Chapter 33

Reinforced Concrete Box and Three-Sided Culverts

Tables

Chapter 33

Reinforced Concrete Box and Three-Sided Culverts

33.1 General

This chapter presents the minimum requirements for selection and designing reinforced concrete culverts. The Department recognizes two types of reinforced concrete culverts other than reinforced concrete pipe. These are concrete box culverts (four-sided) and three-sided concrete culverts. Both of these culvert types are classified as Category 1 structures in accordance with ***Chapter 26***. 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 (floods, scour, surroundings, salt water, historic character, etc.). Unique environments need to be thoroughly evaluated and all environmental requirements satisfied.

Structures with a span greater than or equal to 20 feet are technically not culverts, however, for simplicity all structures in this chapter are referred to as culverts. The procedures for designing culverts and bridges maybe different due to the differing risks associated with the size of the structure. Safety and economic issues and technical complexity can vary significantly with differing site conditions which will dictate the size and type of the most appropriate structural solution. Bridge-size culverts (≥ 20 feet span) warrant more complex hydraulic and foundation treatments, which require the expertise of a bridge engineer. Simpler, less complex and smaller culvert-size structures (≤ 12 feet span) may be designed with minimal oversight of a bridge engineer. Any questions on who should design a specific-size structure should be discussed with the District Structures Engineer.

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:

Bridge-size culverts are defined as any structure, whether of single-span or multiple-span construction, with an interior width greater than or equal to 20 feet when measured horizontally along the centerline of the roadway from face-to-face (inside) of the extreme abutments or sidewalls.

Culverts are defined as any structure, whether of single-span or multiple-span construction, with an interior width less than 20 feet when measured horizontally along the centerline of the roadway from face-to-face (inside) of the extreme abutments or sidewalls.

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/or 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.

33.2 Structure Type Selection

The designer must 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, R.O.W. restrictions, utilities, etc.).

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 (i.e., potentially lower life-cycle costs).

At sites with limited headroom, concrete culverts are generally the least expensive option. 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.

Before a final determination is made to use a large concrete culvert, the use of a short-span bridge should be investigated. 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. For procedural steps on planning short-span bridges, see ***Chapter 26***.

Information on corrugated metal structures (steel and aluminum) is available in the ***Drainage Manual***. When corrugated metal structures are more cost efficient and they may be considered for off-system routes where there will be no major risk of corrosion or by utilizing concrete pedestal walls to ensure there is infrequent water contact with the metal portion of the structure.

33.2.1 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 may 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 precast culvert units should be avoided, if practical. Precast concrete culverts should have square ends, whenever possible. 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 shall be designed for the skewed-end design span. Large skews may lead to units that require additional reinforcement and/or greater wall and slab thickness than typical square units with the same clear opening. Manufacturers should be contacted for information on maximum skews available when only precast culverts are shown in the contract plans.

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%. If matching a steeper slope is necessary, the ends of the precast units should be beveled to create vertical joints and the footings may be stepped and/or the length of the sidewall varied. Precast manufacturers should be contacted for the maximum grade that can be fabricated if the designer is proposing a grade larger than 2%.

When two or more single-cell, precast concrete culverts are placed side-by-side, it is usually not possible to place the walls of adjacent cells tightly together. The standard detail is to provide a 2 to 4 inch gap between the walls of adjacent cells. This gap should be filled 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*** the ***Materials Manual***.

33.2.2 Concrete Box Culverts

When a concrete box culvert is selected as the appropriate structure for the site, a cast-in-place culvert must be designed and detailed in the contract plans. A precast concrete box culvert alternative is usually 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 the Contractor utilizes precast culverts.

33.2.3 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 be considered when scour protection can be adequately provided and/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.

When a three-sided concrete culvert is selected as the appropriate structure for the site a precast culvert should be the preferred option. 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 should 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, show only 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.

A note in the contract plans shall require the Contractor to provide all design details not included in the contract plans. This method should result in the most economical culvert design.

33.2.3.1 Precast Arch and Arch-Topped Units

The following guidelines should be considered when selecting a precast arch or arch-topped culvert:

9. 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.
10. 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°.
11. 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.
12. Arch units are preferred in cases where fills above the precast units exceed 20 feet.
13. Precast arch-topped units are currently available in spans up to 48 feet.
14. 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.
15. Large arch units may be shipped in two pieces and assembled on site. Three-piece units are not permitted.

33.2.3.2 Precast Frame Units

The following guidelines should be considered 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. If a larger rise is necessary, the designer should investigate the need for a pedestal wall.

33.3 Foundation Design

All structures discussed in this chapter, regardless of span and height of fill, are considered buried structures in regard to foundation design. Thus, there is no requirement for seismic analysis. 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 to the designer 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.

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

33.3.1 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.

