Drainage	Chapter: Culverts
	Subject: General

DR 601-1 INTRODUCTION

Generally speaking, culverts are hydraulic conduits used to convey water from one side of a highway and/or entrance to the other. Culverts are generally a single run of pipe or box section that is open at both ends (this is what distinguishes culverts from storm sewers). Culverts can be designed hydraulically to take advantage of submergence at the inlet to increase hydraulic capacity.

Hydraulically a culvert is different than a storm sewer because storm sewers have multiple openings which accept water. Culverts generally collect all the water that they convey at the inlet of culvert. Since water is typically flowing in a channel, the water is usually spread out much wider than the culvert opening. Directing the water into the culvert introduces losses that cause water to pond at the inlet.

Another aspect of culvert design is the selection of the culvert inlet and outlet. These appurtenances usually consist of headwalls and may be constructed with or without wings. Headwalls may be designed to fit the fill slopes of the highway, or the fill material can be graded to match the headwall. Culvert headwalls are attached to the ends of a culvert to reduce erosion, inhibit seepage, retain the fill, improve the aesthetic and hydraulic characteristics and make the ends structurally stable. Headwalls are broadly classified as safety headwalls and non safety headwalls. The use of no headwall is also a design choice.

A majority of the culverts depicted on highway plans have the allowable cover height and their appurtenances designated in the Standard Drawings. Special structures should be reviewed by the Division of Structural Design.

DR 601-2 HYDRAULIC STRUCTURE TYPES

There are many different hydraulic structure types utilized by KYTC for culverts. Table 601-1 summarizes these structures. Some of the structures listed in this table are used in storm sewer construction as well. Hydraulic structures that are used for culverts are precast box culverts, cast in place box culverts, pipes and bottomless structures.

Table 601-1 Hydraulic Structure Types Used For Culverts			
TYPE	**SHAPE**	**MATERIAL**	**SIZE DESIGNATION**
Precast Box Culvert (DR 603)	Single Cell or Multi-Cell Rectangle	concrete[1]	span x rise (feet)
Cast In Place Box Culvert (DR 603)	Single Cell or Multi-Cell Rectangle	concrete	span x rise (feet)
Pipe (DR 602)	Circular	concrete, steel, aluminum, and plastic	Diameter (inches)
	Pipe Arch	concrete, steel and aluminum	Equiv. Circ. Pipe or span x rise -for small sizes- (inches) -for large sizes- (feet)
	Elliptical	concrete, steel and aluminum	Equiv. Circ. Pipe or span x rise (inches)
	Circular Structural Plate	steel and aluminum	diameter (inches)
	Arch Structural Plate	steel and aluminum	span x rise (feet)
3-Sided Structures [2] (DR 604)	Non-circular steel and aluminum	structural plate steel and aluminum	span x rise (feet)
	Parabolic or Semi-Circular Concrete and Steel	special	span x rise (feet)

1. Box culverts are available in metal as well; however these are not typically used on KYTC projects.
2. 3-Sided structures are prefabricated shapes such as arches or boxes that are bottomless. The shapes are typically placed on strip footing foundations.

Large culverts are often compared to bridges when determining a hydraulic structure type for a particular location. The following general guidance is given to aid in this comparison.

Culverts are used:

- where bridges are not hydraulically required,
- where debris and ice are tolerable, and
- where more economical than a bridge.

Bridges are used:

- where culverts cannot be used,
- where more economical than a culvert,
- to satisfy land-use requirements,
- to mitigate environmental harm caused by a culvert,
- to avoid floodway encroachments, and
- to accommodate ice and large debris.

DR 601-3 ENVIRONMENTAL AND PERMITTING

Environmental and permitting issues for culverts are very similar to that of bridges. For a more detailed discussion on these issues see DR 802. The primary environmental differences between culverts and bridges are listed below:

- Wetland and stream impacts caused by culverts are more significant when compared to bridges. The footprint of a culvert is larger than that of a bridge for similarly sized streams. This is due to the necessity of fill material for culvert construction.
- Culverts will usually not have a natural bottom.
- Culverts may need to have special considerations incorporated into the design for fish and wildlife passage. The FHWA publications HDS 5 “Hydraulic Design of Highway Culverts” and “Design for Fish Passage at Roadway-Stream Crossings: Synthesis Report” contain additional guidance on fish passage.
- Culverts usually have smaller openings, thus have more impacts to natural stream flows.

DR 601-4 LARGE DRAINAGE STRUCTURES

Large drainage structures require collection of more significant field information that what is required for smaller structures. Large drainage structures include any structure that meets the following criteria.

- All bridges
- Culvert pipes with a diameter (or equivalent) of 54” or more.
- Culvert pipes with improved inlets
- All cast in place box culverts
- All precast or metal box culverts 4’ span x 4’ rise or larger
- All bottomless (3-sided) Structures

Discussions of survey and field data collection requirements for large drainage structures are discussed in DR 1104.

Some large drainage structures have additional plan requirements. See DR 1103 for more information.

DR 601-5 ADVANCED SITUATION FOLDERS

Advanced Situation Folders are documents that are used to initiate the structural design of structures that are under the purview of the Division of Structural Design. This primarily includes cast in place box culverts and bridges. Advanced situation folders serve as the order form for structural plans and convey the dimensions and layout of these structures. See SD 202 of the Structural Design Manual and DR 300 of the Drainage Manual for specific requirements of the Advanced Situation Folders.

Drainage	Chapter: Culverts
	Subject: Pipe

DR 602-1 GENERAL

Pipes are fully enclosed structures that are used to transport water. Pipes are circular, arched or elliptical in shape. There are several different types of pipes used in KYTC projects. The pipes have various shapes, materials and fabrication techniques. This becomes important when contractors select pipes specified in the plans. Table 602-1 lists several different types of pipes commonly used on KYTC projects by their shape, material and fabrication technique.

Table 602-1 Pipe Types	
Circular Pipe	
Description, Material & Fabrication	**Designation**
Reinforced Concrete Pipe	RCP
Spiral Rib Steel Pipe	SRS
Corrugated Steel Pipe with Helical Seam	CSPHS
Corrugated Steel Pipe with Longitudinal Seam	CSPLS
Corrugated Steel Pipe with Longitudinal Seam with Steel Bolts	CSPLSSB
PolyVinyl Chloride Pipe	PVC
High Density PolyEthylene Pipe	HDPE
Spiral Rib Aluminum Alloy Pipe	SRA
Corrugated Aluminum Alloy Pipe with Longitudinal Seam with Steel Bolts	CAPLSSB
Corrugated Aluminum Alloy Pipe with Helical Seam	CAPHS
Non-Circular Culvert Pipe	
Description, Material & Fabrication	**Designation**
Reinforced Concrete Pipe Arch	RCPA
Reinforced Concrete Horizontal Elliptical Pipe	RCHEP
Reinforced Concrete Vertical Elliptical Pipe	RCVEP
Corrugated Steel Pipe Arch	CSPA
Spiral Rib Steel Pipe Arch	SRSA
Corrugated Aluminum Alloy Pipe Arch	CAPA
Corrugated Aluminum Alloy Pipe Arch with Aluminum or Steel Bolts	CAPAASB
Spiral Rib Aluminum Alloy Pipe Arch	SRAA

Unless there are other special requirements, pipes are labeled on the plans according to their bidding classifications discussed in DR 602-2. Therefore, the designations listed above are not usually placed on the plans. Instance when specifying certain pipe may be necessary are discussed in DR 602-4.

PIPE MATERIALS

The materials used for pipe on KYTC projects include:

- Reinforced Concrete
- Steel With a Protective Metallic Coating of:
    - Zinc (Galvanized)
    - Aluminum Type 2
- Aluminum Alloy
- High Density Polyethylene
- Polyvinyl Chloride

ADDITIONAL PROTECTIVE MEASURES

Additional protective measures may be required to mitigate the effects of corrosion and/or abrasion (See DR 605). Metal (which includes Steel and Aluminum Alloy) pipe may require additional protective measures applied to the base metal product such as:

- Bituminous Coating
- Bituminous Paving
- Polymeric Coating

Reinforced Concrete pipe may require extra protection in the form special requirements for the class of pipe, reinforcement, wall thickness and the compressive strength of the concrete.

The additional protective measures for metal and concrete pipe are covered in Section 810 of the Standard Specifications for Road and Bridge Construction.

DR 602-2 BIDDING CLASSIFICATIONS

KYTC classifies pipes into bidding classifications according to their usage. The pipe types listed in Table 602-1 can be used as entrance pipe, storm sewer pipe and/or culvert pipe. The different bidding classifications have varying requirements in materials, cover height and protective coatings.

It is imperative that the general term culvert introduced in DR 601 not be confused with the bidding classifications discussed below. Both Culvert Pipe and Entrance Pipe fall under the general definition of a culvert.

The measurement, payment and construction of these structures is covered in Section 701 of the current Standard Specifications.

ENTRANCE PIPE
Entrance Pipes are generally small pipes installed in a roadside ditch to allow water to pass under an entrance to residential and/or commercial properties. To be classified as an entrance pipe, the pipe must:

- Be placed under an entrance with an ADT of less than 400.
- Have a diameter (or equivalent) of 48" or less
- Be placed under a maximum fill of 15 feet

Pipes that exceed these thresholds are classified as culvert pipe (or storm sewer pipe if applicable) regardless of their proximity to an entrance. As such, these pipes are subject to the same material and coating requirements as Culvert Pipe.

Refer to DR 609 for size and cover height limits for entrance pipe.

CULVERT PIPE
Culvert Pipes are generally pipes that are open on both ends and drain water from one side of the roadway to the other. Pipes that do not meet the classifications for Storm Sewer Pipe or Entrance Pipe shall be classified as Culvert Pipe.

Refer to DR 609 for size and cover height limits for culvert pipe.

STORM SEWER PIPE
A definition of storm sewer is presented in DR 701-1. Discussion of the requirement for storm sewer pipe is reserved for that chapter.

DR 602-3 BID ALTERNATES

Designers shall list specific information on the plans for each pipe on the project. This information is shown in Table 602-2 and shall be listed on the Pipe Sheets and the Pipe Drainage Summary Sheets. See DR 1103 for more specific information on Pipe Sheets and Pipe Drainage Summary Sheets.

Using this information, contractors have the option to install any of the alternate pipe types listed in Standard Drawings RDI-001 through RDI-012 for the pipes designated in the plans. This series of Standard Drawings is collectively referred to as the "Fill Height Tables." Additional requirements for the various pipe types are given in Standard Drawings RDI-016 though RDI-035. Specifying pipe alternates in this manner allows for competitive bidding of material and fabrication types.

Table 602-2 Alternate Bidding Criteria	
ITEM	**VALUE**
Pipe Classification	Entrance, Culvert, Storm Sewer
Size	Diameter or Equivalent Diameter
Cover Height	Maximum distance from the top of pipe to the top of the subgrade
Design pH Level	Low, Medium or High
Abrasion Level	Indicate only Highly Abrasive situations

Pipes that are not circular in shape are designated as an equivalent circular pipe size. Equivalent pipe sizes for the various non circular pipe types are given in Standard Drawing RDI-016.

Section 701 of the current Standard Specifications covers the measurement, payment and construction of culvert, storm sewer and entrance pipe.

DR 602-4 EXCEPTIONS TO BID ALTERNATES

Certain cases may warrant the specification of a particular pipe. In these instances the pipe shall be specified on the plans and noted as "no alternate". These cases include:

- Short extensions of existing systems - extend in kind
- Pipes projecting out of the fill - omit concrete alternates
- Pipes on extremely steep slopes - omit concrete alternate
- Pipes in or near outlet control when the outlet control analysis shows unacceptable headwater elevations – specify the following alternates:
  - Concrete pipe
  - HDPE Pipe
  - Fully Lined Annular Corrugated
  - Fully Lined Helical Corrugated
  - Spiral Rib
- As specified by a local municipality if the municipality is taking ownership of the facility
- Abrasion considerations (See DR 605)

DR 602-5 WALL THICKNESSES

Pipe dimensions are generally stated in terms of the internal measurements. The designer often needs to know the wall thicknesses of pipe materials. This becomes especially important when sizing vault structures for storm sewers. Since concrete pipes have the largest outside diameter for a given pipe size, they should be used to check outside dimensions in critical situations such as sizing pipe chambers.

Perhaps the most comprehensive reference for wall thicknesses for the various concrete pipes and reinforced concrete box culvert sections is the Headwall Supplement to the Standard Drawings. The wall thicknesses for the various pipe sizes are labeled as "T" on these drawings and are tabulated for the various pipe sizes. Wall thicknesses for the various pipe types vary according to the size of the pipe. An estimate of the outside diameter of a circular concrete pipe can be obtained from the following formula:

EQUATION 602-1
WALL THICKNESS OF CIRCULAR CONCRETE PIPE

$$T = \frac{D_I}{12} + 1$$

Where:

T = Wall Thickness (in)
D_I = Inside Diameter (in)

For non-circular concrete pipe, refer to Standard Drawings RDH-010, RDH-110 and RDH-220. The Standard Drawings can be found at the following web address: http://transportation.ky.gov/design/standard/standard_drawings.html

Drainage	Chapter: Culverts
	Subject: Box Culverts

DR 603-1 PRECAST REINFORCED CONCRETE BOX CULVERT SECTIONS

Precast Reinforced Concrete Box Culvert Sections are rectangular shaped sections that can be used for culverts and storm sewer applications. These sections are constructed of reinforced concrete and are typically cast at a plant and delivered to the construction site.

