CHAPTER DR-06
CULVERTS & HEADWALLS

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DR-06.100 FUNDAMENTALS

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DR-06.110 General

Culverts are hydraulic conduits other than bridges installed to convey water from one side of the highway right-of-way to the other, or act as discharge outfalls for water collected within the right-of-way. They are to be designed not only to transport water, but also to be of sufficient size to prevent damage to the highway and adjacent properties.

Culvert design also includes structural analyses to ensure that the wall strengths and material strengths will withstand various fill heights and vehicular loads. Use the fill height tables in the Standard Drawing RDI-Series for circular, non-circular pipe culverts, and precast box culverts. There are also typical installation and bedding drawings in the RDI-Series.

Another aspect of culvert design is the selection of the culvert inlet and outlet. These appurtenances are known as the headwalls and may be constructed with or without wings. Headwalls may be designed to fit the fill slopes of the highway or visa versa.

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. Two basic types of headwalls are available. They 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 and special appurtenances shall be reviewed by the Division of Bridges. Special structures and their appurtenances which exceed the limitations depicted on the Standard drawings shall also require a letter of approval for the use of special designs from the Director, Division of Design.

In some installations it is necessary to install or extend culverts with bends in the alignment. From a hydraulic standpoint, durability of the structure, maintenance, and abrupt changes in direction or slope are totally undesirable. Therefore, a maximum of 15 degrees deflection in horizontal or vertical alignment will be permitted. Angles greater than 15 degrees will be permitted only where a series of angles (15 degrees or less) and chords (approximately 50 feet long) are used to arrive at the total desired deflection or bend.

DR-06.120 Culvert Designations

Culverts and their size designations are:

CULVERTS	MATERIAL	SIZE DESIGNATION
Box Culverts -	Rect. concrete, steel, and aluminum	span x rise (in feet)
Pipe -	circ. concrete, steel, aluminum, and plastic	diameter (in inches)
Pipe Arch	Non-circ. concrete, steel and aluminum	span x rise (in inches, for small sizes), (in feet, for large sizes) or (Equivalent Circular Pipe)
Elliptical Pipe	Non-circ. concrete, steel and aluminum	span x rise (in inches) or (Equivalent Circular Pipe)
Structural Plate Pipe	steel and aluminum	diameter (in inches)
Structural Plate Pipe Arch	steel and aluminum	span x rise (in feet)
Arches (special)	Concrete or Steel	span x rise (in feet)

The word "Equivalent" in pipe designation means a non-circular pipe which has the same perimeter as the circular pipe.

DR-06.130 Box Culverts

Box Culverts are generally rectangular-shaped structures which may be designed as cross drains or storm sewers (see Section 06.120). The height and/or width may be changed by the designer to meet particular hydraulic requirements.

There are four types of box culverts in use:

Reinforced Concrete	RCBC
Pre-Cast Concrete	PCCBC
Corrugated Aluminum	CABC
Corrugated Steel	CSBC

DR-06.140 Entrance Pipes

Entrance pipes are generally small pipes installed in a road-side ditch to allow water to pass under an entrance to residential and commercial properties adjacent to a highway. The limitations for pipes to be classified as entrance pipes are:

1. 15 feet maximum fill height;
2. Pipes 48" or less in diameter or equivalent; and
3. Entrance traffic less than 400 ADT.

Pipes which exceed these limits shall be designed using cross drain pipe criteria in Section 06.040.

DR-06.150 Culvert Pipes

Culvert Pipes are divided into two (2) basic categories:

1. CROSS DRAIN PIPE - a pipe which conveys surface water from one side of a roadway to the opposite side. This includes pipes used for median drainage purposes. Also classified as cross drain pipes, for design purposes, are pipes under entrances which exceed the requirements for entrance pipes.

2. STORM SEWER PIPE - a pipe which connects two or more drop box inlets and/or manholes in a drainage system which is primarily designed to carry roadway surface drainage. An exception to this criteria shall be pipe conveying bridge end drainage which is classified as cross drain pipe. Also classified as storm sewer pipe are pipes which connect two or more median inlets and transport water longitudinally below the median.

DR-06.160 Pipe Types

The following types of pipes may be used as discussed by the material in this chapter. Also given are the abbreviations which may be used on project plans.

PIPE TYPES	ABBREVIATION
Reinforced Concrete Pipe	RCP
with Extra Protection	EPRCP
Reinforced Concrete Pipe Arch	RCPA
with Extra Protection	EPRCPA
Reinforced Concrete Elliptical Pipe	RCEP
with Extra Protection	EPRCEP
Corrugated Steel Pipe	CSP
Bituminous Coated	BCCSP
Fiber Bonded	FBBCCSP
Fully Lined	BCCSPFL
Polymer Coated	PCCSP
Aluminized Type 2	CSPA2
Bituminous Coated	BCCSPA2
Spiral Ribbed Steel Pipe	SRSP
Bituminous Coated	BCSRSP
Corrugated Steel Pipe Arch	CSPA
Bituminous Coated	BCCSPA
Fully Lined	BCCSPAFL
Corrugated Steel Elliptical Pipe	CSEP
Bituminous Coated	BCCSEP
Fully Lined	BCCSEPFL
Aluminized Type 2	CSEPA2
Corrugated Aluminum Alloy Pipe	CAP
Bituminous Coated	BCCAP
Fully lined	BCCAPFL
Corrugated Aluminum Alloy Pipe Arch	CAPA
Bituminous Coated	BCCAPA
Fully Lined	BCCAPAFL
Corrugated Aluminum Alloy Elliptical Pipe	CAEP
Bituminous Coated	BCCAEP
Fully Lined	BCCAEPFL
Spiral Ribbed Aluminum Alloy Pipe	SRAP
Bituminous Coated	BCSRAP
Polyethelylene Pipe(Double Wall)	PEP

See current Standard Specifications (Section 800) for material requirements for the acceptable pipe types.

PIPE ALTERNATES

Pipe material alternates shall be required for all pipes with the following exceptions:

1. Pipes not shown as allowable for the cover height;

2. Short extensions of existing systems (extend in kind);

3. Pipes projecting out of the fill (omit concrete alternate);

4. Pipes which have a break at the shoulder line (omit concrete alternate as displayed in Standard Drawing RDI-005);

5. Installations where the pH is less than 4.0 (use Extra Protection Concrete, Fiber Bonded Steel, and HDPE alternates);

6. No Alternates Pipe, other than in 1 through 5, or Special Design Pipes shall require approval in writing by the Director, Division of Design.

NOTES AND COMMENTS

DR-06.200 PHYSICAL STANDARDS

DR-06.210 Acidity and Abrasion

Certain site conditions must be met at each location to comply with standards and insure a more effective and longer-lasting project. Soil conditions and water quality conditions must be collected on site, along with data determining the physical layout of the proposed culvert. The information necessary is: the size of the bedload particles and the pH or Resistivity of the water. The more restrictive of the abrasion or corrosion potential shall govern for the selection of possible alternates.

ABRASION CONDITIONS

The abrasion of the culvert material is a function of the velocity of flow through the culvert and the size of the bedload material carried by the water. This information is used to determine the level of abrasion potential and the protection necessary. Level A conditions will require no additional coatings for the culverts. Level B shall require Bituminous Coating and Paving for galvanized steel culverts. Level C shall require extra protection for the concrete box and concrete pipe culverts, fiber bonding added to the bituminous coating for galvanized steel culverts, and Bituminous coating and paving for the aluminum and aluminum coated pipes. Higher than Level C shall require special protection design for all culverts. See Exhibit 06.906 for the abrasion levels.

ACID CONDITIONS

Data indicating the acidity of runoff and the potential for acid runoff will be collected for use in establishing acceptable culvert coatings. Neutral drainage is defined to be runoff with a pH of greater than 6.0. No special coating is required. Acid drainage is runoff with a pH of less than 6.0. The galvanized steel alternate shall be Bituminous Coated and Paved. Highly acid drainage is runoff with a pH less than 4.0. Concrete alternates shall have sacrificial concrete, Metal alternates shall be fiber-bonded bituminous coated.

Actual pH values will be obtained during the structure survey and recorded on the design summary Form TC 61-100. Potential acidity results from strip mining or other actions (i.e., highway construction), which expose acid-producing soils, shale seams, sand stones, or mineral veins. A judgement based on the potential for opening acid-producing seams must be made and recorded on the Design Summary Sheet (TC 61-100 form) for the site.

Potential acidity can be evaluated from geologic maps, geology, coal resource reports, soil profiles, and other reference materials.

The following coal seams are known to be highly acidic:

COUNTY	COAL SEAM
Bell	Jackrock/Hance
Clay	Horse Creek
Clinton	Stearns #2
Harlan	Number 9
Knox	Jellico
Laurel	Lilly/Jellico
Perry	Number 9
Wayne	Stearns #2
Whitley	Rivergem

These seams, when encountered, may produce a pH as low as 2.2. Therefore the two special pipe types must be specified. Western Kentucky contains some "hot" seams, but these will not normally be encountered. Drainage from mine openings should be carefully analyzed because of a potential for high-acid runoff.

Tests to determine the pH of runoff will 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. Tests may be supplemented by measurements of specific resistivity and chemical analyses for sensitive locations and sites where the recorded pH is less than 4.0.

DR-06.220 Box Culverts

Whenever the opening required is equivalent to that of a 60 inch pipe or more (and does not exceed the largest pipe permitted) an estimated cost comparison between a pipe and suitable box culvert shall be shown in the situation drainage folder. This will not be necessary for situations where a shallow height box culvert is to be installed and a pipe cannot be considered because it would produce excessive headwater.

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Size limitations for precast concrete, steel and aluminum box culverts are those depicted by industry. Size limitations for Cast-In-Place concrete box culverts are as follows:

1. Minimum height 4 feet for all projects with 4 or more lanes on new locations, 3 feet for all other roads;

2. Maximum height 16 feet;

3. Minimum span 4 feet;

4. Maximum single span 20 feet.

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 angle of wingwalls desired. Angles of wingwall flares in increments of 15 degrees will be permitted from 0 degrees to 90 degrees with the 30 degree flare being desirable.