If the elevation of the rock surface varies by 2 feet or less, the wall height should be constant and the footing height varied. 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.

33.3.2 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. However, 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.

To avoid differential settlement, concrete box culverts should never be founded partially on rock and partially on earth. 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 located in streambeds should have a designed undercut and backfill. The standard undercut and backfill by ***Section 125*** of the ***Specifications for Road and Bridge Construction*** is 4 feet. The District Geotechnical Engineer should be consulted to determine the depth of the undercut and type of backfill material required for sites not located in streambeds or where significant settlement is anticipated.

A concrete box culvert can be considered if settlement is expected and the foundation material is fairly uniform. However, 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 may require mechanical connections between units when significant differential settlement is anticipated. ***Design Standards Index No. 291*** provides criteria for cast-in-place bond beams to satisfy this requirement when joint openings are expected to exceed 1/8 inch. A Geotechnical Engineer 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, the problem should be referred to 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.

33.3.3 Three-sided Culvert Foundation Design

When a three-sided structure is selected for a site, a cast-in-place footing design must be included in the contract plans. There are several types of culverts that may meet the project specifications. The designer must decide which specific type of unit would best fit that particular application and use those vertical and horizontal reactions for design of the foundations. The designer may contact 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.

33.4 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 however precast counterfort and binwalls may also be considered. Cast-in-place wingwall designs are provided by the Department's standard box culvert computer programs.

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.

When precast wingwalls are permitted the designer should be aware of potential conflicts with ROW limits and utilities. 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 and/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 shall be 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.

33.5 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 subbase and/or highway pavement 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 ***Design Standards Index No. 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 programs.

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 guardrail 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, the following criteria shall be used:

16. 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.
17. 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.

33.6 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. For culverts founded on highly permeable soils or with significant hydraulic gradients, the designer should investigate the need for deeper cutoff walls. The cutoff wall may also act to stiffen the bottom slab for skewed box culverts.

Cutoff walls shall always be specified at each end of the barrel. When a concrete apron is provided, an additional cutoff wall shall also be shown 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 cast-in-place and the cost should be 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.

33.7 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.

When a precast culvert is specified with a concrete apron, the apron must be cast-in-place and the cost should be 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.

33.8 Subbase Drainage

Draining surface and ground water away from the culvert through the subbase is almost as important as the conveyance of water through the culvert. All flat-topped or nonarched culverts should have a minimum longitudinal slope of approximately 1%, if possible, to drain the water that permeates through the pavement and subbase, away from the top of the culvert.

In situations where there is low fill (< 12 inches below the base coarse) ***Design Standards Index No. 280*** and ***Index No.289*** requires additional friable base or coarse aggregate material above the top and along the sides of the culvert to eliminate maintenance problems.

For deeper culverts, if a longitudinal slope is not possible, a 1% slope (wash), perpendicular to the centerline of the culvert, can be used. The wash can be from the centerline to each side or all in one direction. The wash can be formed into a cast-in-place culvert but is difficult to form on precast culverts. On precast culverts, the wash can be added after the culvert is in place by placing a shim course of asphalt or concrete.

An alternate solution in low fill conditions is to place a concrete pavement on top of the culvert. The minimum depth of concrete required is 6 inches. The concrete pavement is less susceptible to potholes than asphalt but is more costly and should have a longer service life. Contact the District Structures Design Engineer for guidance when considering the use of a concrete pavement section. Exclude precast units in the contract plans if there is concern about movement of units cracking the concrete pavement. Post-tensioning to connect precast units is not recommended.

33.9 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 ***Specifications for Road and Bridge Construction*** but will need to be included as a note in the contract plans when required for box culverts.

33.10 Traffic Railings

The Department has set policy that requires highway rail to meet NCHRP 350 Test Level-3 (TL-3) and requires bridge traffic railings to meet AASHTO LRFD TL-4 in most situations. See ***Chapter 6*** of the ***Structures Design Guidelines*** for more information. Concrete culverts may be highway-size or bridge-size by definition, and therefore, the guardrail requirements can theoretically vary by the span of the structure.

Any roadside protection placed at a culvert should be provided as highway guardrail or as bridge traffic railing. Highway guardrail should be used whenever it meets applicable safety standards since it is the most cost-efficient barrier type.