Standard Drawing RDI 100 lists the sizes and allowable fill heights for standard precast reinforced concrete box culvert sections. If a box culvert is needed that exceeds the limitations in RDI 100, a special design cast in place box culvert can be used. See DR 603-2 “Cast in Place Reinforced Concrete Box Culverts (RCBC)” for more information.

The measurement, payment and construction of these structures is covered in Section 611 of the current Standard Specifications. The bid item for these structures is “Precast Concrete Box Sections, Size.”

WALL THICKNESSES

Wall thicknesses for these structures are shown on RDH-1000 through RDH-1135. The wall thickness is shown as “T” in these drawings and is tabulated much like the concrete pipes. The dimensions shown in the Standard Drawings are for box sections that have a cover height of 2’ or more. For this situation, the bottom and top slab and the left and right wall thicknesses are the same for each box section size. However, when cover heights are below 2’, the top and bottom slabs are thicker for box culvert sections with a span of 6’ or less. Table 603-1 gives the top and bottom wall thickness for these box culverts.

Table 603-1
Wall Thicknesses for Reinforced Concrete Box Culvert Section, Cover Height Less Than 2’

Span	Top Slab Thickness (Inches)	Bottom Slab Thickness (Inches)
3’	7	6
4’	7.5	6
5’	8	7
6’	8	7

DR 603-2 CAST IN PLACE REINFORCED CONCRETE BOX CULVERTS (RCBC)

Cast in place box culverts are reinforced concrete structures that are formed and placed at the construction site. These structures are specially designed and fall under the purview of the Division of Structural Design. As such, they can be designed for a multitude of sizes and/or fill heights. In the Structural Design manual these are referred to as Reinforced Concrete Box Culverts or RCBC's.

As with other large hydraulic structures, after hydraulic requirements are determined, an Advance Situation Folder is compiled. This document provides the size and layout information to the Division of Structural Design so that can the structural design can proceed. For more information on Advance Situation Folders see DR 300 and DR 601.

DR 603-3 ECONOMIC COMPARISONS

When the opening required for a culvert is equivalent to a 60 inch pipe or larger, a cost comparison should made between any other hydraulic structure types and a suitable box culvert. This economic analysis is not necessary if project constraints require a particular culvert type.

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Drainage	Chapter Culverts Subject Special Use Structures

DR 604-1 INTRODUCTION

In instances where standard hydraulic structures do not meet the projects requirements, special use structures may be utilized. Early coordination with the Division of Structures and the Geotechnical Branch is required to use these structures.

Proper documentation of the decision to implement special use structures must be included in the Drainage Folders.

DR 604-2 BOTTOMLESS (3-SIDED) STRUCTURES

There are a myriad of options for bottomless (3-sided) structures. Shapes and structural criteria are dictated by the manufacturers of these structures. Use of these structures is essentially a special design process. These structures have commonly been referred to as 3-sided culverts in recent KYTC policy.

Bottomless structures can provide benefits that more traditional practices may not be able to provide. Bottomless structures provide natural stream bottoms and can be constructed without disturbing the channel bottom. Provided that there is adequate foundation materials, bottomless structures can also reduce construction times. The following instances may warrant consideration of a bottomless structure:

- To provide quick construction time in order to re-open a roadway
- To address environmental concerns, such as having a “natural” channel bottom
- To provide required aesthetics
- Special geometric or hydraulic constraints
- Economics

FOUNDATIONS

A primary structural consideration in using bottomless structures is the foundation. These structures are generally founded on strip footings. In effect this is taking the entire load above the structure and concentrating it on narrow strip footings. When shallow, non erodible rock is present, this is not an issue.

However, constructing strip footings on soil or erodible rock for wet crossings is highly undesirable. If shallow non erodible rock is not available, deep foundations (piling, drilled shafts, slab footings on rock, etc.) should be used. However, this often makes the usage of these structures cost prohibitive. Another option to consider when shallow rock is not available is to place a full structural slab under the structure that at a minimum covers the entire footprint of the culvert.

A geotechnical investigation is required for all bottomless structures. See DR 1104 for more information on geotechnical investigations.

Use of 3-sided structures requires approval from the Division of Structural Design and the Geotechnical Branch.

BOTTOMLESS REINFORCED CONCRETE STRUCTURES

KYTC has investigated several bottomless reinforced concrete structures. A list of approved bottomless reinforced concrete structures is contained on the drainage website. http://transportation.ky.gov/design/drainage/drainage.html
This list is intended to give designers a starting point when developing plans for these structures. This document is entitled "KYTC Approved List for 3-Sided Culverts."

There are two classes of shapes for these structures: arches and flat tops. Arches approximate circular, parabolic or elliptical shapes and have several different variations. Flat tops are rectangular shaped. Flat top shapes have haunches at the corners for added strength.

SPECIAL DESIGN PROCEDURE FOR BOTTOMLESS REINFORCED CONCRETE STRUCTURES

KYTC has adopted a specialized procedure for including these structures in the plans. First the designer shall contact the Division of Structural Design to obtain a structure number to be used to identify the structure. This number will be used later to archive the plans for the structure and shall be clearly shown in the title block of all plan sheets related to the structure.

The designer shall pick a structure from one of the suppliers on the "KYTC Approved List for 3-Sided Culverts." This structure will be analyzed for hydraulics in the usual manner and plans developed based on this structure.

The designer should pick alternate structures from each of the other suppliers listed in the "KYTC Approved List For 3-Sided Culverts" that meet project criteria. These alternates shall have a width and flow area greater than or equal to the structure used in the analysis. These structures shall be listed as alternates on the layout sheets. It should also be documented in the Drainage Folder if alternates are allowed.

Criteria that are deemed critical to the design and/or function of the culvert will be listed on the plan sheets. This includes but is not limited to:

- Culvert Length Along Centerline of Structure
- Wing Wall Lengths and Angles (See DR 608-8)
- Headwall Elevations
- Wing Tip Elevations
- Foundation Bearing Pressure Requirements
- Scour Countermeasures

The designer must ensure that the selected alternates will meet project criteria, including but not limited to, the effects to water surface elevations upstream and downstream of the structure. Constraints such as low cover heights may limit the number of alternate structures. The designer should avoid listing alternates that have significantly different widths and/or rises. If no other structure will meet design constraints, the designer can designate one shape with no alternate.

Sample plan sheets to be included in the plan set are provided on the drainage web site in a MicroStation file titled “Example3-sidedculvert.dgn”. Included is a General Plan needed for these structures. Also shown is a Culvert Situation Sheet that is typically developed on all KYTC large drainage structure projects. The General Notes shown on the General Plan sheet should be included in every project as directed in the sample plan.

When it becomes necessary to attach guardrail to the structure, the Attached Guardrail Notes as shown in the General Plan sheet should be included as well.

Vendor generated plan sheets should not be used in KYTC plan sets. The final detail drawings from the vendor will be supplied to the contractor for construction. These drawings will be archived under the aforementioned structure number obtained from the Division of Structural Design.

The Bid Items required for Bottomless Reinforced Concrete Structures will be “3-Sided Culvert” measured in linear feet and “Foundation Preparation” measured as a lump sum for each structure. Also, “Structure Excavation Solid Rock” will be needed for most projects to pay for work necessary to provide a relatively level rock surface for the structure. Refer to section 603 of the KYTC Standard Specifications for Road and Bridge Construction for more information.

DR 604-3 CONTRACTING CONSIDERATIONS

Since special use structures are not covered in normal KYTC policy, additional considerations must be addressed when using them. These structures often have assembly requirements that are not familiar to KYTC employees. Furthermore, the details of these structures are often not determined in the design process. The general process for implementing special use structures involves the steps listed below. Estimated times for this process is given in parenthesis. These times will vary greatly from project to project and are only presented to give the designer and idea of timing for this process.

- General design and layout information is determined in the design process and listed in the plans. Listing of alternate structures in the plans is advised.
- Contractors determine requirements for these structures from the plans and proposal and consult with the suppliers of these structures to determine costs for bidding purposes
- Once awarded the project's contractor orders detail shop drawings from the supplier for the structures they intend to use (4 weeks)
- Shop drawings are sent to KYTC Construction staff for review and approval (4 weeks)
- Suppliers fabricate and deliver the components to the site (8-12 weeks)

If a special use structure has been selected for fast construction times, this process must be considered. As can be ascertained from the times given above, it could take up to 20 weeks from award date before a structure will be delivered to the site. This becomes particularly important, if the timeframe between the letting date and the date that the structure needs to be completed is small.

DR 604-4 OTHER SPECIAL USE STRUCTURES

Other special use structures may be used if the aforementioned structures do not meet the project needs. These options include but are not limited to:
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- Structural Plate Pipe
- Structural Plate Arches
- Metal Box Culverts
- Metal Arches

These structures will be designed and analyzed on a case by case basis. Coordination with the Drainage Branch, Geotechnical Branch and the Division of Structural Design is necessary to ensure that the hydraulic, geotechnical and structural criteria are met.

DR 604-5 ALTERNATE BIDDING

Another option to incorporate special use structures into a project is to bid them against bridges and/or cast in place box culverts. In this case the project team should contact the Division of Structural Design to inquire about this possibility.

If the Division of Structural Design is agreeable to this, plans can be developed for multiple alternates allowing contractors to select the alternate they choose during the bidding process.

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Drainage	Chapter: Culverts
	Subject: Culvert Hydraulics

DR 605-1 INTRODUCTION

An exact theoretical analysis of culvert flow is extremely complex because the flow is usually nonuniform with regions of both gradually varying and rapidly varying flow. An exact analysis involves backwater and drawdown calculations, energy and momentum balance, and application of the results of hydraulic model studies. For example, the U.S. Geological Survey has defined 18 different culvert flow types based on inlet and outlet submergence, the flow regime in the barrel, and the downstream brink depth. Often, hydraulic jumps form inside or downstream of the culvert barrel. In addition, the flow types change in a given culvert as the flow rate and tailwater elevations change.

DR 605-2 HYDRAULIC DESIGN SERIES NUMBER 5, REVISED 2005 (HDS 5)

Because of the complexities involved in culvert analysis, more simplified methods are used to analyze culverts. These methods are described in FHWA's Hydraulic Design Series Number 5 (HDS 5), "Hydraulic Design of Highway Culverts." Most of the discussions on theory as well as the equations behind the theory are left to HDS 5. All references to HDS 5 in this manual refer the 2005 version of the publication. HDS 5 can be downloaded at no cost from the FHWA website at: http://www.fhwa.dot.gov/engineering/hydraulics/highwaydrain/index.cfm

The methodologies presented in HDS 5 are based on research by the National Bureau of Standards (NBS) sponsored and supported by the Federal Highway Administration (FHWA), formerly the Bureau of Public Roads (BPR). This research began in the early 1950s and resulted in a series of several reports. These reports provided a comprehensive analysis of culvert hydraulics under various flow conditions.

These data were used by the BPR staff to develop culvert design aids, called nomographs. These nomographs are included in the appendix of HDS 5. Nomographs are very useful because there is no single equation or relationship that can describe the full range of hydraulic considerations needed to describe culvert flow. These nomographs are the basis of the culvert design procedures in HDS 5. The nomographs are still valid today; in fact many computer applications emulate the procedures used to develop these nomographs.

The approach presented in HDS 5 is to analyze a culvert for various types of flow control and then design for the control which produces the minimum performance. Designing for minimum performance- ignores transient conditions which might result in periods of better performance. The benefits of designing for minimum performance are ease of design and assurance of adequate performance under the least favorable hydraulic conditions.

DR 605-3 HEADWATER

Energy is required to force flow through a culvert. This energy takes the form of an increased water surface elevation on the upstream side of the culvert. The depth of the upstream water surface measured from the invert at the culvert entrance is referred to as headwater depth. Simply stated, headwater pushes the water through the culvert.

DR 605-4 ROADWAY OVERTOPPING

In some hydraulic road crossings, a large amount of flow conveyance is provided by overtopping flow. Figure 605-1 shows an example of this situation. In this example the 100 year water surface elevation overtops the road by 2'. The result in this case is that 39% of the conveyance through the crossing is provided by overtopping flow. Raising the grade of the roadway in this case will necessitate a much larger culvert due to the loss in overtopping conveyance.

The project team may have to weigh the economic benefits of designing a road at high grade to avoid inundation of the road against designing the road at a low grade (hence lower cost) and allowing the road to overtop.