The designer should position the box culvert with both the inlet and outlet parapets perpendicular to the stream flow, where at all possible.

Paved aprons shall be specified when high outlet velocities are anticipated or when culverts are founded on material subject to undercutting.

The top slab of a concrete box culvert should be used as a part of the pavement when at least one (1) foot of backfill (bottom of the subgrade to the top of the culvert) cannot be obtained in the pavement grade design. The one foot of cover shall be a minimum with two feet of cover being desirable. Pavement thickness, culvert geometry, and roadway grade must be known or estimated prior to making the decision. The designer is cautioned to remember to account for the diminished height of the box culvert due to a thickened top slab in such installations.

Level C abrasion and low pH conditions amy require the addition of sacrificial concrete to the flow line and sides of box culverts.

DR-06.230 Entrance Pipes

The sizes for entrance pipes shall be 15 inches minimum, 48 inches maximum, or the equivalent. Pipes larger than 48 inches, pipes placed under 15 feet of cover, or pipes placed under entrances with more than 400 vehicles per day, shall be classified as cross drain pipes. Minimum cover from the top of the pipe to subgrade shall be 0.5 foot with a desirable minimum cover of 1.0 foot. HDPE requires 2 feet of cover.

DR-06.240 Culvert Pipe

The minimum cover from the top of a cross drain pipe to subgrade is 1.0 foot with a desirable cover of at least 2.0 feet. The fill height is limited to 120 feet for circular pipe , and 15 feet for non-circular pipe.

The minimum cover from the top of median drain pipe to subgrade shall be 1.0 foot with a desirable cover of at least 2.0 feet.

ALTERNATE PIPE SIZES

Hydraulically equivalent pipes shall be used to obtain the same headwaters. Alternate sizes, as well as materials, may be specified when a hydraulic analysis indicates the need.

SIZE LIMITS

The minimum size for cross drain pipes shall be 18 inches (and equivalent non-circular). Pipes less than 30 inches shall not be used where fill heights over the top of the pipe are more than 30 feet.

The maximum size for cross drain pipe shall be 144 inches or its equivalent. Larger sizes may be used in limited application after review by the Drainage Section and approval by the Director, Division of Design.

The minimum size of median drain pipe shall be 15 inches for circular pipe, 17 inches x 13 inches for concrete or metal pipe arch, and 23 inches x 14 inches for concrete elliptical pipe.

The maximum size of median drain pipe shall be 30 inches for circular pipe, 30 inches x 19 inches for concrete elliptical pipe, and 28 inches x 20 inches for pipe arches.

The minimum size for mainline storm sewer pipe shall be 15 inches or equivalent. Connections of 25 feet or less between inlets and the main trunk of the storm sewer system may use 12 inch circular pipe, provided these pipe do not cross from one side of the highway to the other.

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The maximum size for storm sewer pipe shall meet the same requirements as cross drain pipe.

Storm sewer pipe size or equivalent is available in 3 inch increments from 12 inches to 36 inches and in 6 inch increments above 36 inches. The smallest non-circular size is a 15 inch equivalent.

SPECIAL DESIGN LARGE PIPE

Special manufacturer's design is required for D-Load reinforced concrete circular pipe: Class IV (90" to 144") and Class V (78" to 144"). The manufacturer shall certify the allowable cover height and shall furnish a drawing or description which includes the following data:

Wall thickness;
Concrete strength;
Inner and outer cage steel area;
Description of any auxiliary steel(number of lines, spacing, steel area, and location).

Special metal pipe will require the documentation of the design which will consist of corrugations, plate thickness, coating and allowable cover height.

Material samples shall be supplemented where necessary and submitted to the Director, Division of Materials.

DR-06.250 Multi-Barrel Box Culverts

Multiple barrel box culverts should be considered in the preliminary drainage design. For situations requiring a wide span culvert, particularly in high fill situations, an economic analysis should be made comparing a single span with a multiple span culvert and the best alternative selected.

In areas where light drift poses a potential problem for a multi-barrel culvert, extend interior wall(s) of the barrel cells on a slope from the top of the parapet to the flowline of the culvert out to align with the ends of the wingwalls. A paved apron is required for these situations. Multiple span culverts should not be considered for areas where the possibility of heavy drift exists.

One of the major problems with single cell box culvert installations is sediment or debris blockage of a portion of the opening. This will happen where streams are relatively flat but subject to frequent, rapid rise and fall of water elevations during flooding periods. For these situations, the designer may wish to consider a multi-barrel installation. The inlet channel can be constructed so as to divert 100% of the low flows of the stream through one barrel. A curb approximately one-half the box rise with a minimum of 2 feet can be constructed on the inlet apron to divert the water through the "low flow barrel." This will allow the other barrel(s) to function only during periods of high flows hence, thus, encouraging the "high flow" barrel(s) to stay relatively clean and unblocked.

DR-06.260 Arches

A reinforced concrete arch or a corrugated metal arch may be an alternate drainage structure in a high fill situation or in lieu of a multiple barrel box culvert to eliminate future maintenance problems from drift. To select a suitable Arch Culvert, first select the proper size box culvert to pass the design storm considering permissible head at the inlet. Next, compute the normal depth (dn) for the selected structure. This depth multiplied by the span, or spans, will give the waterway area (An). The arch culvert size may then be determined. Use Exhibits 06.907 through 06.909 to determine the hydraulics for these large arches.

REINFORCED CONCRETE ARCH CULVERT (RCAC)

A parabolic RCAC, properly designed and constructed, should have a height one-half to two-thirds the span at the spring line, or the widest horizontal point of the cross section. The following parabolic nomenclature and the associated formulas shall be used to size the proposed structure.

Exhibit 06.908 is a tabulation showing the area of the arch culvert below the normal depth line, the hydraulic radius of the section for an arch with the height two-thirds the span for spans 16 to 44 feet. Exhibit 06.907 is for heights one-half the span.

CORRUGATED METAL ARCH CULVERT (CMAC)

The CMAC is a circular arc shaped structure with height-to-span ratios from 0.3 to 0.5 for arches of 6′ to 26′ span. Proprietary design arches of greater span and with different height-to-span ratios are available.

Exhibit 06.909 is a tabulation showing the area of the arch culvert below the line of normal depth and the hydraulic radius of the section for a semi-circular metal arch.

The foundation must provide ample support for footings for an arch culvert. This does not necessarily mean solid rock, but the material must be of sufficient density to give the necessary support. All arch structures should have a non-reinforced bottom concrete slab for erosion control. If the culvert is to be metal, the concrete bottom will include the footing for the arch. For concrete arches, the bottom slab will be the bottom of the designed structure.

NOTES AND COMMENTS

DR-06.300 HYDRAULIC DESIGN

DR-06.310 General

The hydraulic design for any culvert is dependent upon the purpose, location, and site conditions of the installation. As a starting point in the design, use the following general requirements:

For pipes and metal box culverts:

Determine the depths of flow in the natural channel or those resulting from the backwater from an existing downstream structure for a range of discharges.

Set allowable headwaters for the 5 Year, Design, and 100 Year floods based upon:

allowable increase in flow depth for the 5 Year flood;

shoulder elevation, ditch breakover, elevation of development for the Design Flood;

normal 100 Year flow plus one foot for drainage areas greater than one square mile;

other controls that may be noted for the sites.

Size circular and non-circular pipes, metal boxes, and arches accordingly.

For concrete box culverts:

Determine the depths of flow and the allowable headwaters as above.

Set box height at the 5 Year flow or greater. The box width shall be such that the headwater does not exceed the allowable.

Variations from these general limits are permissible provided ample documentation is placed on the Design Summary Sheet (Form TC 61-100) in the portion of the form labeled "Design Control Summary." The allowable headwaters associated with given return interval discharges may require the use of a larger culvert than one required by the above 5 - Year criteria. Where an existing culvert size does not meet the above requirements but is well documented as performing satisfactorily, then an equivalent culvert may be used to replace the existing.

Culvert flow can be divided into two categories:

1. flow with inlet control
2. flow with outlet control.

These two types of flow require different methods of calculation. The headwater depths for both inlet control and outlet control can be computed from the charts shown in HDS No.5. The higher value should be used to indicate the type of control and headwater depth. This information can also be obtained by using the Department's computerized culvert programs or similar programs which have been pre-approved by the Drainage Section.

Improved inlet design shall be considered for any single or double box culvert or circular pipe operating in inlet control. Designers should become familiar with the additional design steps contained in Section 06.400.

The decision to use a box culvert, pipe culvert, arch or other structure should be made after considering economics, relationship between streambed elevation and allowable headwater elevation, the slope of the stream, allowable outlet velocity, the shape of the stream, and the fill height.

DR-06.320 Allowable Headwater (AHW)

The allowable headwater elevation is the elevation of any upstream control. Sound judgement must be applied to the selection of this elevation and to the discharge with which the elevation is to be associated.

Nuclear power plants, etc. should be associated with an extremely rare storm, say Q_{500} . Houses, buildings with equipment and other valuable property shall be associated with the discharge for a 100 year return interval storm, Q_{100}. Farmland and barns could be associated with the design discharge, say the discharge for a 25 year return interval storm, Q_{25}.

DR-06.330 Tailwater

The tailwater depth (TW) is the depth of flow in the downstream channel just below the culvert outlet. Judgement 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. This is done by imputing the channel and overbank area data into a water surface profile computer program for an analysis of the channel.

Sites with downstream controls may require the determination of the hydraulics for downstream structures. The headwaters for these structures may be the tailwater for the proposed structure.

