plans when required for box culverts.

265.10 Traffic Railings

For information regarding roadside barriers or traffic railings refer to ***FDM 215***.

265.11 Design Requirements for Concrete Culverts

Refer to the ***Chapter 3*** of the ***Structures Design Guidelines*** for design and analysis requirements.

265.12 Design Details

Provide a complete cast-in-place design in the contract plans when a box concrete culvert is proposed for a site. Standard details for concrete box culverts are provided in the ***Standard Plans, Index 400-289***. The contractor is usually permitted to substitute precast concrete box culverts for cast-in-place box culverts in accordance with ***Section 410*** of the ***Standard Specifications***. The contractor may select a standard precast box culvert design in accordance with ***Standard Plans, Index 400-292*** or provide a custom design. Design and fabrication details for precast box culverts, including calculations for custom designs, must also comply with the requirements of ***Standard Plans, Index 400-291*** and be submitted to the Engineer of Record for approval.

Provide either a complete cast-in-place design or a conceptual precast barrel design with a complete foundation and wingwall design, in the contract plans when a three-sided concrete culvert is proposed for a site. The contractor is permitted to substitute precast three-sided culverts for cast-in-place three-sided culverts in accordance with ***Section 407*** of the ***Standard Specifications***. Design and fabrication details for precast three-sided culverts, including calculations, must be submitted to the Engineer of Record for approval. Do not place wildlife shelves in hydraulic structures.

The bar designations in ***Table 265.12.1*** should be used for box culvert reinforcement:

Table 265.12.1 Bar Identification Schedule

BAR IDENTIFICATION SCHEDULE		
C.I.P. (LRFD) Index 400-289	**Precast (LRFD) Index 400-292**	**Description / Bar Location**
105	As1	Top Corner Bars
106	As1	Bottom Corner Bars
102	As2	Top Slab, inside face transverse bars
103	As3	Bottom Slab, inside face transverse bars
101	As1/As7	Top Slab, outside face transverse bars
104	As1/As8	Bottom Slab, outside face transverse bars
108	As4	Exterior wall, inside face vertical bars
105/106	As1	Exterior wall, outside face vertical bars
107	-	Interior wall, vertical bars both faces
110/111	As6/As9	Top Slab longitudinal bars (temperature reinf.)
109/112	As9	Bottom Slab longitudinal bars (temperature reinf.)
113/114		Exterior wall longitudinal bars (temperature reinf.)
115/ 116…		Interior wall longitudinal bars (temperature reinf.)
111	As5	Top Slab inside face longitudinal bars (design distribution reinforcement)

Additional reinforcing bars and designations must be added as required. No standardized bar designations are provided for three-sided culverts.

Modification for Non-Conventional Projects:

Delete ***FDM 265.12*** and replace with the following:

265.12 Design Details

Provide complete details for the proposed concrete culvert in the contract plans.

265.13 Computer Design and Analysis Programs

The Department's ***LRFD Box Culvert Program*** (Mathcad) from the Structures Design Office website is available for LRFD designs. This program analyzes monolithic single or multi-barrel box culverts with prismatic members and integral bottom slabs only. The program requires input for all member thicknesses, material properties and reinforcing area utilizing a trial and error design methodology.

Other computer programs are available for design of reinforced concrete culverts such as BOXCAR and CANDE. Generally these other computer programs should only be used for preliminary designs or independent quality assurance checks. Consult with the State Structures Design Office before using one of these other programs in lieu of the FDOT box culvert program.

265.14 Design and Shop Drawing Approvals

The Engineer of Record for the contract plans has design and shop drawing approval authority for precast concrete box and three-sided culverts. All calculations and shop drawings require a quality assurance review for general compliance of contract requirements and for suitability of the design for the given design conditions.

Standard precast concrete box culvert designs are available in ***Standard Plans***, ***Index 400-292*** for a limited number of box culvert sizes. Modification of FDOT standard box culverts or design of special size box or three-sided culverts is delegated to Contractor's Engineer of Record in accordance with the ***Section 407*** and ***Section 410*** of the ***Standard Specifications***. The Contractor is responsible for providing all design computations and details for these units.

Modification for Non-Conventional Projects:
Delete ***FDM 265.14*** and replace with the following: **265.14 Design and Shop Drawing Approvals** The Engineer of Record for the contract plans has shop drawing approval authority for precast concrete box and three-sided culverts.