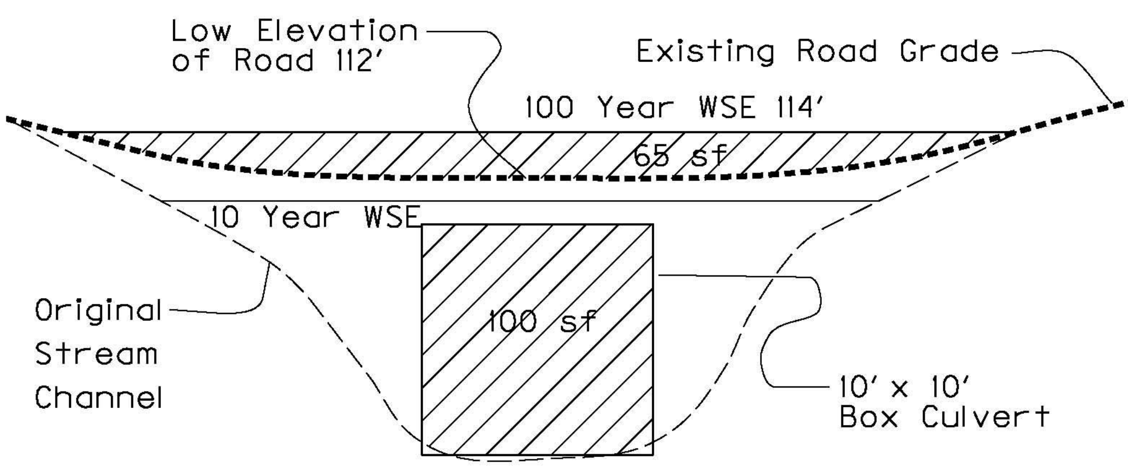

FIGURE 605-1
ROADWAY OVERTOPPING

Roadway overtopping flow is typically analyzed as a broad crested weir. Chapter III of HDS 5 presents a discussion of roadway overtopping flow and a weir equation for calculating flow over roadways.

In a culvert installation with no overtopping, the resulting headwater elevation for a given flow rate is directly solvable. Overtopping flow complicates the hydraulic analysis of a road crossing because the headwater elevation, flow through the culvert and the flow over the roadway are all unknown. This requires the use of performance curves, or a trial and error approach to solve for these variables.

DR 605-5 TAILWATER

The tailwater depth is the depth of flow in the channel or receiving water immediately downstream of the culvert outlet. The tailwater depth influences the hydraulics of the culvert. Judgment is needed to evaluate possible tailwater conditions. During the field survey, downstream controls should be located and noted.

The tailwater depth may be determined by using the Manning formula. Depending on the flood impact or accuracy needs, this may be accomplished by single section analysis or by step-backwater analysis (See DR 503).

Situations that are influenced by a downstream structure may require the determination of the hydraulics of the downstream structure. It may be determined that the headwater for the downstream structure is the tailwater for the proposed structure.

DR 605-6 TYPES OF FLOW CONTROL

The basis for the classification of flows in HDS 5 is dependant on the location of the control section. A control section is a location where there is a unique relationship between the flow rate and the upstream water surface elevation. Many different flow conditions exist over time, but at a given time the flow is either governed by the inlet geometry (inlet control); or by a combination of the culvert inlet configuration, the characteristics of the barrel, and the tailwater (outlet control). These two types of flow require different methods of calculation.

The general design procedure is to compute the headwater depths for both inlet control and outlet control. This can be accomplished via the charts shown in HDS No.5 or by computer program. The higher headwater value is then used to indicate the type of control and headwater depth.

Table 605-1 shows the factors influencing the performance of culverts in inlet and outlet control. These factors will be discussed in succeeding sections.

DR 605-7 INLET CONTROL

Inlet control occurs when the culvert barrel is capable of conveying more flow than the inlet will accept. This means that the discharge capacity of the culvert is controlled at the culvert inlet by the depth of headwater and the inlet geometry.

The control section of a culvert operating under inlet control is located just inside the entrance. Critical depth occurs at or near this location, and the flow regime immediately downstream is supercritical.

Hydraulic characteristics downstream of the inlet control section do not affect the culvert capacity. Therefore, the roughness, length of the culvert barrel, and outlet conditions (including depth of tailwater) are not factors in determining the culvert's capacity. An increase in barrel slope reduces headwater to a small degree; however, any correction for slope can be neglected for conventional culverts flowing with inlet control. The upstream water surface elevation and the inlet geometry represent the major flow controls for culverts flowing in inlet control. The inlet geometry includes the barrel shape, cross-sectional area, and the inlet edge.

Table 605-1
Factors Affecting Culvert Performance

Factor	Inlet Control	Outlet Control
Headwater Elevation	X	X
Inlet Area	X	X
Inlet Edge Configuration	X	X
Inlet Shape	X	X
Barrel Roughness		X
Barrel Area		X
Barrel Shape		X
Barrel Length		X
Barrel Slope	*	X
Tailwater Elevation		X
*Barrel slope affects inlet control performance to a small degree, but may be neglected.		

TYPES OF INLET CONTROL

For low headwater conditions, culverts in inlet control act as weirs. When the headwater is large enough to submerge the entrance, culverts flowing in inlet control act as orifices. In between weir and orifice flow is a transition zone that is poorly defined. The hydraulics of this zone are approximated by plotting the weir and orifice equations together and connecting them with a line tangent to the two curves. Figure III-4 in HDS 5 illustrates this concept. This transition zone is inherent in the nomographs in HDS 5.

Figure III-1 in HDS 5 contains sketches of some examples of inlet control. As discussed above. Flow types and assumptions depend highly on the amount of submergence of the inlet and outlet.

INLET CONTROL EQUATIONS

The equations used to define inlet control, and hence the nomographs, are contained in appendix A of HDS 5. For flow in the transition zone, the unsubmerged (weir) and submerged (orifice) equations must be plotted together and results empirically approximated as described above.

DR 605-8 OUTLET CONTROL

Outlet control flow occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. The control section for outlet control flow in a culvert is located at the barrel exit or further downstream. Either subcritical or pressure flow exists in the culvert barrel under these conditions. All of the geometric and hydraulic characteristics of the culvert play a role in determining its capacity. These characteristics include all of the factors governing inlet control, the water surface elevation at the outlet, and the slope, length, and hydraulic roughness of the culvert barrel.

Figure III-7 in HDS 5 contains sketches of some examples of outlet control. Outlet control performance is highly dependent on whether or not the barrel is flowing full.

Outlet control flow conditions can be calculated based on energy balance. The total energy (H_L) required to pass the flow through the culvert barrel is made up of the entrance loss (He), the friction losses through the barrel (Hf), and the exit loss (Ho). Other losses, including bend losses (Hb), losses at junctions (Hj), and loses at grates (Hg) should be included as appropriate. Further discussion of these losses and the equations governing outlet control are presented in Chapter III of HDS 5. It should be noted that these equations were developed for full flow throughout the culvert barrel. When the barrel is not flowing full backwater calculations or approximations are required. This is discussed further in section III-A-2 in HDS 5.

DR 605-9 INLET EDGE CONFIGURATIONS

In a flow contraction, the effective cross-sectional area of the barrel may be reduced to about one half of the actual available barrel area. As the inlet edge configuration is improved, the flow contraction is reduced, thus improving the performance of the culvert. Therefore, the configuration of the edge of the upstream end of the culvert is a major consideration when determining headwater elevations. This is especially true when the culvert flows in an inlet control regime.

The inlet edge descriptions discussed here are as presented in HDS 5 and are listed in Table 9 for inlet control and Table 12 for outlet control.

For culverts operating in inlet control, variables used in the unsubmerged (weir) and submerged (orfice) inlet equations shown in Appendix A are assigned values according to their inlet edge description. For an unsubmerged inlet these variables are K and M, for submerged inlet they are c and y. For culverts operating in outlet control, the entrance loss coefficient, Ke, is defined by the inlet edge description.

The inlet edge descriptions used in various hydraulic programs are widely varying and will seldom match the descriptions in HDS 5. For Entrance Pipe and Culvert Pipe the designer should assume a square edge headwall condition. For Precast Concrete Box Culvert Sections assume a square edge headwall with the proper flare angle (wing angle). Cast in Place Box Culverts are often constructed with a top bevel as well.

DR 605-10 PERFORMANCE CURVES

Performance curves are representations of flow rate versus headwater depth or elevation for a given flow control device, such as a weir, an orifice, or a culvert. Performance curves can be used to help understand the hydraulics for a crossing for a full range of flows. Figure 605-2 shows a typical performance curve for a culvert installation that experiences overtopping flow.

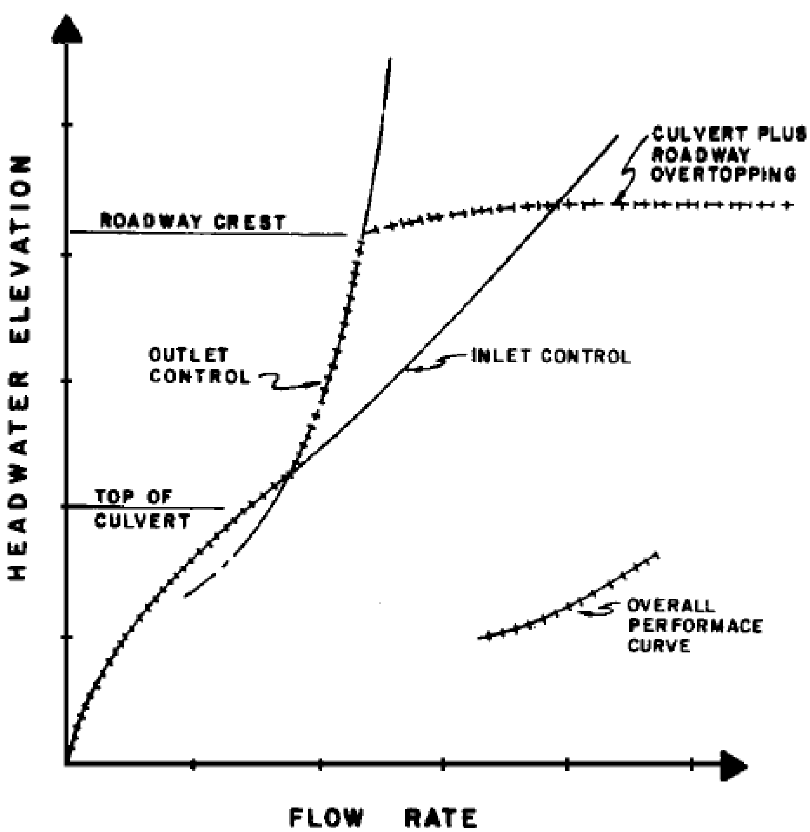

FIGURE 605-2
COMBINED PERFORMANCE CURVE

Using the combined culvert performance curve, it is an easy matter to determine the headwater elevation for any flow rate, or to visualize the performance of the culvert installation over a range of flow rates. When roadway overtopping begins, the rate of headwater increase will flatten severely. The headwater will rise very slowly from that point on.

DR 605-11 CORROSION

Corrosion is an important consideration when determining the effects that the surrounding environment can have on a pipe material. While all pipe materials can deteriorate due to being placed in corrosive environments, some materials have a more pronounced reaction to these environments.

The most common indicator of a potentially corrosive environment is adverse pH conditions in the soil and/or water. Low pH conditions indicate an acidic condition in the soils or runoff while high pH values indicate an alkaline (basic) condition.

Data indicating the pH of runoff and/or the potential for adverse pH conditions will be collected for use in establishing acceptable culvert coatings.

RUNOFF PH CONDITIONS

Tests to determine the pH of runoff shall be undertaken with material such as pH paper or instruments. The test will be made during the summer months or other times when low flow occurs.

Neutral drainage is defined to be runoff with a medium pH range of 5.0 to 9.0. Acid drainage is runoff with a pH less than 5.0. Basic drainage is runoff with a high pH greater than 9.0. Acidic and basic drainage situations require special considerations for pipe materials as noted below in the Construction Requirements section below.

Tests may be supplemented by measurements of specific resistivity and chemical analyses for sensitive locations and sites where the recorded pH is less than 5.0.

POTENTIAL ADVERSE PH CONDITIONS

Potential adverse pH conditions resulting from surrounding soils and geology should be evaluated for KYTC projects. Potential acidity can result from strip mining or other actions, which expose acid producing soils, acid shale seams or other acid producing formations. Several sources of information should be consulted to determine areas that present potential adverse pH conditions.
These sources include:

- geologic maps and reports
- geotechnical reports,
- coal resource reports,
- soil maps and profiles,
- NRCS Web Soil Survey http://websoilsurvey.nrcs.usda.gov/

- Kentucky Mine Mapping Information System http://minemaps.ky.gov/

Drainage from mine openings and toxic overburden soils should be carefully analyzed because of a potential for high acid runoff. The Drainage website contains a listing of known acid mine drainage locations.

Engineering judgment must be used to determine if a potential adverse soil pH condition exists.

CONSTRUCTION REQUIREMENTS

Adverse pH conditions require extra protective measures for certain culvert materials, and restricts the usage of some materials. Adverse pH values from field tests and/or data indicating potential adverse pH conditions are recorded on the design summary form TC 61 100. The results of these pH assessments are also shown on the Pipe Drainage Summary Sheets included in the plan set. The pH values for each pipe entry in the Pipe Drainage Summary Sheet are listed as L, M or H corresponding to low (pH 0-4), medium (pH 5-9) and high (pH 10-12) pH values respectively. These pH values are used by contractors and pipe suppliers to determine the material requirements for each pipe in the project in accordance with Standard Drawing RDI-035.