DR-06.340 Inlet Control

Inlet control means that the discharge capacity of a culvert is controlled at the culvert inlet by the depth of headwater (HW) and the inlet geometry (including the barrel shape, the cross-sectional area, and the type of inlet edge). Sketches of inlet-control flow for both unsubmerged and submerged projecting entrances are shown in Exhibit 06.901.

In inlet control, 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.

In all culvert design, headwater or depth of ponding at the entrance to a culvert is an important factor in culvert capacity. The headwater depth (or headwater, HW) is the vertical distance from the culvert invert at the entrance to the energy line of the headwater pool (depth + velocity head). Because of the low velocities in most entrance pools and the difficulty in determining the velocity head for all flows, the water surface and the energy grade line (EGL), at the entrance, are assumed to be coincident. Thus, the headwater depths given by the inlet control charts can be higher than will occur in some installations. For the purpose of measuring headwater, the culvert invert at the entrance is the low point in the culvert opening at the beginning of the full cross section of the culvert barrel for the conventional culvert.

DR-06.350 Outlet Control

Culverts flowing with outlet control may flow with the culvert barrel full or part full for part of the barrel length or for all of it, (see Exhibit 06.902). The procedures given in this section provide methods for the accurate determination of headwater depth. The method for the part full flow condition gives a solution for headwater depth that decreases in accuracy as the headwater decreases.

The head (H), or energy required to pass a given quantity of water through a culvert flowing in outlet control, with the barrel flowing full throughout its length, is made up of three major parts. These three parts are usually expressed in feet of water and include an outlet velocity head (Hv), an entrance loss (He), and a friction loss (Hf). This energy is obtained from ponding of water at the entrance and expressed in equation form as:

$$H = Hv + He + Hf \qquad \text{(Equation 1)}$$

The outlet velocity head (Hv) equals 1 $V^2/2g$, where "V" is the mean or average velocity in the culvert barrel. The mean velocity is the discharge (Q), in cfs, divided by the cross-sectional area (A), in sq. ft., of the barrel. The coefficient "1" is the outlet loss coefficient for ends projecting and most headwalls. This coefficient may be reduced in high tailwater situations by adding a flared top to extended wingwalls.

The entrance loss (He) depends upon the geometry of the inlet edge. This loss is expressed as a coefficient (ke) times the barrel velocity head ($V^2/2g$) and is expressed as:

$$He = ke * V^2/2g$$

The friction loss (Hf) is the energy required to overcome the roughness of the culvert barrel:

$$Hf = (29 \; n^2 \; L / R^{1.33}) \; (V^2/2g)$$

Where:

- n = Manning's friction factor
- L = length of culvert barrel (ft.)
- V = mean velocity of flow in culvert barrel (ft./sec.)
- g = acceleration of gravity (32.2 ft./sec.^{2})
- R = hydraulic radius or A/WP (ft.)
- A = area of flow for full cross-section (sq.ft.)
- WP= wetted perimeter (ft.)

Substitute in Equation 1 and simplify. For full flow:

$H = (1 + ke + 29 * n^2 * L / R^{1.33}) \quad (V^2/2g)$ (Equation 2)

DR-06.360 Computer Solutions

Chapter 12 contains the material and program documentation for culvert design.

NOTES AND COMMENTS

DR-06.400 IMPROVED INLETS

DR-06.410 General

Improvement of the inlet as presented in the FHWA's Hydraulic Design Series No. 5 (HDS-5) will result in the inlet design and barrel size most appropriate for a given combination of site characteristics.

Two basic types of improved inlets, side-tapered and slope-tapered inlets, are available. The side-tapered inlet (see Exhibit 06.904) 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 (see Exhibit 06.905) incorporates a fall between the face and the throat. Either method of inlet improvement may be used for box culverts. A rectangular to circular entrance transition is available for 30" through 60" circular pipes in the Standard Drawings. This side-tapered transition was developed to allow the use of the non-circular headwalls available. Side-tapered inlets for other sizes and Slope-Tapered inlets for pipes are recommended but will require a review by the Division of Bridges.

Culverts operating in inlet control under conventional design shall be studied to determine size requirements utilizing side-tapered and slope-tapered improved inlets. This study shall be conducted after a conventional design of the culvert has been prepared as indicated in Section 06.200.

Faces for both the side-tapered and slope-tapered inlets should be oriented normal to the direction of flow in the stream. By constructing the entrance in this manner, hydraulic performance will be improved and structural design complications reduced. The embankment may be warped to fit the culvert.

The total cost of various alternatives should be considered in the final culvert selection. For instance, a slope-tapered installation will probably require more excavation than a culvert with its invert near the original stream flowline. If this excavation must be made through rock or other difficult material, it may be more economical to use a side-tapered design, assuming that both designs are hydraulically feasible, even though the barrel size of the slope-tapered culvert may be smaller. One of the Alternates shall be the conventual sized culvert.

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The culvert barrel cost usually far out-weighs the cost of the inlet structure. Therefore, if a very long culvert operates in inlet control, opportunities may exist for greater saving by using an improved inlet and reducing the barrel size. Short culverts should also be analyzed for possible cost reductions through the use of improved inlets. Many significant savings have been recorded for these structures, especially in cases where the capacity of an existing culvert was increased by addition of an improved inlet rather than by replacement of the entire culvert.

DR-06.420 Definitions

The following definitions are provided for better understanding of the material in this section:

AHW - Allowable Headwater - Elevation to which water may rise at the entrance of a culvert through which a specific daischarge is flowing

B - Width of the barrel for a box culvert

Bf - Width of the face for improved inlet section

D - Height of a box culvert or diameter of a circular pipe

dc - Critical depth for a box culvert or circular pipe used to determine the outfall condition for the outlet control

dn - Normal depth of flow for a box culvert or circular pipe or specific shape

Hf - Depth of the water at the face of a culvert caused by a conventional inlet or an improved inlet

Ht - Depth from the throat invert elevation to the water surface at the face of the culvert, caused by throat constriction

HWF - Headwater at the face caused by the face control = Elevation Face + **Hf**

Fall - Elevation Face minus Elevation of Throat (Throat Control) or **HWF** design: **Ht** - Elevation Face

HWO - Headwater at the face caused by outlet control = H + Ho + Elevation Outlet

Where:

Ho = dc + D/2 or "TW," whichever is greater
[Note: "dc" cannot exceed "D"]
H = friction head of culvert

$$H = (1 + ke + 29\ n^2 * L / R^{1.33})\ (V^2/2g)$$

[Note: Use ke = 0.2]

HWT - Headwater at the face caused the throat constriction = Elevation Throat + **Ht** or Elevation Face - **Fall** + **Ht**

N - Number of barrels in culvert

Q - Discharge

TW - Tailwater = **dn** for outlet channel or depth of flow caused by downstream constriction

IMPROVED INLET DIMENSIONS

L1 - Length of Improved Section = (**Bf** - **B**) (**Taper**)/2

L2 - Length of Sloped Portion = (**Fall**) (**Sf**)

L3 - Length of Side Tapered Portion = **B**/2 (Minimum)

Sf - **Fall** Slope = 3:1

Taper- Side Wall Taper = 4:1

DR-06.430 Side-Tapered Inlets

Side-tapered inlets may be used in conjunction with all single and double barrel box culvert sizes or a limited range of pipe sizes.

IMPROVED PIPE CULVERTS

Through the use of an improved inlet, pipe barrel sizes may be improved (reduced). The maximum improvement for circular pipes is limited to 6 inches. An analysis of the reduced pipe size is required. Transition sections, which are constructed between the headwalls and the reduced size pipes, are available for improved sizes 30" through 60".

Elliptical equivalent headwalls are used in conjunction with the transition sections where the headwall is two sizes larger than the improved pipe. For example, if an improved pipe is 36", then a 48" elliptical equivalent headwall will be required.

For circular pipes, the transition sections which are improved inlets are standard.

Bf	D	L1=L3	Taper
3.92	30	4	5.65:1
4.58	36	4	5.07:1
5.33	42	5	5.45:1
6.08	48	5	4.80:1
6.75	54	5	4.45:1
7.50	60	6	4.80:1

Therefore, the throat elevation equals the inlet invert minus L*So.

IMPROVED BOX CULVERTS

The barrel and face heights of the side-tapered inlet are the same except for the addition of a top bevel at the face. Therefore, the enlarged area is obtained by making the face wider than the barrel and providing a tapered sidewall transition from the face to the barrel. Side taper ratios may range from 6:1 to 4:1. The 4:1 taper is recommended since it results in a shorter inlet. The designer shall check for maximum improvement possible, then determine the need for further improvement.

The throat and the face are possible flow control sections in the side-tapered inlet. Each of the possible control sections should be sized to pass the design discharge without exceeding the allowable headwater elevation.

THROAT CONTROL

In order to utilize more of the available culvert barrel area, the control at design discharge generally should be at the throat rather than at the face or crest.

FACE CONTROL

The face width, the inlet edge condition and sidewall flare angle affect the performance of the face section. These are less favorable inlet edge conditions:

1. Wingwall flares of 15 degrees to 26 degrees and a 1:1 top edge bevel,

2. Wingwall flares of 26 degrees to 90 degrees and square edges (no bevels). A 90 degree wingwall flare is commonly termed a Headwall.

The desirable inlet edge conditions include:

1. Wingwall flares of 26 degrees to 45 degrees with a 1:1 top edge bevel,

2. Wingwall flares of 45 degrees to 90 degrees with a 1:1 bevel on the side and top edges.

Note that undesirable design features, such as wingwall flare angles less than 15 degrees and 26 degree flare angles without a top bevel, are not covered by charts. The 8-inch top radius approximates a 1:1 bevel.

DR-06.440 Slope-Tapered Inlets

Numerous slope-tapered box culverts have been designed and constructed throughout the state. However, only two slope tapered pipe culverts have been use by the department.

Excluding outlet control operation, the slope-tapered inlet with a vertical face has two potential control sections: the throat, and the face.