The anchorage/support of the guardrail or traffic railing is determined by the amount of fill over the top of the culvert. If there is more than a minimum of 4 feet of fill, a zero offset or greater (from the face of guardrail to shoulder break) and a 1:2 or flatter slope, use highway guardrail with standard length posts. When the embankment slopes exceed 1:2 for zero offset or there is less than 4 feet of fill, the preferred option for guard rail depends upon the amount of fill and the size of the culvert as described below:

18. Culverts with less than 5 feet outside widths (railing length) and less than 4 feet of fill should have the posts straddle the outside of the culvert. This assumes the use of standard post spacing of 6.25 feet and W-beam guard rail posts.
19. Culverts between 5 feet and 20 feet outside width (railing length) and less than 4 feet of fill may have posts attached to the top of the box or posts shortened. See ***Design Standards Index No. 400*** for guidance on the appropriate option.
20. Culverts with more than 20 feet outside widths (railing length) and less than 4 feet of fill should have guardrail anchored into the headwall or individual concrete pedestals. When the guardrail is anchored to a headwall or pedestal, either thrie-beam or a concrete traffic railing shall be used.

Concrete traffic railing is generally not recommended due to the short length of culverts unless it is being connected to barrier along the highway. The transition of the thrie-beam guardrail onto the traffic railing face will use up most of the length of traffic railing on the culvert. For example, 32” F-Shape traffic railing has a 16 feet transition from the end of traffic railing to the end of the thrie-beam terminal connector.

Designers should note that the location of the first and last posts is critical on culverts.

Headwalls under guardrail should be a minimum of 18 inches wide and the base plate must be located so that it is located at least 12 inches away from any construction joint or free end of the concrete headwall. Placement of base plates and bolts in the top slab should be avoided due to anchor embedment length problems and potential damage to the top of the culvert barrel.

33.11 Design Requirements for Concrete Culverts

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

33.12 Design Details

When a box concrete culvert is proposed for a site, the designer is required to provide a complete cast-in-place design for the contract plans. Standard details for concrete box culverts are provided in the ***Design Standards Index No. 289*** (LRFD) or ***Index No. 290*** (LFD). The contractor is usually permitted to substitute precast concrete box culverts for cast-in-place box culverts in accordance with ***Section 410*** of the ***Specifications for Road and Bridge Construction***. The contractor may select a standard precast box culvert design in accordance with ***Design Standards Index No. 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 ***Design Standards Index No. 291*** and be submitted to the Engineer of Record for approval.

When a three-sided concrete culvert is proposed for a site, the designer is required to provide either a complete cast-in-place design or a conceptual precast barrel design with a complete foundation and wingwall design, for the contract plans. The contractor is permitted to substitute precast three-sided culverts for cast-in-place three-sided culverts in accordance with ***Section 407*** of the ***Specifications for Road and Bridge Construction***. Design and fabrication details for precast three-sided culverts, including calculations, must be submitted to the Engineer of Record for approval.

The bar designations in ***Table 33.1*** should be used for box culvert reinforcement:

Table 33.1 Bar Identification Schedule

BAR IDENTIFICATION SCHEDULE			
C.I.P (LFD) Index No. 290	**C.I.P (LRFD) Index No. 289**	**Precast (LRFD) Index No. 292**	**Description / Bar Location**
A1	105	As1	Top Corner Bars
A2	106	As1	Bottom Corner Bars
A100	102	As2	Top Slab, inside face transverse bars
A200	103	As3	Bottom Slab, inside face transverse bars
A300	101	As1/As7	Top Slab, outside face transverse bars
A400	104	As1/As8	Bottom Slab, outside face transverse bars
B1	108	As4	Exterior wall, inside face vertical bars
B2	105/106	As1	Exterior wall, outside face vertical bars
B3	107	-	Interior wall, vertical bars both faces
C1	110/111	As9	Top Slab longitudinal bars (temperature reinf.)
C1	109/112	As9	Bottom Slab longitudinal bars (temperature reinf.)
C1	113/114		Exterior wall longitudinal bars (temperature reinf.)
C1	115/ 116…		Interior wall longitudinal bars (temperature reinf.)
C1	109	As6	Bottom Slab inside face longitudinal bars (design distribution reinforcement)
C2	111	As5	Top Slab inside face longitudinal bars (design distribution reinforcement)

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

33.13 Computer Design and Analysis Programs

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

For LFD designs the Department's "Reinforced Concrete Box Culvert & Wingwall Design and Analysis Computer Program" (***PSTDN55***), is available from the Structures Design Office website. This program will design and/or analyze a one-, two-, three-, or four-cell reinforced concrete box culverts with prismatic members (cast-in-place), with or without bottom slabs. All cells are assumed to be the same size for any one culvert and the clear opening dimensions remain constant. Using the span, rise, and fill height, the program will design the box culvert by either Service Load Design or Load Factor Design. The program will design wall and slab thicknesses and the required reinforcement.

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. Designers should consult with the State Structures Design Office before using one of these other programs in lieu of the FDOT box culvert programs.

33.14 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 ***Design Standards Index No. 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 ***Specifications for Road and Bridge Construction***. The Contractor shall be responsible for providing all design computations and details for these units.

THIS PAGE INTENTIONALLY LEFT BLANK