For Cast In Place Box Culverts in acidic conditions, acid water conditions are specified in the Advanced Situation Folder. This alerts the Division of Structural Design of this condition, for which special design considerations are utilized. Exhibit 508 of the Structural Design Manual shows details for Cast in Place Box Culverts for acid water conditions.

DR 605-12 ABRASION

Abrasion is defined as the erosion of culvert material due primarily to the natural movement of bedload in the stream. Over time abrasion can wear the invert of many culvert materials.

The abrasion of the culvert material is a function of the velocity of flow through the culvert and the size of the bed load material carried by the water. Severe abrasion is defined as areas that have heavy bed loads of sand, gravel, and rock and culvert velocities exceeding 15 ft/s. This velocity should be calculated using the 2 year storm.

CONSTRUCTION REQUIREMENTS

When severe abrasion conditions are expected specify concrete pipes with extra protection or metal pipes as specified in Section 810 of the Standard Specifications for Road and Bridge Construction. For Cast In Place Box Culverts, specify highly abrasive conditions in the Advanced Situation Folder. Exhibit 508 of the Structural Design Manual shows details for Cast in Place Box Culverts for highly abrasive conditions.

DR 605-13 WATER SURFACE PROFILE ANALYSIS

For large structures with small length to width ratios, culvert analysis procedures become inaccurate. For these situations, a more appropriate analysis can be conducted using water surface profile calculations commonly used in bridge design. Generally speaking large culverts with spans over 20' or culverts that have drainage areas in excess of one square mile will be analyzed with water surface profile analyses. See DR 803 for further discussion of hydraulic modeling with water surface profile analyses.

DR 605-14 OUTLET VELOCITY

Culvert outlet velocities shall be calculated to determine the need for erosion protection at the culvert exit. Culverts usually result in outlet velocities that are higher than the natural stream velocities. These outlet velocities may require flow readjustment or energy dissipation to prevent downstream erosion. See DR 1000 for more information on energy dissipaters and outlet protection.

The first step in determining the outlet velocity at a culvert exit is to estimate the depth and resulting flow area. Then the continuity equation (Q=VA) is used to determine the velocity.

If the culvert is operating under inlet control use one of the following methods to determine the outlet depth:

- Calculate the water surface profile through the culvert. Begin the computation at d_c at the entrance and proceed downstream to the exit. Determine at the exit the depth and flow area.

- Assume normal depth and velocity. This approximation may be used because the water surface profile converges towards normal depth if the culvert is of adequate length. This outlet velocity may be slightly higher than the actual velocity at the outlet.

If the culvert is operating under outlet control the cross sectional area of the flow is defined by the geometry of the outlet and either critical depth, tailwater depth or the height of the conduit. In this case use one of the following methods to determine the outlet depth:

- Critical depth is used where the tailwater is less than critical depth.

- Tailwater depth is used where tailwater is greater than critical depth but below the top of the barrel.

- The total barrel area is used where the tailwater exceeds the top of the barrel.

Drainage	Chapter: Culverts
	Subject: Headwalls & End Treatments

DR 606-1 INTRODUCTION

The ends of culverts are treated to improve hydraulics, provide safety for errant vehicles, and provide support for the surrounding soil. There are 3 basic types of end treatments: projecting end, mitered end and headwall. The most common end treatments are headwalls.

When outlet velocities for a culvert are too large for the receiving channel, outlet protection or energy dissipaters may be required. See DR 605 & DR 1000 for more information.

DR 606-2 PROJECTING ENDS

A projecting culvert is one in which the barrel extends beyond the face of the roadway side slope. The projected end is vulnerable to culvert end displacement and failure, usually due to erosion around the culvert end. However, large structures such as headwalls on the end of a culvert can fail due to their own weight. When using a projected end, the erosion control function of a headwall could be performed by rip-rap. Projected ends are generally low cost alternatives and are generally not recommended in a clear zone.

End anchors and intermediate anchors may be used to anchor the end of a projected end installation to alleviate some of the concerns with stability. Refer to Standard Drawings RDX-060, “Intermediate and End Anchors for Circular Pipe” and to RDX-065, “Intermediate and End Anchors for Non-Circular Pipe”.

DR 606-3 MITERED ENDS

A mitered end is formed when the culvert barrel is cut to conform to the plane of the roadway side slope. Mitering is used primarily with large metal culverts and must be well anchored and protected to withstand hydraulic, earth and impact loads.

The mitered end offers some hydraulic improvement over the projecting end but may create safety and structural stability problems. Mitered ends should not be used with skews greater than fifteen degrees.

DR 606-4 HEADWALLS

Headwalls are concrete structures placed at the ends of a pipe. Headwalls provide the following benefits at the end of a culvert structure:

- provide stability for end of the pipe
- prevent erosion
- retain the surrounding soil
- promote hydraulic efficiency
- Provide safety for errant vehicles (Safety Headwalls)

Dependent upon skew, location, and facility type, these structures are designed to accommodate single and multiple lines of circular and non-circular pipe sizes.

A typical headwall and its various features are noted in Figure 606-1. For standard KYTC headwalls that are attached to Culvert Pipe, Entrance Pipe and Precast Reinforced Concrete Box Sections the headwall is a self contained unit. For Cast In Place Box Culverts, these features are constructed individually at the end of the culvert. This is covered in DR-608-7.

The parapet wall serves to retain the fill on the top of the culvert. The wing walls retain the fill on the sides of the culvert and provide a transition for the flowing water to enter the culvert barrel. Wing walls enhance the hydraulics for culverts by maintaining the approach velocity and alignment. Inlet and outlet paving provide an armored surface for the turbulent water that enters or exits the culvert. The apron prevents the inlet / outlet paving from being undermined by scour. This inlet paving is optional on some of the larger KYTC headwalls.

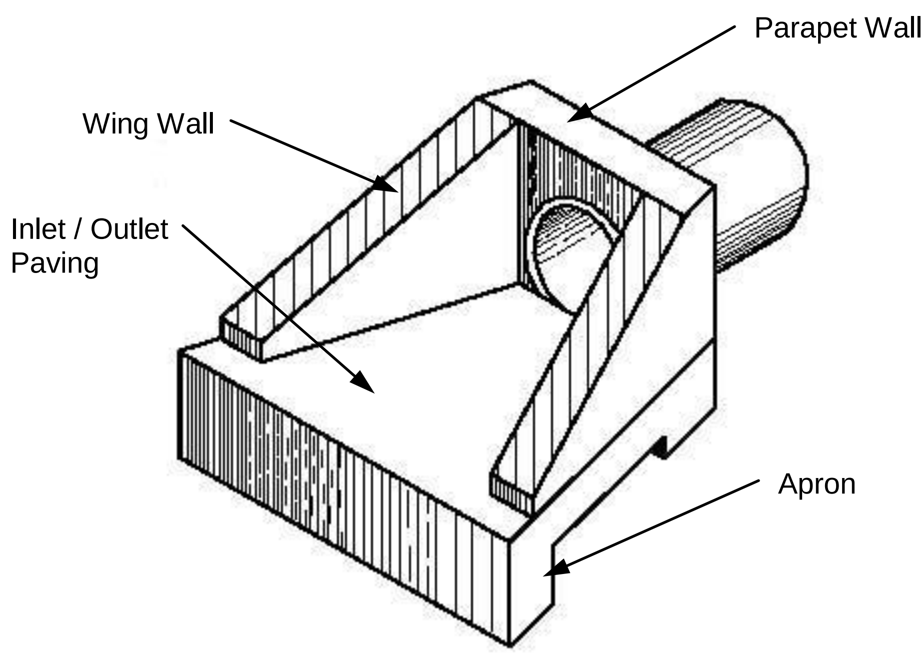

FIGURE 606-1
PRECAST CULVERT HEADWALL

There are two basic categories of standard headwalls used in Kentucky: Non-Safety Headwalls and Safety Headwalls. Table 606-1 summarizes the standard headwalls used on KYTC projects.

DR 606-5 SAFETY HEADWALLS

Safety Headwalls are designed to be traversable by errant vehicles. By definition, all safety headwalls can and should be used within the clear zone. Chapter HD-800 discusses the clear zone concept and other roadside design issues. Section DR-608-3 of the Drainage Manual discusses more safety considerations for end treatments used on culverts.

Grates used on safety headwalls have been designed to make the headwalls traversable. For more specific information on traversable designs see the AASHTO Roadside Design Guide.

These grates have been designed to minimize collected debris but good judgment should be exercised in using these grates where clogging may cause upstream property damage.

SLOPED BOX OUTLET TYPE 1

This headwall is constructed on a 4:1 slope and has a structural steel grate with four inch openings. The primary application of this structure is for median drain outlets. It is recommended for use as an outlet only.

SLOPED AND FLARED BOX INLET - OUTLET

This headwall is a modification of the Sloped Box Outlet Type 1. The opening and grates have been widened or flared to improve hydraulics when used as an inlet. This structure is primarily intended for use on 4:1 or flatter slopes.

SLOPED BOX INLET OR OUTLET TYPE 1

This headwall is of the same general design as the Sloped Box Outlet Type 1 and follows the same requirements. This headwall is constructed on a 4:1 slope.

SLOPE BOX INLET OR OUTLET TYPE 2

This headwall is constructed on a 6:1 slope and accommodates a fifteen inch circular equivalent pipe through the side wall. This headwall is designed for the pipe to enter or exit at a 90° angle.

METAL END SECTIONS TYPE 1 AND 2 (PARALLEL STRUCTURES)

These headwalls are constructed of bituminous coated metal and are used on 6:1 and 10:1 slopes.

TABLE 606-1 KYTC STANDARD CULVERT HEADWALLS				
NAME	**STANDARD DRAWING**	**CULVERT SHAPE**	[1]**CULVERT SIZE RANGES**	**SKEW**[2]
SAFETY HEADWALLS				
Sloped Box Outlet Type 1	RDB-100	Circular	15" - 24"	0°,15° & 30°
Sloped And Flared Box Inlet - Outlet	RDB 105	Circular	18" - 36"	0°,15° & 30°
Sloped Box Inlet or Outlet Type 1	RDB-110	Elliptical, Pipe Arch	15" & 18"	0°
Sloped Box Inlet or Outlet Type 2	RDB-111	Pipe Arch	15"	0°
Metal End Section Type 1 and 2 [3]	RDB-150	Circular, Elliptical, Pipe Arch	15" – 72"	0°
Metal End Section Type 3 and 4	RDB-155	Circular, Elliptical, Pipe Arch	15" – 72"	0°
Sloped & Parallel Headwalls	RDH-030	Circular, Elliptical, Pipe Arch	12"-21"	0°
NON SAFETY HEADWALLS				
Concrete Headwall	RDH-005, RDH-010	Circular, Elliptical, Pipe Arch	12"-27"	0°
Sloped & Flared Headwalls	RDH-020	Circular, Elliptical, Pipe Arch	12"-27"	0°
U-Type Headwall	RDH-050	Circular	12"-36"	0°
Pipe Culvert Headwalls	RDH-110, RDH-120	Circular, Elliptical, Pipe Arch	30"-108"	0°, 15° 30°, 45°
Steel Pipe Arch Headwalls [4]	RDH-400, RDH-405 RDH-410, RDH-415	Structural Plate Pipe Arch	See Std Dwg	0°, 15° 30°, 45°
18" – 24" Double And Triple Culvert Headwalls	RDH-500	Circular	18"& 24"	0°
Double & Triple Pipe Culvert Headwalls	RDH-510 RDH-520 RDH-530	Circular	30"-48"	0°, 15° 30° & 45° [4]
Precast Box Culvert Headwalls	RDH-1000, RDH1005 RDH-1010,RDH-1015	Box	See Std Dwg	0°, 15° 30° & 45°

1. See Applicable Standard Drawings for More Specific Culvert Size Accommodations.
2. Available in Pre-Designed Shapes for Use in a Skew. All Headwalls Can Be Used on Skews by Warping Fill.
3. When Used on 10:1 Slopes Pipe Sizes are Limited Due to Length of Structure
4. Triple Barrels Only available in 0° Skew.

METAL END SECTIONS TYPE 3 AND 4 (CROSS STRUCTURES)

These headwalls are constructed of bituminous coated metal and are used on 4:1 and 6:1 slopes.

SLOPED & PARALLEL HEADWALLS

This type of headwall is to be used with slopes 4:1 or flatter. It is recommended that this headwall be used primarily on the outlet end of installations.

DR 606-6 NON SAFETY HEADWALLS

Since non safety headwalls are not considered traversable by errant vehicles, they should only be used outside of the clear zone limits. They may also be used behind guardrail or any other type of barrier that would prevent an errant vehicle from reaching them.

Standard KYTC non safety headwalls are discussed below. The discussion of these headwalls is broken up by their titles as listed in the Headwall Supplement of the Standard Drawings.

CONCRETE HEADWALLS

Concrete headwalls are broken into Standard, Raised, Standard Ell, Raised Ell headwalls. The concrete headwalls are simple concrete retaining walls encircling the pipe. The use of these concrete headwalls is limited by present safety requirements and hydraulic innovations.

The Standard and Raised headwalls are of the same configuration except that the Raised headwall is taller and wider. Standard and Raised Concrete Headwalls are used primarily at locations on:

- road widening projects where right-of-way restrictions limit the available area at an inlet or outlet
- locations where a wing-type headwall would interfere with ditch flow paralleling the roadway.