The bend is located at the intersection of the fall slope and the barrel slope. The distance, L3, between the bend and the throat must be at least 0.5B, measured at the soffit or top of the culvert, to assure that the bend section will not control. Therefore, the hydraulic performance need only be evaluated at the face and throat sections.

THROAT CONTROL

As with side-tapered inlets, throat control performance should usually govern in design since the major cost is in construction of the barrel.

For RCBC's the throat elevation is variable and may be set at an elevation other than the stream bed elevation. Since Ht calculations are the same for side-tapered and slope-tapered inlets, the same procedure is used for both in throat control calculations.

If the FALL is less than D/4, the face is designed as a side-tapered face. If the FALL is less than 1.5D and greater than or equal to D/4, the face is designed as a slope-tapered face.

Site conditions may limit the FALL (i.e., the throat elevation may be below the stream bed and necessitate excavation which may or may not be desirable). If the FALL is excessive the barrel size may have to be increased or the HWT allowed to exceed HWF slightly by making the FALL = L1*So.

The culvert barrel slope will be different from So, when the FALL is not equal to L1*So. This new slope is approximately: So - FALL/L1.

The resulting velocity will identify the need for increasing the FALL, or using outlet protection. Increasing the FALL, while reducing the outlet velocity, places a factor of safety in the culvert, which is desirable when the discharges are doubtful.

FACE CONTROL

In order to achieve throat control at the design discharge, the HWF value is limited to the HWT value.

DR-06.450 Dimensional Limits

The maximum improvement for box culvert widths shall be 50 percent. The smallest improved box culvert barrel shall be 4 feet x 4 feet.

SIDE-TAPERED INLETS

1. 6:1>Taper>4:1 Tapers greater than 6:1 may be used but performance will be underestimated.

2. Wingwall flare angle from 15 degrees to 26 degrees with top edge beveled or from 26 degrees to 90 degrees with or with-out bevels.

SLOPE-TAPERED INLETS

1. 6:1>Taper>4:1 Tapers 6:1 may be used, but performance will be underestimated.

2. 3:1>Sf>2:1 If Sf>3:1, use side-tapered design

3. Minimum L3 = 0.5 B

4. 1.5D>FALL>D/4 For FALL<D/4, use side-tapered design. For FALL>1.5D, estimate friction losses between face and throat.

5. Wingwall flare angle from 15 degrees to 26 degrees with top edge beveled or from 26 degrees to 90 degrees with or with-out bevels.

The geometrics of the inlet are calculated by making L1, L2, and L3 compatible. If L1 - L3 is greater than L2 then L3 is increased (L3 = L1 - L2). If L1 - L3 is less than L2 then the taper is varied, and

TAPER = L2 + L3 (Bf - B) / 2,

remembering the limits for the taper.

DOUBLE BARREL IMPROVEMENTS

An addition to the comments and limitations for single barrel slope-tapered inlets is the face must be proportioned on the basis of the total clear width.

No design procedure is available for a culvert with more than two barrels.

DR-06.460 Performance Curves

A performance curve is a plot of discharge versus headwater depth or elevation. Performance curves shall be developed for culverts with side-tapered or slope-tapered inlets to insure that the designer is aware of how the culvert will function over a range of discharges, especially those exceeding the design discharge.

Calculate performance curve points: Q_{design} - #. Q_{design}, Q_{100}, and Q_{100} + # where # = Q_{100} - Q_{design}.

DR-06.470 Design Procedure

STEP 1: Perform conventional culvert design. (See Section 06.200)

STEP 2: Select culverts to be analyzed for improved inlets.

STEP 3: Perform throat control calculations.

STEP 4: Design face section.

STEP 5: Do performance curve calculations.

NOTES AND COMMENTS

DR-06.500 HEADWALLS

DR-06.510 Projecting Ends

Installations which do not employ the use of a headwall are described as having projecting ends. A projecting culvert is one in which the barrel extends beyond the face of the roadway side slope. The concrete pipes with their socket-ends and the metal pipes with a collar to create 1:1 bevels (or a 6" eccentric reducer) are as hydraulically efficient at the inlet end as the beveled headwalls for inlet control. The "1" outlet loss coefficient is valid for both headwalls and ends-projecting. The erosion control function of a headwall could be performed by rip-rap at a lesser cost.

Each situation must be carefully evaluated to determine whether the application of a headwall or no headwall will serve the more useful purpose. The projected end is vulnerable to culvert end displacement and failure, usually due to erosion around the culvert end. On the other hand, a structure on the end of a culvert can be so large that it will fail due to its own weight pulling it over after slight erosion. The economics, safety, and durability of each alternative should be considered. Therefore, projecting ends should be studied for pipe culverts in rural areas with inlets and outlets outside the project clear zone.

Abbreviated plans are addressed in the Design Guidance Manual. This type of project is an example of one where projecting ends are recommended for cross drain structures less than 54 inches in diameter or their equivalent. These structures require some measure of stabilization to insure their continued operation. End anchors and intermediate anchors shall be used. Detailed drawings of anchors are available in the Standard Drawings for both circular pipe and non-circular pipe.

End projecting may be an alternative design for high fill projects where normal pipe placement involves the use of a long structure on a steep gradient with high outlet velocities. The structure may be shortened by elevating it in the fill and allowing the outlet end to project. Some means of energy dissipation and slope stabilization at the outlet will make this a viable alternative.

DR-06.520 Mitered End

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 improvement over the projecting end but there still exits a safety and structural stability problem. Mitered ends should not be used with skews greater than 15 degrees.

DR-06.530 Headwall Categories

Headwalls are reinforced or non-reinforced concrete structures normally constructed at both ends of a pipe. The exception to this is abbreviated plan projects where pipe sizes less than situation size (48" or smaller) require end anchors instead of headwalls.

These structures provide stability for the pipe, prevent erosion and promote hydraulic efficiency of a pipe. Dependent upon skew, location, and facility type, these structures are designed to accommodate single and multiple lines of circular and non-circular pipe sizes. The dimensions and quantities for the available designs may be found in the current edition of the Department of Highways Standard Drawings Manual (RDH- Series).

There are two basic categories of headwalls used in Kentucky. These are NON-SAFETY HEADWALLS (Section 06.440) and SAFETY HEADWALLS (Section 06.450). Both categories are hydraulically designed for particular uses which will be explained in their respective sections.

DR-06.540 Non-safety Headwalls

The most important element to consider when choosing which particular non-safety headwall to use is that some form of protection must be provided, since by design, these headwalls pose a vehicular hazard. This protection may be in the form of guardrail, some natural or man-made barrier, or simply by location of the headwall to reduce the possibility of vehicular contact with the structure or the opening it creates.

Non-safety headwalls may be used outside the project clear zone.

They shall also be used on all projects at locations where guardrail is required, regardless of slope, except in depressed medians.

CONCRETE HEADWALL

These Standard, Raised, Standard Ell, Raised Ell and U-Type Headwalls are perhaps the oldest designs still employed by the state today. The use of these concrete headwalls is limited by present safety requirements and hydraulic innovations.

These CONCRETE headwalls are simple concrete retaining walls encircling the pipe. The exposed side is vertical to improve the efficiency of the pipe inlet. They may be used with pipes 12" through 27" diameter circular and non-circular equivalents.

The standard and raised headwalls are of the same configuration except that the raised headwall is taller and wider. The raised headwall was designed to be used at the pipe outlet on narrow roadways because the original criteria required that the tops of the inlet headwall and outlet headwall be at the same elevation when both headwalls are close to the edge of the shoulder. Thus, to get a proper drainage slope on the pipe, the taller, raised headwall should be used at the outlet.

Standard and raised headwalls are used primarily at locations not exceeding 45 degrees skew, locations such as road widening projects where right-of-way restrictions make its use desirable, locations where a wing-type headwall would interfere with ditch flow paralleling the roadway, and may be used at other locations deemed appropriate by the designer.

STANDARD ELL HEADWALL

These headwalls are modifications of the proceeding ones, in that a second wall is added forming an ell shape. The two walls are usually constructed at a 90 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.

The original criteria for use of Ell headwalls was used in the roadway ditch of a cut section at the inlet end of the culvert when the centerline grade is 1% or greater and at both inlet and outlet ends at crossroad intersections when it is necessary to divert the flow. The designer is to follow these guidelines.

U-TYPE HEADWALL

Another headwall in this series is the U-TYPE. It is an ell headwall with a third wall added to form the U-shape. As above, the angles between the walls are usually constructed at 90 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 in most instances. 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. Its design prevents erosion at the sides of the headwall and provides flowline protection against erosion at the inlet and outlet. The headwall is compact and will improve aesthetics of the roadway, particularly in urban areas. It is also designed to accommodate a single line of 12" through 27" circular and non-circular pipe. The wing angles are normally constructed at approximately 15 degrees, but may be altered to accommodate flow.

This headwall may be used on all culvert pipe cross drains with the following exceptions:

1. Locations where safety headwalls are required.
2. Locations where multiple pipe culverts are used.
3. Locations exceeding 45 degrees skew.
4. Locations such as road-widening projects where right-of-way restrictions dictate the use of a concrete headwall.
5. Locations where this headwall will interfere with ditch flow paralleling the roadway.
6. Locations where 12" - 27" pipe culverts are used on abbreviated plan projects.

PIPE CULVERT HEADWALL

Pipe culvert headwalls are designed to accommodate 30" through 108" circular pipe and 30" through 72" non-circular pipe for skews of 0, 15, 30 and 45 degrees. 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.

STANDARD MULTIPLE LINE HEADWALL

These headwalls are of the same design as those in Standard Headwall section, above and generally follow the same criteria. These headwalls accommodate 18" - 24" double and triple lines of circular pipe. The headwall selected for use shall accommodate the largest diameter pipe for situations where more than one pipe size is included.