Ell and Raised Ell Headwalls are modifications of the Standard and Raised Headwall. These headwalls include a second wall perpendicular to the main wall forming an “L” shape. The two walls are usually constructed at a ninety degree angle to each other, but the angle between them may be varied to conform to the angle of intersection which will fit a particular situation.

Ell headwalls are useful in roadway ditches when there is a need to divert flow perpendicular to the ditch line.

18” – 24”DOUBLE AND TRIPLE PIPE CULVERT HEADWALLS

These multiple line headwalls are of the same design as those in Concrete Headwall section above and generally follow the same criteria. These headwalls accommodate eighteen inch through twenty four inch double and triple lines of circular pipe.

U-TYPE HEADWALL

These headwalls consist of three walls joined together to form a U shape. As with the Ell Headwalls discussed above, the angles between the walls are usually constructed at ninety degrees but may be varied to fit the situation. The primary use of a U -TYPE headwall is to retain slopes in narrow conditions.

SLOPED & FLARED (S & F) HEADWALL

This structure was designed in 1974 to replace the Standard and Raised headwall where possible. This headwall is designed to fit closer to the toe of slope, thus creating less of a vehicular hazard than the Standard or Raised headwall. However, it is still considered non traversable and does not qualify as a safety headwall. Its design prevents erosion at the sides of the headwall and provides flowline protection against erosion at the inlet and outlet. This headwall is compact and will improve aesthetics of the roadway, particularly in urban areas.

PIPE CULVERT HEADWALL

These large reinforced concrete wing-type structures are designed for a 2:1 slope but may be used with any slope by warping the fill to fit the headwall. These headwalls are paved between the wings to prevent erosion and undermining at the inlet and outlet.

DOUBLE & TRIPLE PIPE CULVERT HEADWALLS

Double and triple pipe culvert headwalls are of the same design as the Pipe Culvert Headwalls section, described above.

DR 606-7 BID ITEMS AND CONSTRUCTION SPECIFICATIONS

The headwalls listed in the Standard Drawings are bid by each individual unit. Refer to Standard Drawings RDB–100 to RDB–160. Section 710 of the current Standard Specifications covers the measurement, payment and construction of these items.

The headwalls listed in the Headwall Supplement to the Standard Drawings are bid according the quantities of concrete and steel. Refer to Standard Drawings RDB–100 to RDB–160. Section 610 of the current Standard Specifications covers the measurement, payment and construction of these items.

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Drainage	Chapter: Culverts
	Subject: Improved Inlets

DR 607-1 INTRODUCTION

An improved inlet is a flared culvert inlet with an enlarged face section and a hydraulically efficient throat section. Improved inlets improve the hydraulics of a culvert, especially when the culvert operates under inlet control.

In a flow contraction, the effective cross-sectional area of the barrel may be reduced to about one half of the actual available barrel area. As the inlet edge configuration is improved, the flow contraction is reduced, thus improving the performance of the culvert. Improved inlets improve culvert performance primarily by reducing the contraction at the inlet control section, which is located at the throat of the improved inlet.

Although improved inlets improve the efficiency of the culvert, they also increase the costs of the installations. The benefits of improving the inlet must outweight the costs of the installation. In light of this, improved inlets should only be considered for long culverts operating in inlet control.

There are two basic types of improved inlets, side-tapered and slope-tapered inlets.

The side-tapered inlet has an enlarged face area with the transition to the culvert barrel accomplished by tapering the sidewalls. The intersection of the sidewall tapers and barrel is defined as the throat section.

The slope-tapered inlet incorporates a fall between the face and the throat. Either method of inlet improvement may be used for box culverts.

DR 607-2 SIDE TAPERED INLETS

The side-tapered inlet has an enlarged face section with the transition to the culvert barrel accomplished by tapering the side walls (See Figure 607-1). The face section is about the same height as the barrel height and the inlet floor is an extension of the barrel floor. The inlet roof may slope upward slightly, provided that the face height does not exceed the barrel height by more than 10 percent. The intersection of the tapered sidewalls and the barrel is defined as the throat section.

Figure 607-1 SIDE – TAPERED INLET

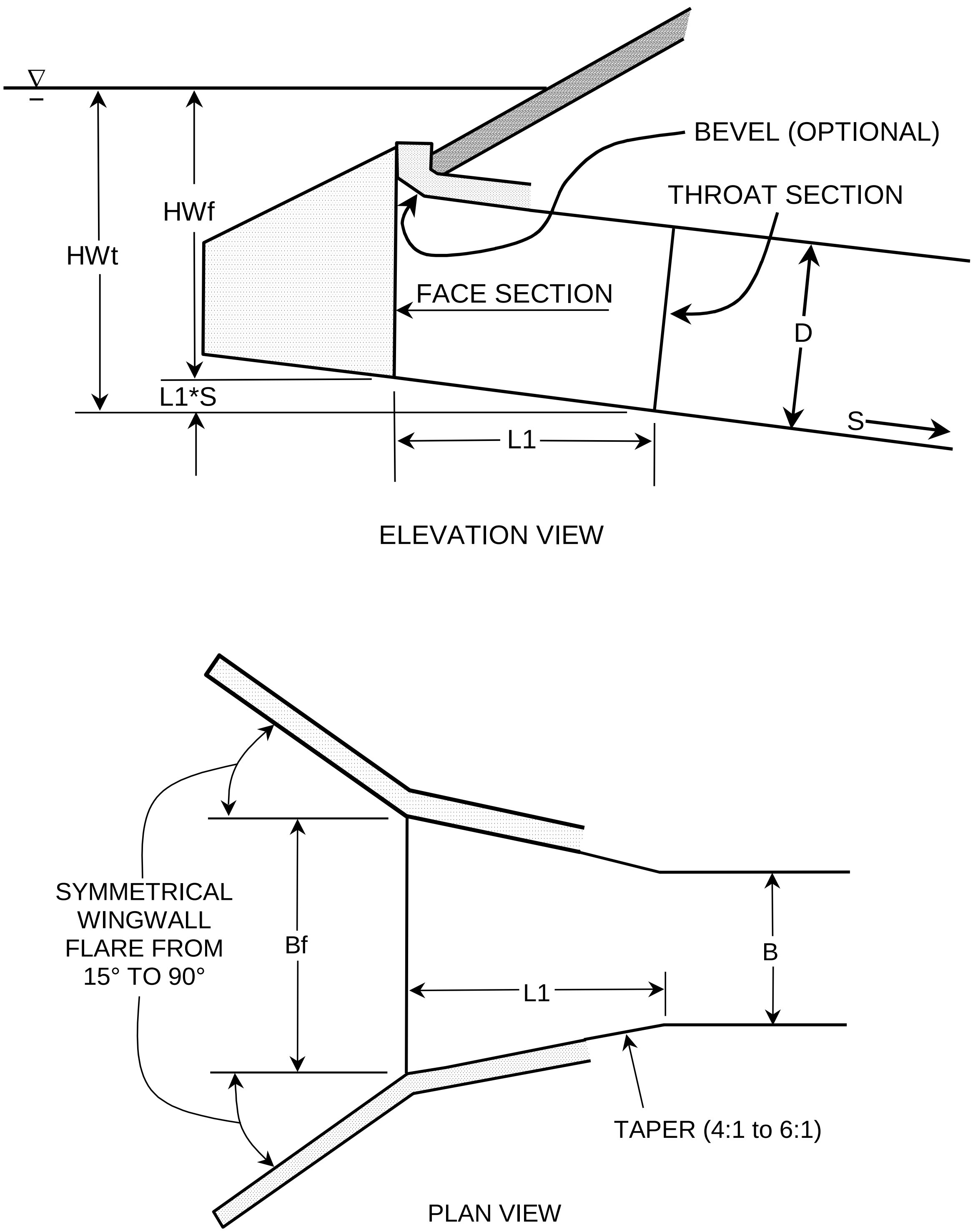
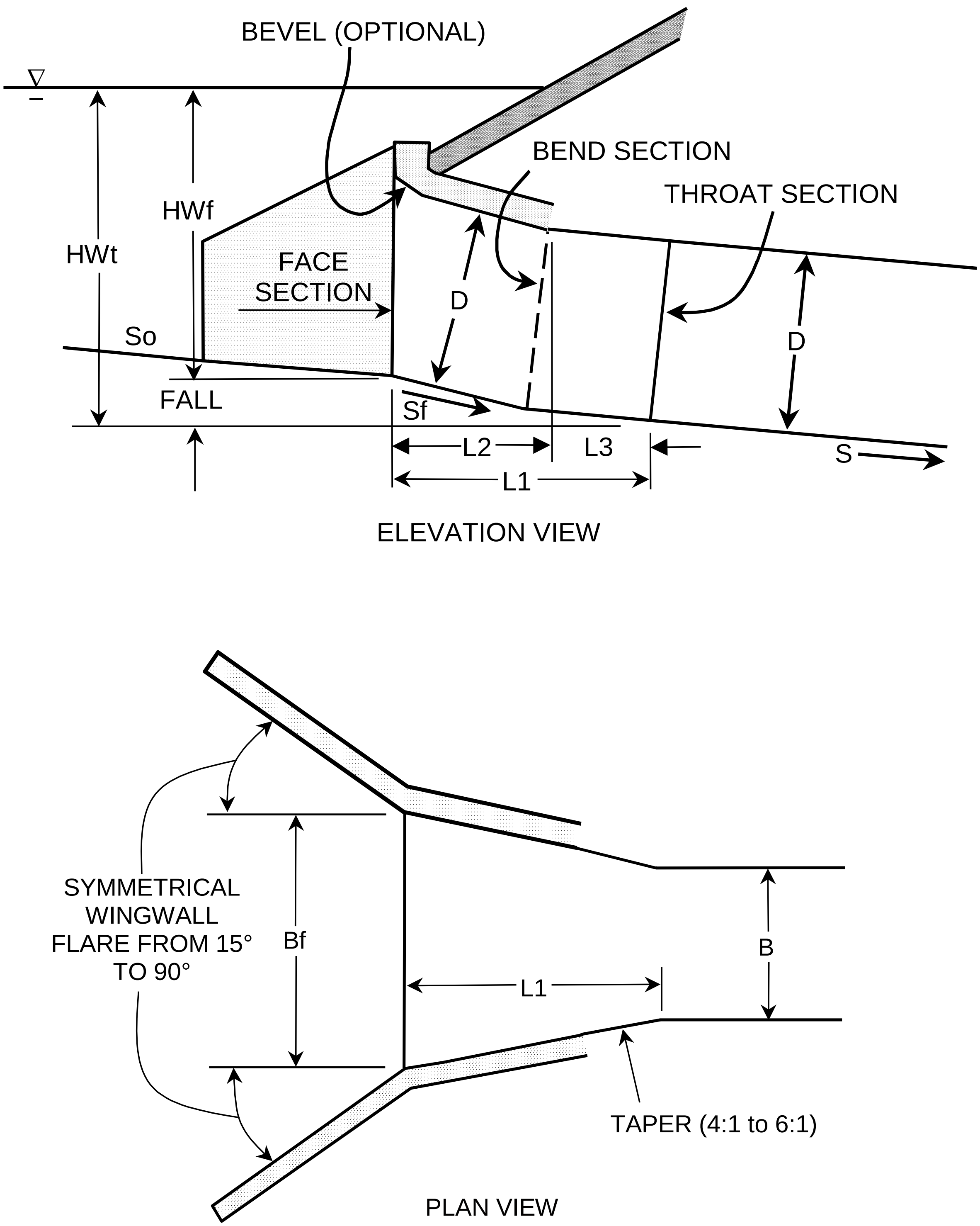


Figure 607-2 SLOPE – TAPERED INLET



There are two possible control sections, the face and the throat. HW_f, shown in Figure 607-1, is the headwater depth measured from the face section invert and HW_t is the headwater depth measured from the throat section invert.

DR 607-3 SLOPE TAPERED INLETS

The slope-tapered inlet, like the side-tapered inlet, has an enlarged face section with tapered sidewalls meeting the culvert barrel walls at the throat section (Figure 606-2). In addition, a vertical FALL is incorporated into the inlet between the face and throat sections. This FALL concentrates more head on the throat section. At the location where the steeper slope of the inlet intersects the flatter slope of the barrel, a third section, designated the bend section, is formed.

A slope-tapered inlet has three possible control sections, the face, the bend, and the throat. Of these, only the dimensions of the face and the throat section are determined by the design procedures of HDS 5.

DR 607-4 CONTROL SECTIONS

In the design of tapered inlets, the goal is to maintain control at the throat section for the range of design headwaters and discharges. This is because the throat section has the same geometry as the barrel, and the barrel is the most costly part of the culvert. The inlet face is then sized large enough to pass the design flow without acting as a control section in the design discharge range. Some slight over sizing of the face is beneficial because the cost of constructing the tapered inlet is usually minor compared with the cost of the barrel.

For slope tapered inlets, the bend section is located at a minimum distance of D/2 upstream of the throat. This ensures that the bend section will not act as the control section.

DR 607-5 KYTC SIDE TAPERED INLET

KYTC has a standard side tapered inlet for circular pipe culverts. This improved inlet consists of a standard headwall connected to a transition section that is used to transition from a circular pipe section to an enlarged rectangular face section. The transition section is shown in Standard Drawing RDX 150. A standard KYTC headwall is attached to the upstream end of the enlarged face section on the transition. To account for the enlarged face an elliptical equivalent pipe headwall is used. The size of the headwall used is shown in the row labeled “Ellipt Equiv Hdwl To Use” on Standard Drawing RDX 150.

As an example, an improved inlet for a 36” circular pipe would consist of a 48” equivalent Pipe Culvert Headwall attached the a transition section as shown in RDX 150.

Pipe Culvert Headwalls are discussed in DR 606-6. The list below cross references the dimensions in RDX-150 to those shown in Table 607-1.

Table 607-1 Dimension Variables For KYTC Side Tapered Inlet	
RDX 150	**Figure 605-1**
W	Bf
L	L1
Pipe Diameter	B

DR 607-6 DESIGN GUIDANCE

Design guidance for improved inlets can be found in Section IV of HDS 5. This publication refers to improved inlets as tapered inlets.

Drainage	Chapter: Culverts
	Subject: Layout Considerations

DR 608-1 LOCATION

A culvert should ideally be located in the existing channel bed to minimize costs associated with structural excavation and channel work. However, this is not always possible. Some streambeds are sinuous and cannot accommodate a straight culvert. In other situations, a stream channel may have to be relocated to avoid the installation of an inordinately long culvert.

DR 608-2 STREAM CHANNEL RELOCATIONS

When relocating a stream channel, it is best to avoid abrupt stream transitions at either end of the culvert. If stream channel relocations are necessary design the channel according to DR 500.

Particular attention should be given to the thresholds listed in DR 506-4. When these Stream Impact Thresholds are exceeded, it often requires additional environmental permitting requirements. The length of stream disturbance includes the length of the culvert and the length of the channel relocations attached to the culvert.

DR 608-3 SAFETY

The clear zone concept is paramount to any discussion on highway safety. The Clear zone is the total roadside area, starting at the edge of the traveled way, available for safe use by errant vehicles. Features that are located in a clear zone have special safety requirements. For further information see chapter HD 800 of the highway design manual and the AASHTO Roadside Design Guide.

The primary drainage features of concern in roadside safety are culvert end treatments. There are two situations that end treatments are designed to accommodate from a safety perspective: cross drainage situations and parallel drainage situations.

Cross drainage structures are structures that are likely to be traversed by an errant vehicle in a direction perpendicular to the headwall and pipe (across the width). Cross drainage structures are used in the classic culvert application when a pipe is carrying water from one side of the road to the other. Some safety measures the designer should consider in order to minimize the obstacles presented by cross drainage structures include:

- Use a traversable design
- Extend the structure so it is less likely to be hit
- Shield the structure
- Delineate the structure if the above alternates are not appropriate

Parallel drainage structures are designed to be traversed by an errant vehicle in a direction parallel to the headwall and pipe (across the length). Parallel Structures are typically used in locations where the pipe needs to run parallel to the traffic. Examples include under driveways, entrances, side roads and median crossovers. Some safety measures the designer should consider in order to minimize the obstacles presented by cross drainage structures include:

- Eliminate the structure
- Use a traversable design
- Move the structure laterally to a less vulnerable location
- Shield the structure
- Delineate the structure if the above alternates are not appropriate

More detailed information on the safety measures listed above can be found in The AASHTO Roadside Design Guide.

DR 608-4 CULVERT (BARREL) SKEWS

The alignment of a culvert barrel with respect to the roadway centerline is referred to as the culvert skew angle. A culvert aligned normal to the roadway centerline has a zero barrel skew angle. For any other alignment, the barrel skew angle is the angle from a line normal to the highway to the culvert centerline. Directions (right or left) must accompany the barrel skew angle as shown in Figure 608-1.

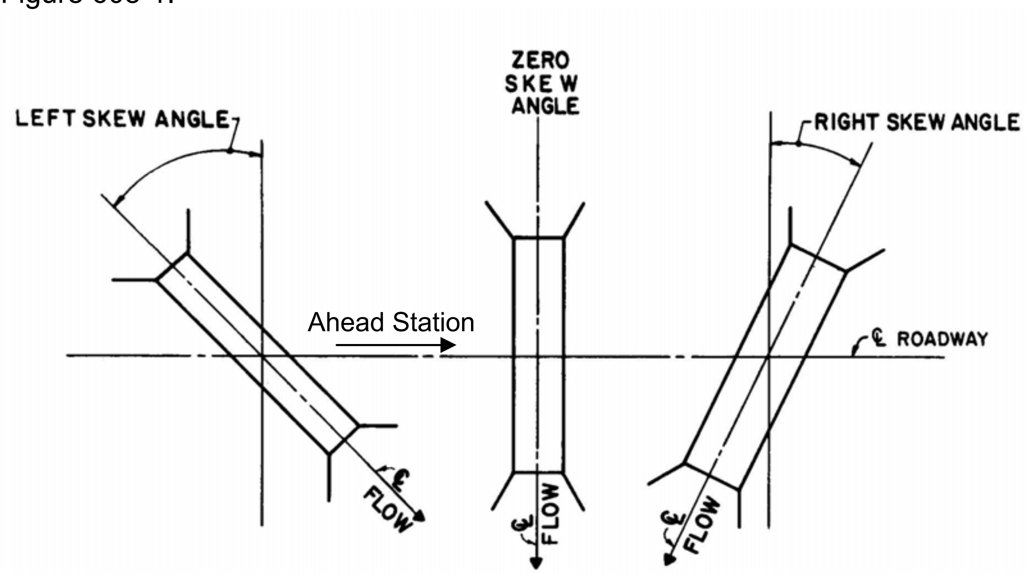


Figure 608-1 Culvert Skew

It is common design practice to place the culvert barrel on an alignment and grade that conforms to the existing stream channel. The barrel skew is established from the stream location and the proposed or existing roadway plan. The advantages of this design practice include a reduction of entrance loss, equal depths of scour at the footings, less sedimentation in multibarrel culverts, and less excavation. A disadvantage of this design procedure is that the inlet may be skewed with respect to the culvert barrel and the culvert will be longer.

It is not always prudent to allow the existing stream bed alignment to dictate the barrel skew angle. Modifications to reduce the barrel skew angle and shorten the culvert barrel may produce a more economical solution in some situations. This often requires modification to the channels upstream and/or downstream of the culvert. See DR 608-2.

DR 608-5 HEADWALL (INLET) SKEWS

The angle from the culvert face to a line normal to the culvert barrel is referred to as the headwall or inlet skew angle.

Culverts which have a barrel skew angle often have a headwall skew angle as well. This is because headwalls are generally constructed with the parapet wall parallel to a roadway centerline to avoid warping of the embankment fill (See Figure 608-2).

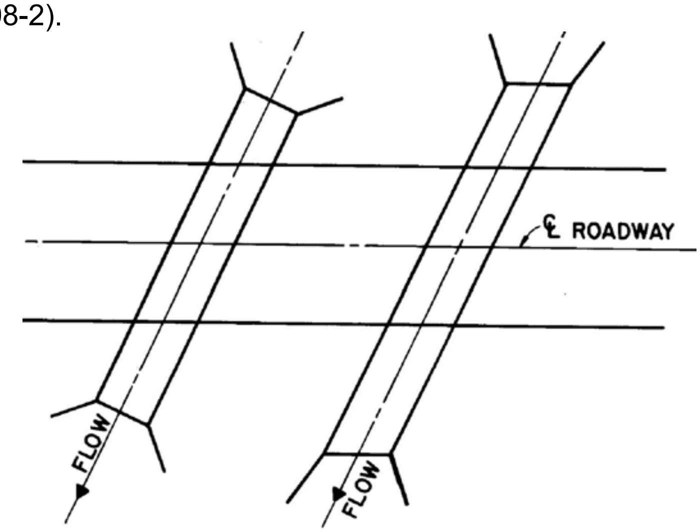


Figure 608-2

Although, skewed inlets slightly reduce the hydraulic performance of the culvert under inlet control conditions, the differences are minor and are often ignored. This skew however, should not exceed 45° where possible.

As indicated in Table 606-1, many Standard KYTC headwalls are designed to be used on skewed culverts. These headwalls are designed with a triangular section that allows the parapet wall to line up parallel with the fill. This triangular section also aligns the back wall of the headwall to be perpendicular to the pipe, so the headwall can abut the end of the pipe. This also avoids having to cut the pipe on adverse angles to match the back wall.

For cast in place structures (RCBC's) the barrel and associated end treatments are poured as separate items. This is discussed later in Section DR 608-8.

DR 608-6 COVER HEIGHTS

Maximum and minimum cover heights apply to most hydraulic structures. Table 610-2 gives recommended cover heights for the various culvert types. Cover height is measured from the top of the structure to the subgrade elevation.

In cases where fill heights are large, the loading due to traffic (live load) becomes negligible, and the majority of the loading on the pipe comes from the weight of the soil above the culvert (dead load). In cases where the cover height is small the majority of the loading on the culvert is due to live load from traffic. Cover heights are an important consideration when laying out culverts.

Precast Reinforced Concrete Box Culvert Sections have differing wall thicknesses than the standard boxes when less than 2' of cover height is provided.

RCBC's are specially designed structures. As such the walls and top slab can be designed for a variety of cover height conditions. The top slab of a concrete box culvert should be used as a part of the pavement when at least one foot of cover cannot be obtained. Pavement thickness, culvert geometry, roadway grade and top slab thickness must be known or estimated prior to making the decision.

DR 608-7 CAST IN PLACE REINFORCED CONCRETE BOX CULVERTS (RCBC)

Since these structures are poured on site, the geometry of the ends treatments works differently than that of standard precast headwalls. Whereas precast headwalls are generally delivered to the site in one structure, the individual components that make up the end treatment for a RCBC are formed and poured separately at the site. Figure 608-3 shows a typical end treatment for an RCBC.

The parts of an end treatment serve the same functions as described in DR 606-4 for headwalls. The parapet wall on the end of an RCBC is sometimes referred to as a headwall. For RCBC's these components are generally much larger than that of small precast culverts. For this reason, the layout of these components, particularly the wing walls, becomes an important factor when designing these structures (See DR 608-8). Section 505 of the Structural Design Manual gives more detailed information for these components.

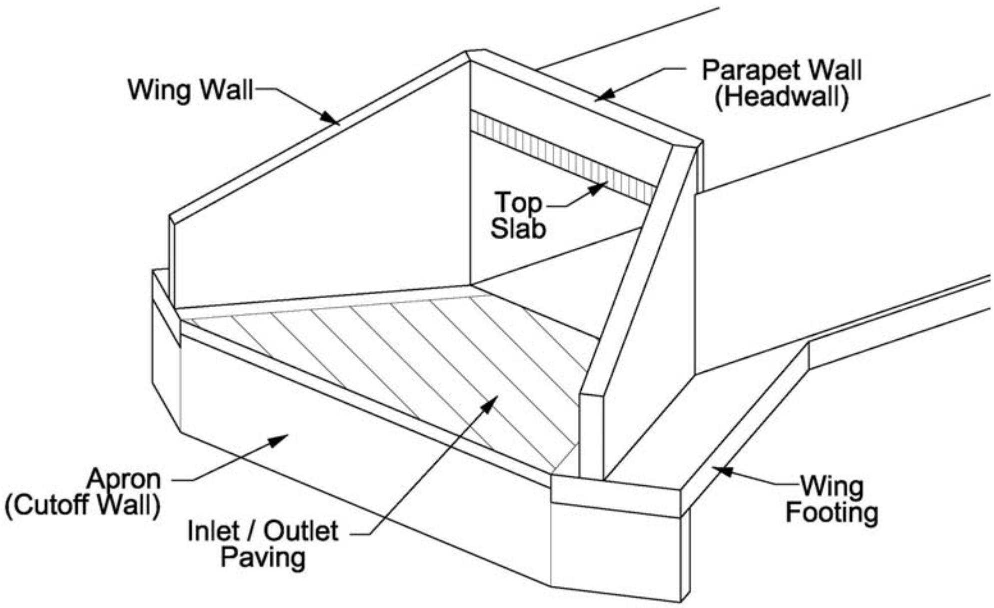


FIGURE 608-3
CAST IN PLACE BOX CULVERT END TREATMENT

Certain information pertaining to the layout of RCBC's must be transmitted to the Division of Structural Design in the aforementioned Advance Situation Folders. See DR 300 "Drainage Folders" for more information the requirements for bridge layout sheets and other information that is required for the Advance Situation Folders.

It is imperative that an open dialog exists between the structural, roadway and drainage designers so that the structural designer gets and accurate description of the structure. The following guidelines should be considered when developing the RCBC layouts.

- Wingwalls are designed for a 2:1 fill slope regardless of the typical section. The designer should indicate on the culvert section and TC 61-100 form the wingwall angle desired. Wingwall flare angles in increments of fifteen degrees are recommended with the thirty degree flare being desirable for a zero degree culvert skew.

- Parapet walls can be perpendicular to the stream flow or parallel to the roadway. When the parapet is perpendicular to the stream flow the hydraulic efficiency is benefited. However, when the parapet is parallel to the roadway, the fill slope does not require warping and the culvert length will be minimized.