DOUBLE & TRIPLE PIPE CULVERT HEADWALLS

These multiple line headwalls are of the same design as the Pipe Culvert Headwalls section, described above. The designs available are for 30" - 48" circular pipe on 0 degrees, 15 degrees, 30 degrees, and 45 degrees skew. Their use shall follow the criteria for Pipe Culvert Headwalls.

DR-06.550 Safety Headwalls

Slopes of 4:1 or flatter provide a greater degree of safety for the motorist, so these structures have been designed to conform to the flatter slopes and have been fitted with gratings for adequate vehicular protection.

The requirements of hydraulic efficiency presented difficulties, which were resolved by the shape of the openings in the grates, as well as flaring the opening. The grates have been designed to minimize the effects of collected debris, but care should be exercised in applying these grates where clogging may cause upstream property damage. In these cases other alternatives such as the use of Non-safety Headwalls and guardrail or extensions of the culvert pipe should be explored. Safety headwalls shall be used when within the project clear zone.

The available designs of safety headwalls are examined in the following sections. Dimensions and quantities of material may be found in the current edition of the Department of Transportation's Standard Drawing Manual (RDB-Series).

Even though the names of these structures are box inlets or box outlets or box inlet/outlets, which is their bid item nomenclature, they still fall in the category of Safety headwalls.

SLOPED & PARALLEL HEADWALL

This type of headwall is to be used with slopes 4:1 or flatter within the project clear zone where the inlet or outlet is perpendicular to the centerline of the highway. In other locations where safety is not necessarily a factor and a sloped headwall is needed, it is recommended that this headwall be used primarily on the outlet end of installations. This headwall may be used with 12", 15", 18" or 21" (and equivalent) cross drain pipe.

SLOPED & FLARED BOX (INLET/OUTLET)

This headwall is a modification of the sloped box outlet in that the opening and grates have been widened or flared to improve hydraulics when used as an inlet.

This structure has also been designed for high volume, high speed facilities incorporating safety features. This structure is primarily intended for use on 4:1 or flatter slopes where the inlet or outlet is located generally within the project clear zone. It may be used on other facilities which do not require safety features provided the slopes are 4:1 or flatter and safety conditions are materially improved by their application. This structure may be used with the 24", 27", 30", and 36" diameter circular pipes.

The S & F box inlet/outlet should not be used at locations facing traffic due to the open end offering a vehicular obstruction. If a safety headwall is needed at such locations, the grates must be re-designed to cover the complete opening and will be treated as special cases.

SLOPED BOX OUTLET TYPE 1

This headwall is constructed on a 4:1 slope and has a structural steel grate with 4 inch openings for cleaner flow. It is designed to accommodate the 24" diameter circular pipe.

The primary application of this structure is for median drain outlets generally located within the project clear zone. Other applications may be made; however, they should never be placed facing traffic, and more ideally placed at right angles to the traffic stream.

SLOPED BOX INLET/OUTLET TYPE 1

Due to research that demonstrated the over-design of this headwall, it is no longer used, but is described here to make the designer aware of its existence and design when working on older improvement projects.

This headwall is of the same general design as the sloped box outlet and follows the same requirements. The difference between these headwalls is the fact that the grate covers the entire opening of this headwall and it is designed to accommodate 15" and 18" equivalent non-circular pipe. Since the opening is completely covered, this headwall may be used, if necessary, facing traffic without alterations.

SLOPE BOX INLET/OUTLET TYPE 2

This headwall is a special application structure designed for retrofitting a crossover to an existing, depressed median. It is constructed on a 6:1 slope and takes a 15" equivalent pipe through the side wall. Application is limited to situations such as crossover additions to existing, depressed medians. Normal drainage patterns should be maintained by positioning the crossover next to an existing drop box inlet. If this method is not practical, then the alternate solution of applying the sloped box inlet/outlet Type 2 is recommended. See the current edition of the Standard Drawings RPM-Series "Permanent and Seasonal U-Turn Median Opening."

NOTES AND COMMENTS

CHAPTER DR-06
CULVERTS & HEADWALLS

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DR-06.900 EXHIBITS
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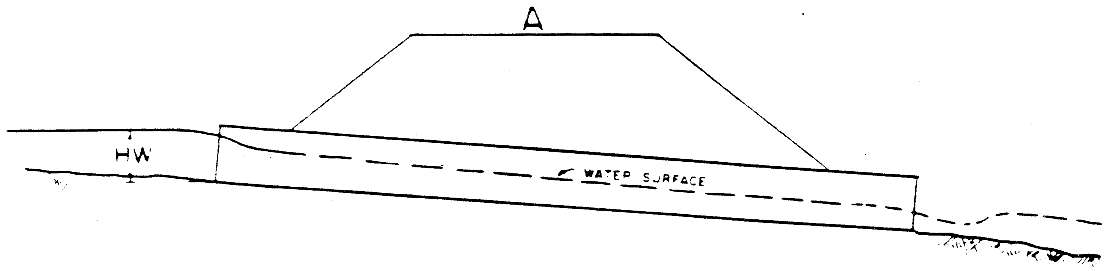
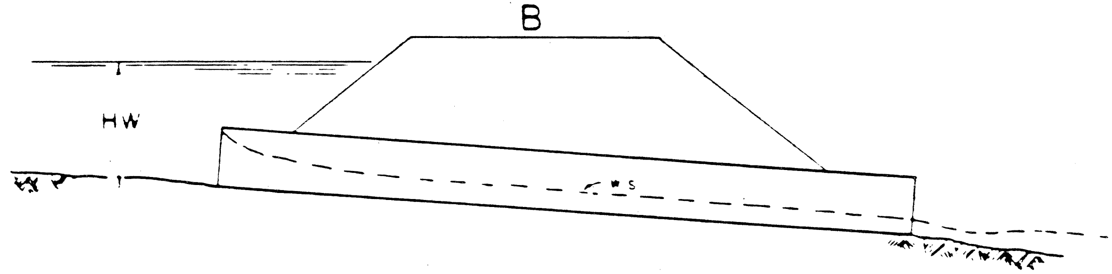
DR-06.900 CHAPTER 6 EXHIBITS