- Inlets/outlet paving shall be specified when high outlet velocities are anticipated or when culverts are founded on material subject to undercutting.

- Structural analysis for a box culvert changes from simple span for the top and bottom slab to rigid frame analysis when the cover is in the range of thirty five to fifty feet. In this range, pipe culverts, concrete arches and metal arches may be more economical and should be analyzed.

- Severely abrasive and corrosive conditions may require the addition of sacrificial concrete to the flow line and sides of box culverts. See DR 605.

DR 608-8 WING WALL LAYOUTS

The Division of Structural Design should be consulted for all wing wall layouts. However, drainage and roadway designers should have some understanding of wing wall layouts to avoid the potential conflicts.

Wing walls for large culvert structures can become an important part of the design due to their size. This is especially true in urban settings where a multitude of objects can be in conflict with road project.

Figures 608-4, 608-5 & 608-6 show the three primary options for the layout of large culvert structures. The following variable definitions apply to these three figures:

Lw = Length of Wing
Sh = Slope of Channel Bank (v/h) (usually 0.5)
Sf = Fill Slope (v/h) (usually 0.5)
Ea = Elevation at Point A
Eb = Elevation at Point B
Θ = Culvert Skew
Φ = Headwall Skew
ω = Wing Angle
δ = Long Wing Angle
β = Short Wing Angle

The wing angles shall be entered into Form TC 61-100 and included in the Drainage Folders. Figure 608-4 shows a standard culvert perpendicular to the road centerline. Although this option is preferred, it may be necessary to skew the culvert. Figures 608-5 and 608-6 show culverts that are skewed to the centerline of the road. In Figures 608-5 the parapet walls are perpendicular to the culvert barrel. This will require the fill slope to be warped to match the parapet wall at the short wing corners. Figure 608-6 shows the parapet walls parrell to the roadway. This is the option most often employed on KYTC projects.

In each of these three options, the first step in determining the wing layout is to select a wing angle. Although these angles may vary from 0° to 90°, 30° is preferred. The next step is to estimate the elevations of points A and B. It is impossible to determine the exact location of these points without knowing the length of the wing, however the variation of these elevations should not vary significantly in these general areas. Using the wing angle and these elevations, the length of wing is calculated according to one of the three following equations:

$$Lw = \frac{Eb - Ea}{Sh(\sin\omega) + Sf(\cos\omega)}$$

Equation 608-1
Wing Length for Standard Wings (Figure 608-4)

$$Lw = \frac{Eb - Ea}{Sh(\sin\delta) + Sf(\cos(90 - \theta - \delta))}$$

Equation 608-2
Wing Length for Long Wings (Figure 608-5, 608-6)

$$Lw = \frac{Eb - Ea}{Sh(\sin\beta) + Sf(\cos(90 + \theta - \beta))}$$

Equation 608-3
Wing Length for Short Wings (Figure 608-5, 608-6)

Using the wing lengths from equations 608-1, 608-2 and/or 608-3, a more accurate location of the points A and B can be determined. A more precise elevation for these points should be determined and compared with the initial guess. If there is significant differences the wing lengths should be calculated again.

Exhibits 504 and 505 in the Structural Design Manual shows wing layouts as well. These exhibits show a more accurate equation that takes into account some of the details of the structure; however the equations above should give results that are accurate enough for an approximate layout.

Figures 608-4, 608-5, and 608-6 show culverts that are symmetrically layed out from the upstream and downstream ends. Although this is how culverts are typically layed out, any combination of headwall skews and wing angles are allowable on the individual wings.

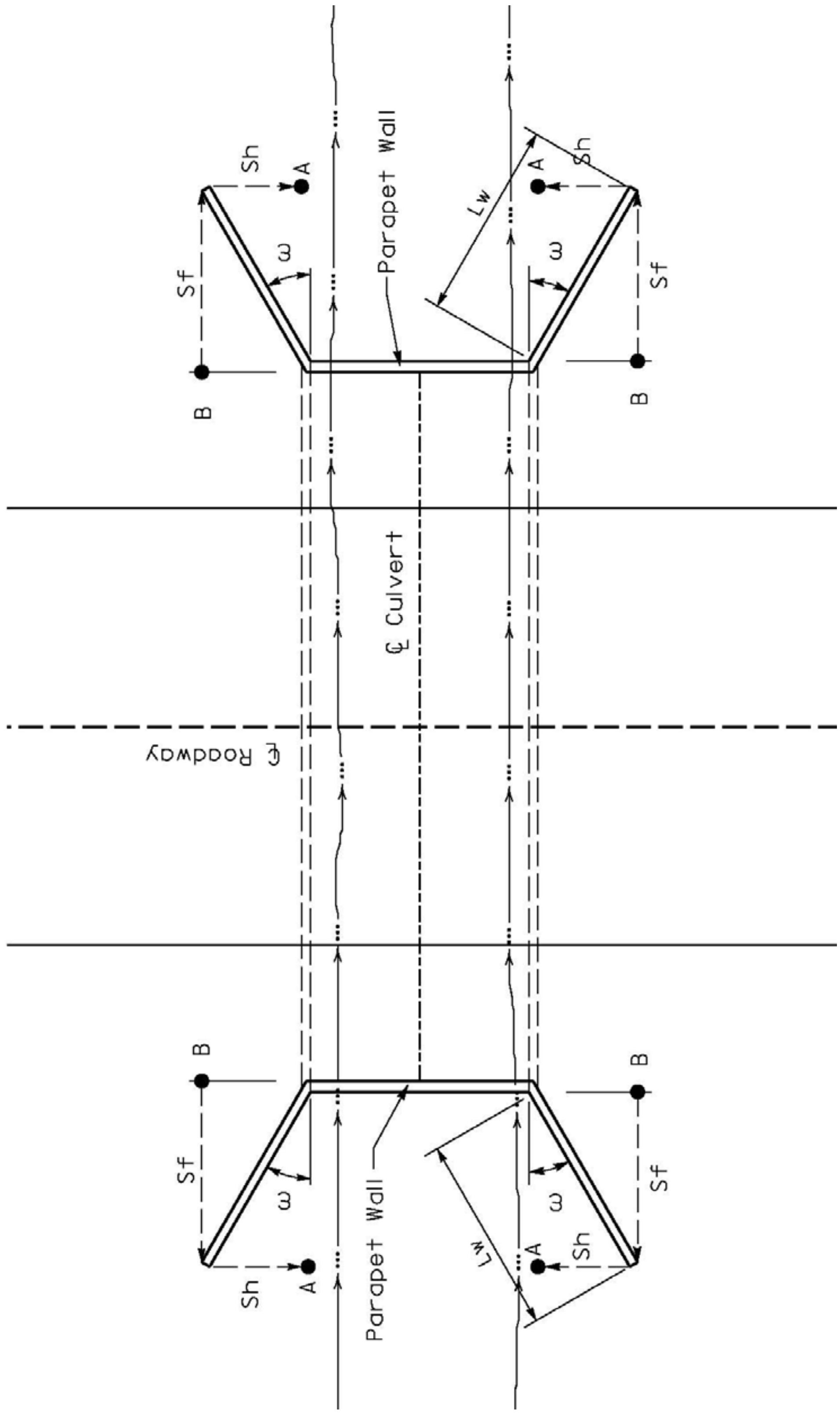


Figure 608-4 Culvert Perpendicular To Roadway

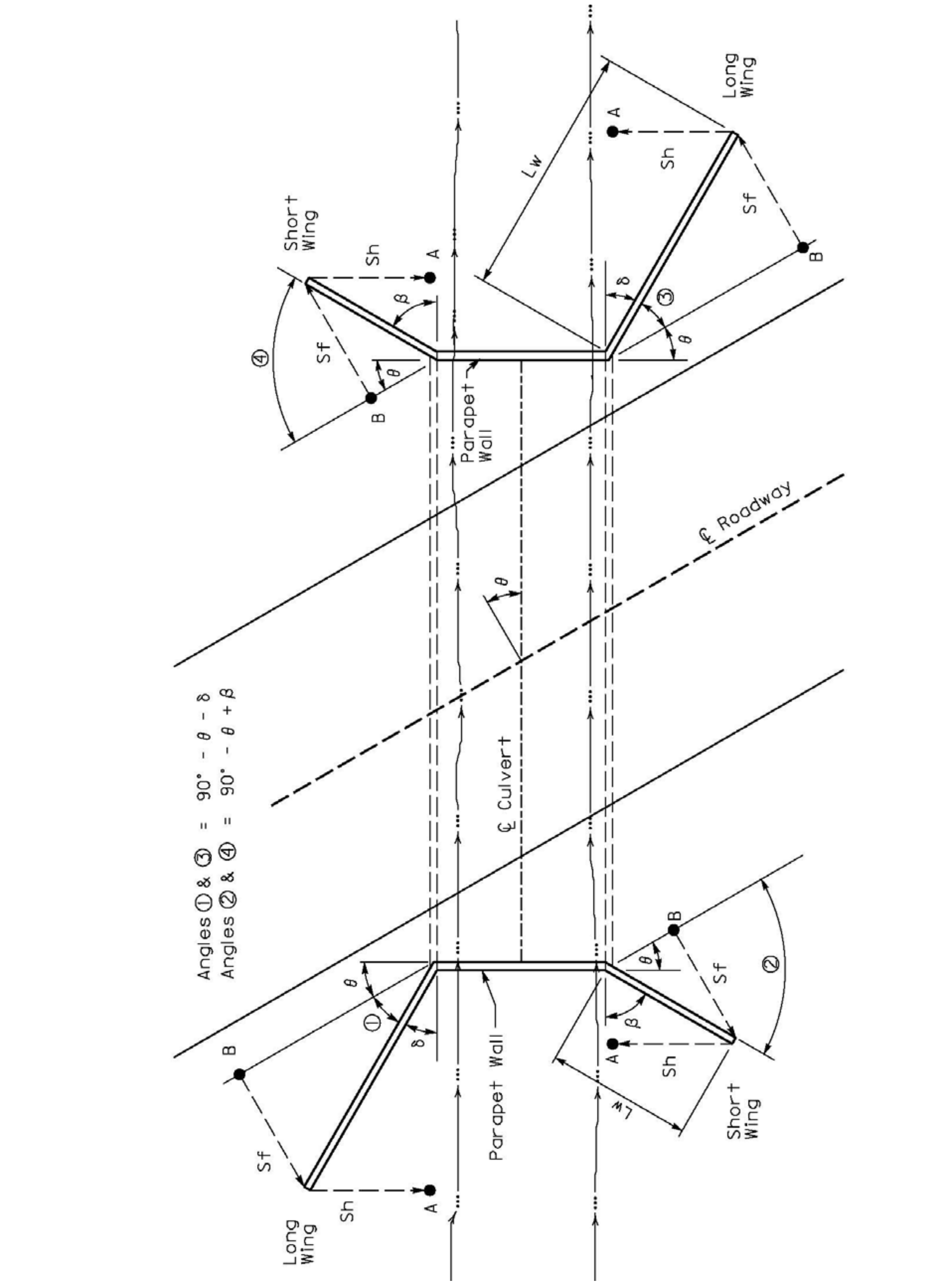


Figure 608-5 Skewed Culvert
Parapets Perpendicular to Culvert

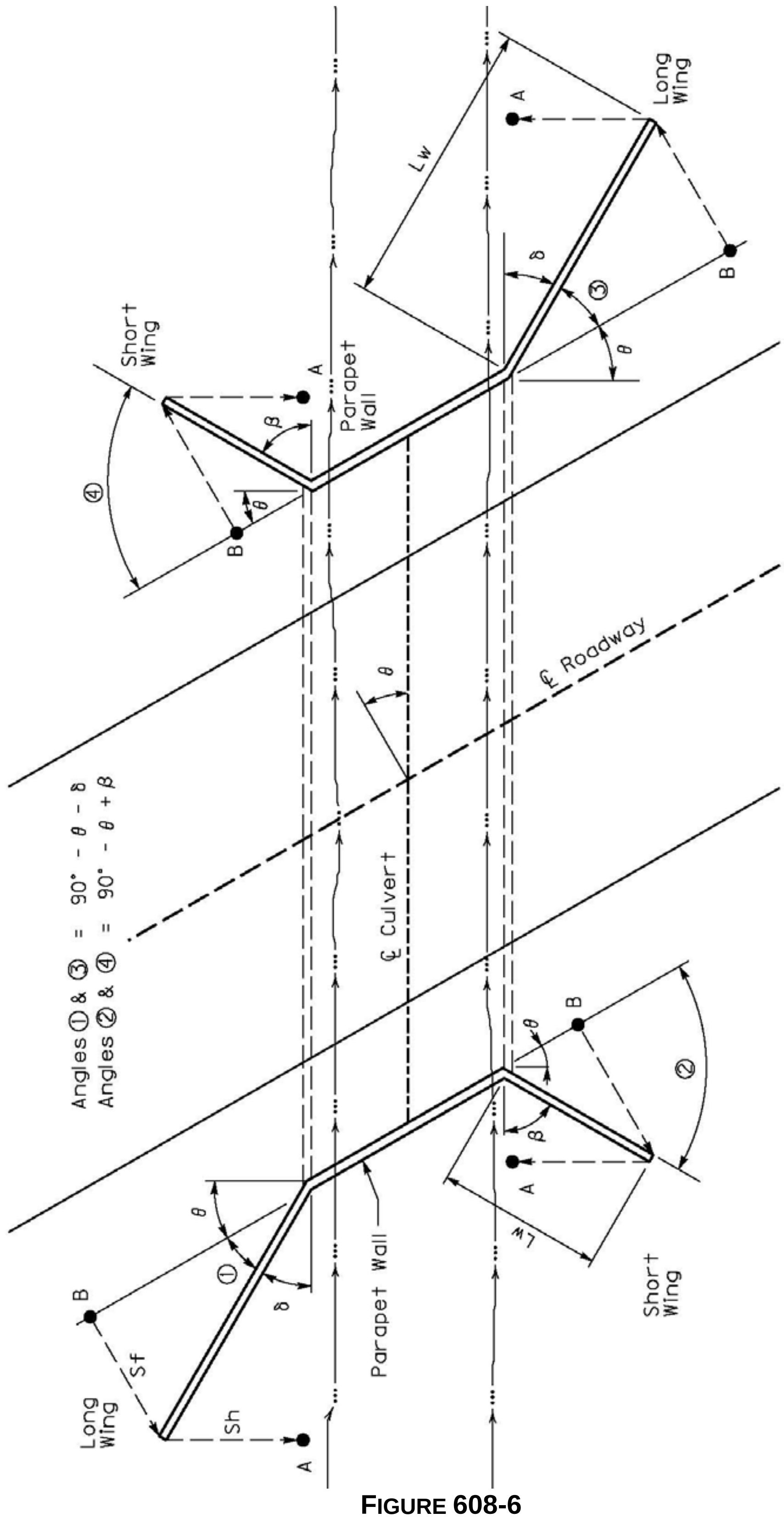


FIGURE 608-6
PARAPETS PARALLEL TO ROADWAY

DR 608-9 **DRIFT AND DEBRIS CONTROL**

Some locations can be expected to have drift and/or debris problems. In these cases, multiple barrel culverts should be avoided if possible. Debris deflectors may be considered in these areas as well. Information on drift should be entered on the TC 61-100 for the structure.

Information pertaining to drift and debris can be obtained by field visits, bridge inspection reports or by contacting district maintenance engineers.

FHWA's HEC 9 "Debris Control Structures Evaluation and Countermeasures" contains guidance on evaluating potential for debris and designing countermeasures.

DR 608-10 **FOUNDATIONS**

Foundations for culvert structures are an important consideration when developing culvert layouts. A geotechnical investigation is an important part of surveying the site for a proposed culvert (See DR 1104). Large drainage structures as defined in DR 601 will require a geotechnical investigation. Once preliminary culvert layouts are developed the designer should contact the Geotechnical Branch to initiate the geotechnical investigation.

Drainage	Chapter: Culverts
	Subject: Design Procedure

DR 609-1 CULVERT DESIGN PROCEDURE

The following design procedure provides a convenient and organized method for designing culverts for a constant peak discharge, considering inlet and outlet control. The procedure does not address the effect of storage, which is discussed in the Storage Chapter DR 900.

Step 1 *Assemble Site Data and Project File*

a. The minimum data are:
  - USGS, site and location maps;
  - embankment cross section;
  - roadway profile;
  - photographs;
  - field visit (sediment, debris);
  - pH conditions and
  - design data at nearby structures.

b. Studies by other agencies including:
  - small dams—NRCS, USACE, TVA, BLM;
  - canals—NRCS, USACE, TVA, USBR;
  - floodplain—NRCS, USACE, TVA, FEMA, USGS, NOAA; and
  - storm drain—local or private.

c. Environmental constraints including:
  - commitments contained in review documents,
  - fish migration, and
  - wildlife passage.

d. Determine design criteria:
  - review DR 610 for applicable criteria,

Step 2 Determine Hydrology

a. See Hydrology Chapter DR 400
b. Determine watershed characteristics

b. Develop drainage area map

Step 3 Analyze and/or Design Downstream Channel

a. See DR 500
b. Minimum data are cross section of channel and tailwater elevations for the analyzed storms

Step 4 Summarize Data on Design Form TC 61-100

Step 5 Select Design Alternative Related Features

- Size
- Shape
- End treatments and/or headwalls (assess need for safety headwall)
- Skew
- Number of barrels
- For large culverts that do not use standard headwalls determine wing wall layout
- Determine inlet edge configuration

Step 6 Calculate Discharges

a. Determine return interval and resulting flow rate for the design storm.
b. Determine return interval and resulting flow rate for the check storm.

Step 7 Determine Headwater

Most computer programs used in drainage design compute the inlet and outlet control headwaters and use the larger value as described below. The steps below assume that the calculations are being done by hand.

a. Determine Inlet Control Headwater Depth
b. Determine Outlet Control Headwater Depth
c. The larger of the values from a and b above is the controlling headwater and is used as the design value.
d. If overtopping flow occurs, calculate headwater depth through trial and error or develop performance curves.

Step 8 Calculate Outlet Velocity

If outlet velocity is larger than the normal velocity in the downstream channel, outlet protection or energy dissipaters may be required (see DR 605 & DR 1000).

Step 9 Review Results

Compare the selected design alternative with constraints and assumptions. If any of the following are exceeded, repeat Steps 5 through 8:

- the barrel must have adequate cover,
- the headwalls and wingwalls must fit site,
- the allowable headwater elevations shall not be exceeded, and
- the frequency of overtopping must be acceptable.

Step 10 Related Designs

Consider the following options:

- flow routing if a large upstream headwater pool exists (See DR 900)
- fish passage

Step 11 Documentation (See DR 300 “Drainage Folders”).

Drainage	Chapter Culverts
	Subject Design Criteria

DR 610-1 DESIGN STORM ALLOWABLE HEADWATER

Headwater elevations calculated for the design storm should maintain 1' of freeboard below the elevation of the lowest point on shoulder in the vicinity of the culvert inlet. Return intervals used for the design storm are discussed in DR 401 "Return Intervals". Larger storms are used for the design storm for roads with higher ADT's.

On projects determined by the project team to be low volume routes, the 1' freeboard criteria may be disregarded. This may include the allowance of overtopping flow as discussed in DR 605-4. This decision must be documented in the project's Drainage Folders.

When replacing an existing culvert with a new culvert, it is good practice to keep the design storm headwater elevation for the proposed culvert at a level that is equal to or less than the design storm headwater elevation for the existing culvert.

DR 610-2 CHECK STORM ALLOWABLE HEADWATER

Evaluation of the check storm headwater elevation is required primarily to assess the impacts to surrounding property. Potential damage to adjacent property or inconvenience to owners should be of primary concern when establishing allowable headwater elevations for the check storm. In urban areas, the potential for damage to adjacent property is greater because of the number and value of properties that can be affected.

The allowable headwater elevations for the check storm are based on acceptable increases in the elevation of the water surface. The check storm evaluation is based on a 100 year return interval, which is referred to as the Base Flood in FEMA studies.

CULVERTS SUBJECT TO NFIP REQUIREMENTS

Projects that encroach on FEMA mapped floodplains are subject to National Flood Insurance Program Requirements (NFIP). KYTC Floodplain Management Criteria as discussed in DR 204 are designed to ensure that KYTC projects follow NFIP criteria. KYTC Floodplain Management Criteria apply to crossings that:

- Have a drainage area larger than one square mile or,
- Encroach onto floodplains that are shown on an NFIP map.

When projects are subject to KYTC Floodplain Management Criteria, ensure that the impacts to water surface elevations are within the allowable increase limits described in DR 204. See DR 204-8 for a discussion on determining the amount of allowable increase. The allowable increase is dependent on several items. Below is a summary of the allowable increases for projects as discussed in DR 204:

- For projects that encroach onto to FEMA mapped floodways the allowable increase is Zero (0).
- For project that encroach onto FEMA mapped floodplains, but do not encroach on a floodway, the allowable increase will be one of the following:
  - Defined by local ordinance
  - One (1) foot for projects not subject to a local ordinance
- For projects that encroach on unidentified floodplains the allowable increase will be one (1) foot, notwithstanding the exception noted in DR 204-9.

CULVERTS NOT SUBJECT TO NFIP REQUIREMENTS

There are no specific allowable increases to the 100 year headwater elevations for culverts not subject to NFIP requirements. However, the designer should be aware of the affects of any increases in these elevations over the existing conditions. Significant increases that could damage surrounding property shall be avoided. Minor increases that could inconvenience surrounding property owners may require the purchasing of drainage easements or right way. It should be documented on the Drainage Design Summary that these impacts where considered.

CULVERT REPLACEMENTS

When replacing an existing culvert with a new culvert, it is good practice to keep the check storm headwater elevation for the proposed culvert at a level that is equal to or less than the check storm headwater elevation for the existing culvert.

DR 610-3 SITE SPECIFIC ALLOWABLE HEADWATER

Other special consideration may be used on a case by case basis to determine additional limits for allowable headwater. These considerations are primarily based on limiting damage to adjacent property. It is not required to develop these site specific criteria, but they may have applications on certain projects.

As an example, a cultivated field may be situated just above the calculated 10 year storm in the existing conditions. The project team can elect to limit the 10 year storm headwater elevations for the proposed conditions to an elevation that is below the field.

These special considerations should be documented in the Drainage Folders and project meeting minutes.

DR 610-4 SIZE LIMITS

Table 610-1 lists size limits for the various hydraulic structures used as culverts. These size limits are for standard KYTC culvert structures. Minimum sizes are necessary to prevent clogging and allow for access for future cleaning an maintenance. Maximum sizes are limited by standardized sizes listed in the Standard Drawings. If a culvert is needed that exceeds these criteria a special design will be required.

Table 610-1 Culvert Size Limits

Structure Type	Minimum Size	Maximum Size
Entrance Pipe [1]	15 “	48 “
Culvert Pipe	18 “	120 “
Culvert or Storm Sewer Pipe, Fill Height 30’ – 65’	24”	120”
Culvert or Storm Sewer Pipe, Fill Height > 65’	54”	120”
Precast Reinforced Concrete Box Culvert	3’ x 2’	12’ x 12’
Cast In Place Concrete Box Culvert	See Below	See Below

1. Entrance pipe larger than 48” are classified as culvert pipe.

Size limits for Cast-In-Place concrete box culverts are as follows:

- Minimum height – (4’) four feet
- Maximum height – (16’) sixteen feet
- Minimum span – (4’) four feet
- Maximum single span – (20’) twenty feet

DR 610-5 COVER HEIGHT LIMITS

The maximum and minimum cover height limits for culvert structures are listed in table 610-2. See DR 608-6 for a more detailed discussion of cover heights. Both the maximum and minimum cover heights are based on the amount of risk involved for each application. The maximum cover height is primarily related to the amount of dead load due to the fill over the pipe that a particular pipe material can withstand. The minimum cover height is related to constructability issues and the amount of live load due to traffic that a pipe material can withstand.

Table 610-2 Cover Height Limits		
Structure Type	**Minimum / Desirable Cover Height**	**Maximum Cover Height**
Entrance Pipe[1]	0.5' / 1'	15'
Culvert Pipe	1.0' / 2.0'	See Standard Drawings
Precast Reinforced Concrete Box Culvert	1.0' / 2.0' [2]	See Standard Drawings
Cast In Place Concrete Box Culvert	Dictated by Structural Design	Dictated by Structural Design

1. Entrance pipe larger than 48" or with fill heights exceeding 15' are classified as culvert pipe
2. Although not advisable, Precast Reinforced Concrete Box Culverts, and Cast in Place Box Culverts can have traffic directly on the top slab. See DR 608-6 for further discussion.
3. Cover height is measured from the top of the pipe to the bottom of the subgrade elevation. The bottom of subgrade will usually be taken as the elevation of the bottom of DGA. Rock roadbed is not considered part of the subgrade.

FLOWABLE FILL FOR LOW COVER HEIGHTS

If the cover height for a Culvert Pipe or Storm Sewer Pipe is less than one pipe diameter (or equivalent diameter), flowable fill is required as backfill material up to an elevation of 1' above the top of the pipe. This should be shown on the pipe sections (See DR 1103). For more information see section 701 of the Standard Specifications for Road and Bridge Construction.

DR 610-6 BENDS

In some installations it is necessary to install or extend culverts with bends in the alignment. Abrupt changes in direction or slope present hydraulic, durability and maintenance problems. Therefore, a maximum of fifteen degrees deflection in horizontal alignment is recommended. A total deflection greater than fifteen degrees may be achieved through a series of bends (fifteen degrees or less) and chords (approximately fifty feet long).

DR 610-7 OUTLET VELOCITY

Culverts usually result in outlet velocities which are higher than the natural stream velocities. Culvert outlet velocities should be calculated to determine the need for erosion protection at the culvert exit. Minor problems can occasionally be avoided by increasing the barrel roughness. Energy dissipaters and outlet protection devices are sometimes required to avoid excessive scour at the culvert outlet. See DR 1000 for more information on outlet protection and energy dissipaters. If the culvert is operating under inlet control, it may also be beneficial to flatten the slope to reduce outlet velocities.