CHAPTER DR-06
CULVERTS & HEADWALLS



PROJECTING END — UNSUBMERGED



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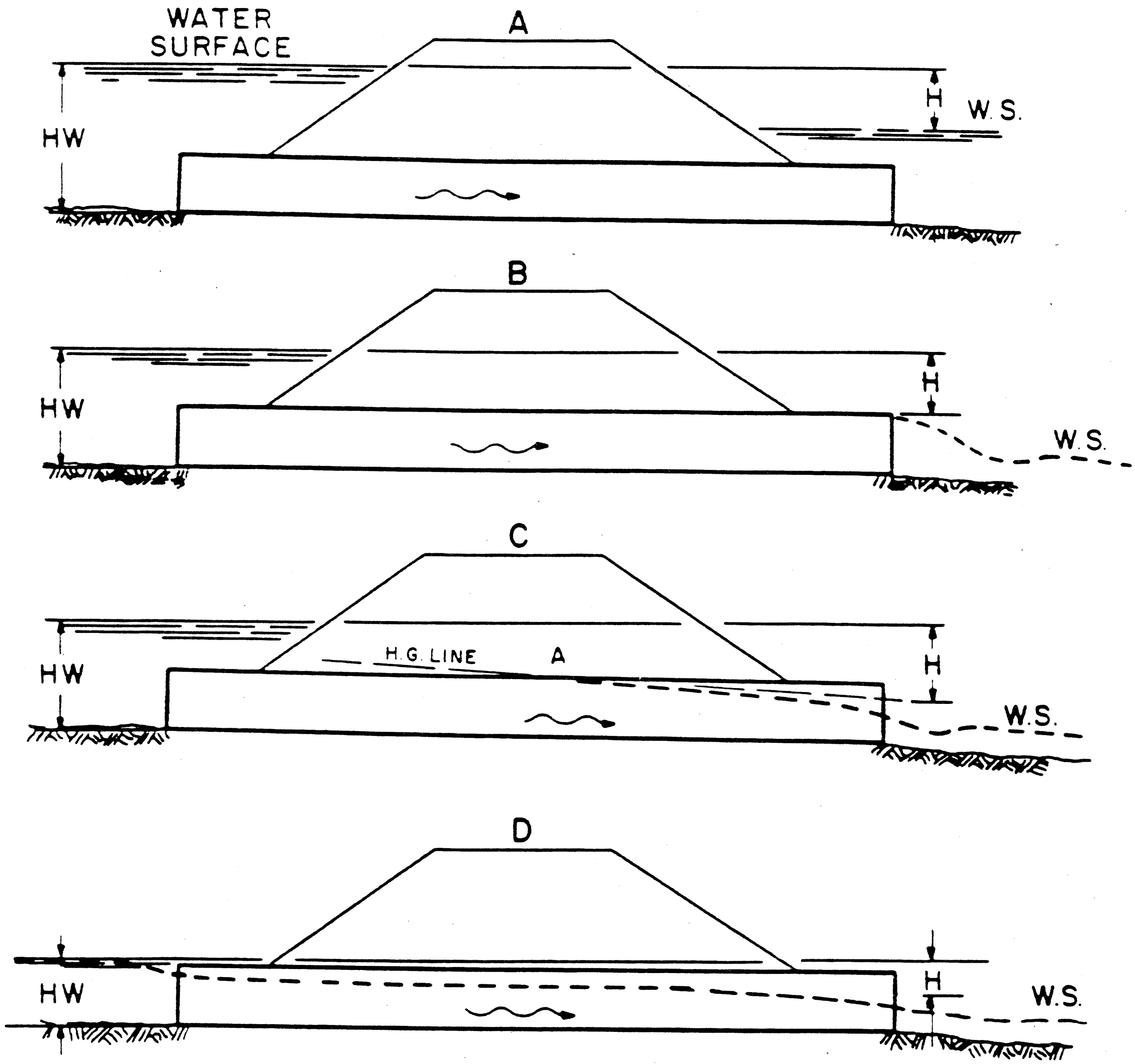
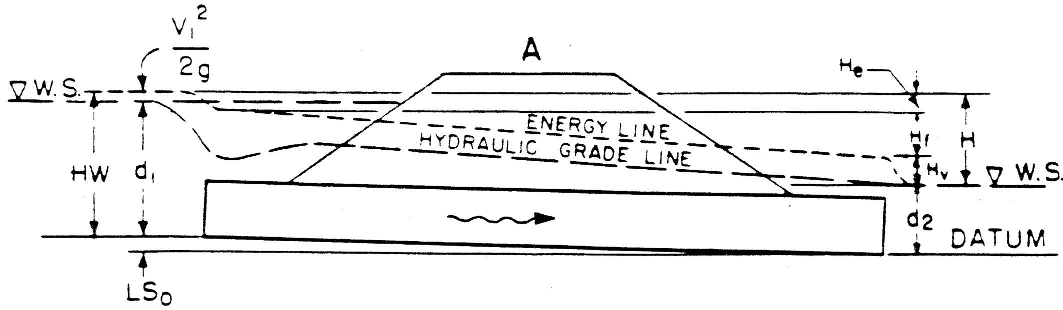
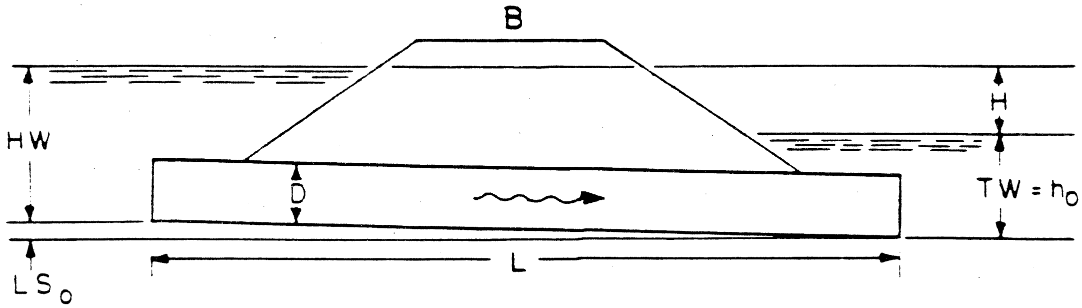
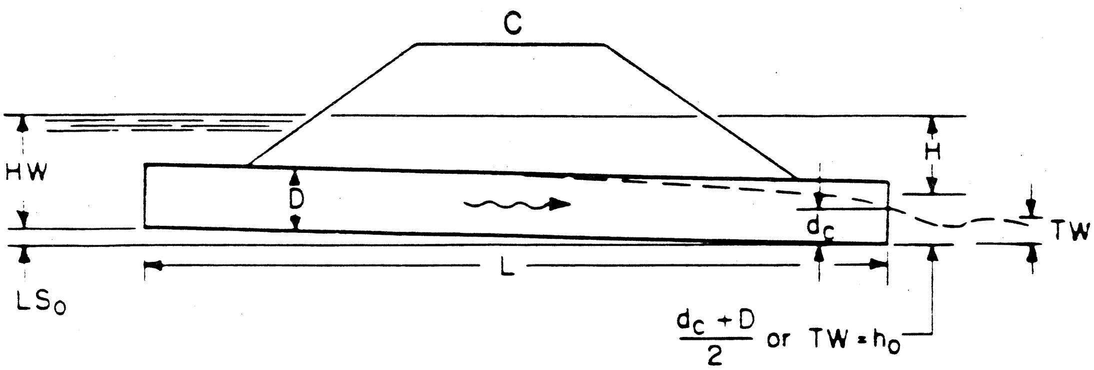
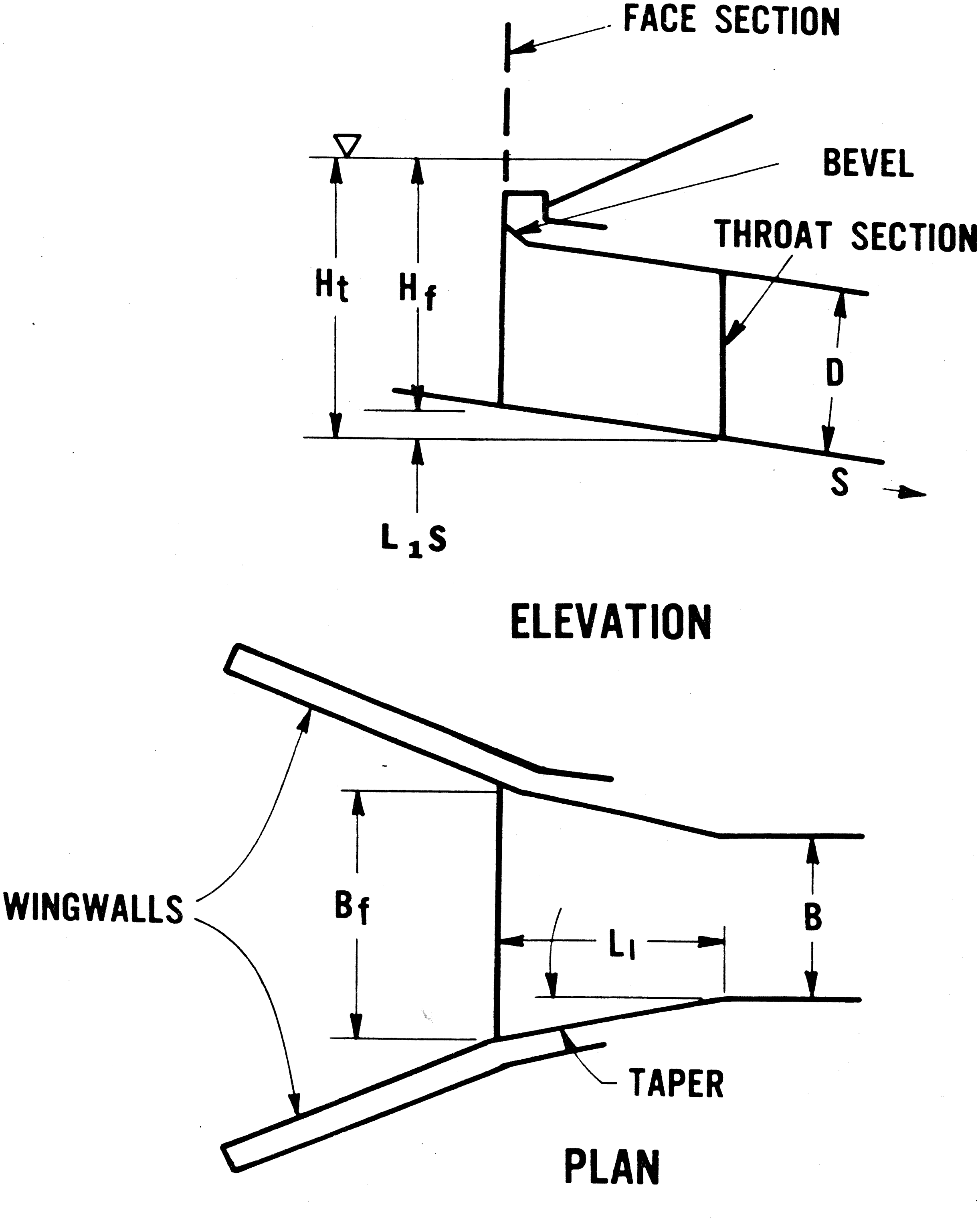

A
WATER
SURFACE
HW
H
W.S.
B
HW
H
W.S.
C
HW
H.G. LINE
A
H
W.S.
D
HW
H
W.S.


A
$\frac{V_1^2}{2g}$
W.S.
HW
d_1
ENERGY LINE
HYDRAULIC GRADE LINE
H_e
H_f
H_v
H
W.S.
d_2
DATUM
LS_0

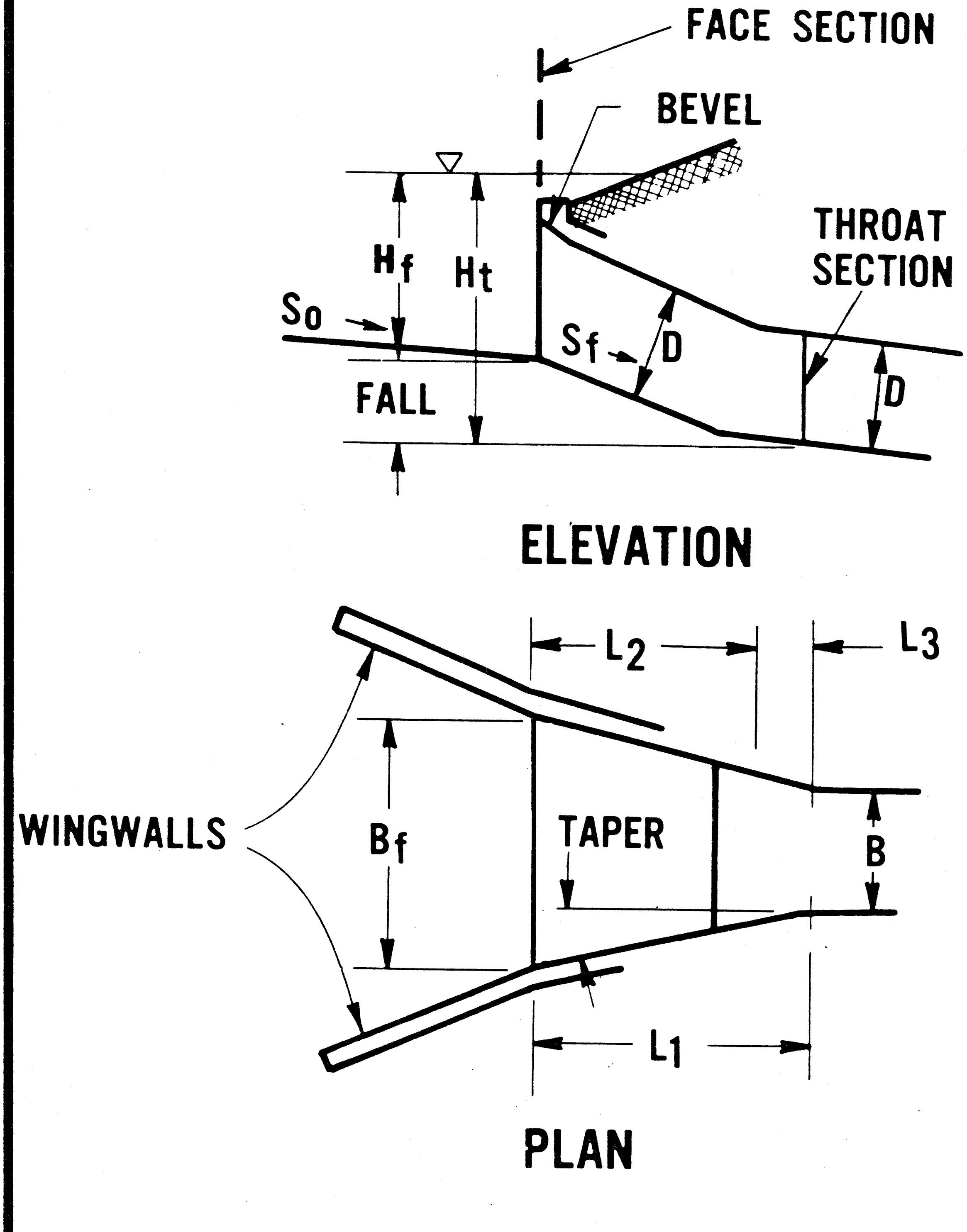

B
HW
D
H
$TW = h_0$
L
LS_0

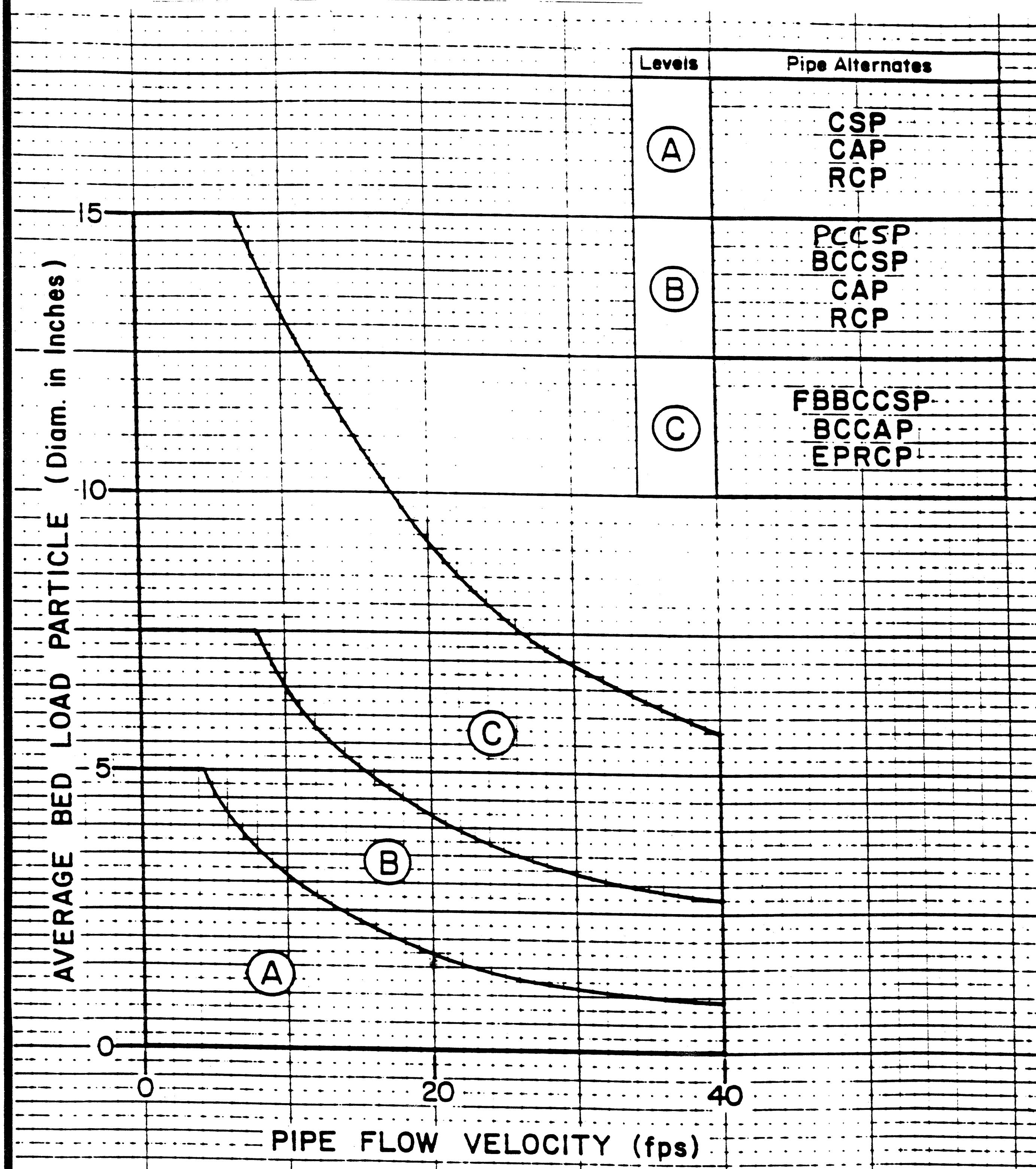

C
HW
D
H
d_c
TW
L
LS_0
$\frac{d_c + D}{2}$ or $TW = h_0$

SIDE - TAPERED INLET



SLOPE - TAPERED INLET





Ⓐ Ⓑ Ⓒ Plot **AVERAGE BED LOAD PARTICLE** vs. **PIPE FLOW VELOCITY**.

See Table Above For Permissible Pipe Alternates.

d_n	Span 16' A	Span 16' r	Span 18' A	Span 18' r	Span 20' A	Span 20' r	Span 22' A	Span 22' r	Span 24' A	Span 24' r	Span 26' A	Span 26' r	Span 28' A	Span 28' r
0.5	7.9	0.46	8.9	0.47	9.9	0.47	10.9	0.47	11.9	0.48	12.9	0.48	13.9	0.48
1.0	15.6	0.85	17.6	0.87	19.6	0.88	21.6	0.89	23.6	0.90	25.6	0.91	27.6	0.91
1.5	23.0	1.18	26.0	1.21	29.0	1.24	32.0	1.26	35.0	1.28	38.0	1.30	41.1	1.31
2.0	30.1	1.46	34.1	1.51	38.1	1.55	42.1	1.59	46.2	1.62	50.2	1.65	54.2	1.67
2.5	36.9	1.70	41.9	1.77	47.0	1.83	52.0	1.88	57.0	1.92	62.1	1.96	67.1	1.99
3.0	43.4	1.90	49.5	1.99	55.5	2.07	61.6	2.14	67.6	2.20	73.7	2.25	79.7	2.29
3.5	49.6	2.06	56.7	2.18	63.8	2.28	70.9	2.36	77.9	2.44	85.0	2.50	92.1	2.56
4.0	55.4	2.19	63.6	2.34	71.7	2.46	79.8	2.56	87.9	2.65	96.0	2.73	104.1	2.81
4.5	60.9	2.30	70.2	2.47	79.3	2.61	88.5	2.74	97.6	2.85	106.7	2.94	115.8	3.03
5.0	66.1	2.38	76.4	2.56	86.6	2.74	96.8	2.89	107.0	3.01	117.1	3.13	127.3	3.23
5.5	70.8	2.43	82.2	2.66	93.5	2.85	104.8	3.02	116.0	3.16	127.2	3.29	138.4	3.41
6.0	75.0	2.47	87.7	2.72	100.1	2.94	112.5	3.13	124.7	3.29	137.0	3.44	149.2	3.57
6.5	78.8	2.47	92.6	2.76	106.3	3.01	119.7	3.22	133.1	3.40	146.4	3.56	159.7	3.71
7.0	82.0	2.45	97.2	2.78	112.0	3.05	126.6	3.29	141.1	3.49	155.5	3.68	169.8	3.84
7.5	84.4	2.40	101.2	2.78	117.2	3.08	133.0	3.34	148.6	3.57	164.1	3.77	179.6	3.95
8.0	85.8	2.22	104.5	2.75	122.0	3.09	139.0	3.38	155.8	3.63	172.4	3.85	189.0	4.05
8.5			107.1	2.69	126.2	3.08	144.6	3.40	162.6	3.67	180.3	3.91	198.0	4.13
9.0			108.5	2.50	129.8	3.05	149.6	3.40	168.8	3.70	187.8	3.96	206.6	4.20
9.5					132.5	2.98	154.0	3.38	174.6	3.71	194.8	4.00	214.8	4.25
10.0					134.0	2.78	157.7	3.34	179.8	3.71	201.4	4.02	222.5	4.29
10.5							160.6	3.26	184.4	3.68	207.4	4.02	229.8	4.32
11.0							162.1	3.05	188.3	3.63	212.8	4.01	236.6	4.33
11.5									191.3	3.55	217.6	3.98	242.8	4.33
12.0									193.0	3.33	221.6	3.92	248.5	4.31
12.5											224.8	3.84	253.4	4.27
13.0											226.5	3.61	257.6	4.22
13.5													260.9	4.12
14.0													262.6	3.89
14.5														
15.0														
15.5														
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22.0														

d_n	Span 30' A	Span 30' r	Span 32' A	Span 32' r	Span 34' A	Span 34' r	Span 36' A	Span 36' r	Span 38' A	Span 38' r	Span 40' A	Span 40' r	Span 42' A	Span 42' r	Span 44' A	Span 44' r
0.5	14.9	0.48	16.0	0.48	17.0	0.48	18.0	0.48	19.0	0.48	20.0	0.49	21.0	0.49	22.0	0.49
1.0	29.6	0.92	31.7	0.92	33.7	0.93	35.7	0.93	37.7	0.94	39.7	0.94	41.7	0.94	43.7	0.95
1.5	44.1	1.32	47.1	1.33	50.1	1.34	53.1	1.35	56.1	1.36	59.2	1.36	62.2	1.37	65.2	1.38
2.0	58.2	1.69	62.3	1.71	66.3	1.72	70.3	1.74	74.3	1.75	78.4	1.76	82.4	1.77	86.4	1.78
2.5	72.1	2.02	77.2	2.05	82.2	2.07	87.2	2.10	92.3	2.11	97.3	2.13	102.3	2.15	107.3	2.16
3.0	85.8	2.33	91.8	2.37	97.8	2.40	103.9	2.43	109.9	2.46	116.0	2.48	122.0	2.50	128.0	2.52
3.5	99.1	2.61	106.2	2.66	113.2	2.70	120.3	2.74	127.3	2.77	134.4	2.80	141.4	2.83	148.4	2.86
4.0	112.2	2.87	120.2	2.93	128.3	2.98	136.4	3.03	144.4	3.07	152.5	3.11	160.5	3.15	168.6	3.18
4.5	124.9	3.10	134.0	3.17	143.1	3.24	152.2	3.29	161.2	3.35	170.3	3.39	179.4	3.44	188.4	3.48
5.0	137.4	3.32	147.5	3.40	157.6	3.47	167.7	3.54	177.8	3.60	187.9	3.66	197.9	3.71	208.0	3.76
5.5	149.5	3.51	160.7	3.61	171.8	3.69	182.9	3.77	194.0	3.84	205.1	3.91	216.2	3.97	227.3	4.02
6.0	161.4	3.69	173.5	3.79	185.7	3.89	197.8	3.98	210.0	4.06	222.1	4.14	234.2	4.21	246.3	4.27
6.5	172.9	3.84	186.1	3.97	199.3	4.08	212.4	4.18	225.6	4.27	238.8	4.35	251.9	4.43	265.0	5.51
7.0	184.1	3.99	198.3	4.12	212.5	4.24	226.7	4.36	240.9	4.46	255.1	4.56	269.3	4.64	283.4	4.73
7.5	194.9	4.11	210.2	4.26	225.5	4.40	240.7	4.52	256.0	4.64	271.2	4.74	286.4	4.84	301.5	4.93
8.0	205.4	4.23	221.8	4.39	238.1	4.54	254.4	4.67	270.6	4.80	286.9	4.92	303.1	5.02	319.3	5.12
8.5	215.5	4.32	232.9	4.50	250.3	4.66	267.7	4.81	285.0	4.95	302.3	5.08	319.6	5.19	336.8	5.30
9.0	225.2	4.41	243.8	4.60	262.2	4.77	280.7	4.94	299.0	5.09	317.4	5.22	335.7	5.35	354.0	5.47
9.5	234.6	4.48	254.2	4.68	273.8	4.87	293.3	5.05	312.7	5.21	332.1	5.36	351.5	5.50	370.8	5.63
10.0	243.5	4.54	264.3	4.76	284.9	4.96	305.5	5.15	326.0	5.32	346.5	5.48	366.9	5.63	367.3	5.77
10.5	252.0	4.58	273.9	4.82	295.7	5.04	317.4	5.24	339.0	5.43	360.5	5.60	382.0	5.76	403.4	5.91
11.0	260.0	4.61	283.1	4.87	306.1	5.10	328.9	5.32	351.6	5.52	374.2	5.70	396.8	5.87	419.3	6.03
11.5	267.5	4.63	291.9	4.91	316.0	5.16	339.9	5.39	363.8	5.60	387.5	5.79	411.1	5.98	434.7	6.15
12.0	274.5	4.64	300.2	4.93	325.5	5.20	350.6	5.44	375.6	5.67	400.4	5.88	425.1	6.07	449.8	6.25
12.5	281.0	4.63	307.9	4.95	334.5	5.23	360.8	5.49	386.9	5.73	412.9	5.95	438.8	6.15	464.5	6.35
13.0	286.8	4.61	315.2	4.95	343.1	5.25	370.6	5.52	397.9	5.78	425.0	6.01	452.0	6.23	478.9	6.43
13.5	292.0	4.57	321.9	4.94	351.1	5.26	379.9	5.55	408.4	5.82	436.7	6.06	464.8	6.29	492.8	6.51
14.0	296.3	4.51	327.9	4.91	358.6	5.25	368.7	5.56	418.4	5.85	447.9	6.11	477.2	6.35	506.3	6.58
14.5	299.7	4.41	333.2	4.86	365.4	5.24	396.9	5.57	428.0	5.87	458.7	6.14	489.2	6.40	519.5	6.63
15.0	301.5	4.16	337.7	4.80	371.6	5.20	404.6	5.56	437.0	5.88	469.0	6.17	500.7	6.43	532.2	6.68
15.5			341.1	4.69	377.1	5.16	411.7	5.54	445.5	5.87	478.8	6.18	511.7	6.46	544.4	6.73
16.0			343.0	4.44	381.7	5.08	418.1	5.50	453.4	5.86	488.1	6.19	522.3	6.48	556.2	6.76
16.5					385.3	4.98	423.7	5.45	460.7	5.84	496.8	6.18	532.3	6.49	567.5	6.78
17.0					387.3	4.72	428.5	5.37	467.2	5.80	504.9	6.16	541.8	6.49	578.3	6.80
17.5							432.1	5.26	473.0	5.74	512.3	6.13	550.7	6.48	588.6	6.80
18.0							434.2	5.00	477.9	5.66	519.1	6.09	559.0	6.46	598.3	6.80
18.5									481.7	5.55	525.0	6.03	566.7	6.43	607.4	6.79
19.0									483.7	5.27	530.0	5.95	573.6	6.39	615.9	6.76
19.5											533.9	5.83	579.7	6.32	623.7	6.73
20.0											536.0	5.55	584.8	6.24	630.8	4.68
20.5													588.8	6.12	637.0	6.61
21.0													590.9	5.83	642.3	6.53
21.5															646.3	6.40
22.0															648.6	6.11

A = Cross Sectional Area of the flow prism at Depth d_n

r = Hydraulic Radius of Culvert at d_n

Height = 1/2 Span

Use Manning's Formula to Calculate the Velocity

d_n	Span 16'		Span 18'		Span 20'		Span 22'		Span 24'		Span 26'		Span 28'		Span 30'	
	A	r	A	r	A	r	A	r	A	r	A	r	A	r	A	r
0.5	8	0.4	9	0.4	10	0.4	11	0.4	12	0.4	13	0.4	14	0.4	15	0.4
1.0	16	0.8	18	0.8	20	0.8	22	0.8	24	0.9	26	0.9	28	0.9	30	0.9
1.5	23	1.2	26	1.2	29	1.2	32	1.2	35	1.2	38	1.3	41	1.3	44	1.3
2.0	30	1.4	34	1.5	38	1.5	42	1.6	46	1.6	50	1.6	54	1.6	58	1.7
2.5	38	1.7	43	1.8	48	1.8	53	1.9	58	1.9	63	1.9	68	2.0	73	2.0
3.0	44	1.9	50	2.0	56	2.1	63	2.1	69	2.2	75	2.2	81	2.3	87	2.3
3.5	51	2.1	58	2.2	65	2.3	72	2.4	79	2.5	86	2.5	93	2.6	100	2.6
4.0	58	2.3	66	2.4	74	2.5	82	2.6	90	2.7	98	2.8	106	2.8	114	2.9
4.5	64	2.4	73	2.6	82	2.7	91	2.8	100	2.9	109	3.0	118	3.1	127	3.2
5.0	70	2.5	80	2.7	90	2.9	100	3.0	110	3.1	120	3.2	130	3.3	140	3.4
5.5	75	2.6	87	2.8	98	3.0	109	3.2	120	3.3	131	3.4	142	3.5	153	3.6
6.0	81	2.7	93	2.9	105	3.1	117	3.3	130	3.4	142	3.6	154	3.7	166	3.8
6.5	86	2.8	99	3.0	113	3.2	126	3.4	139	3.6	152	3.7	165	3.9	178	4.0
7.0	91	2.8	105	3.1	120	3.3	134	3.5	148	3.7	162	3.9	176	4.0	190	4.2
7.5	95	2.9	111	3.2	126	3.4	142	3.6	157	3.8	172	4.0	187	4.2	202	4.3
8.0	100	2.9	116	3.2	133	3.5	149	3.7	165	3.9	182	4.1	198	4.3	214	4.5
8.5	103	2.9	121	3.2	139	3.5	156	3.8	174	4.0	191	4.2	208	4.4	226	4.6
9.0	107	2.9	126	3.3	145	3.6	163	3.9	182	4.1	200	4.3	219	4.5	237	4.7
9.5	110	2.9	130	3.3	150	3.6	170	3.9	190	4.2	209	4.4	228	4.6	248	4.8
10.0	112	2.8	134	3.3	156	3.6	177	3.9	197	4.2	218	4.5	238	4.7	259	4.9
10.5	114	2.7	138	3.2	160	3.6	182	4.0	204	4.3	226	4.6	248	4.8	269	5.0
11.0			141	3.2	165	3.6	188	4.0	211	4.3	234	4.6	257	4.9	279	5.1
11.5			143	3.1	169	3.6	194	4.0	218	4.3	242	4.6	266	4.9	289	5.2
12.0			144	3.0	172	3.6	198	4.0	224	4.4	249	4.7	274	5.0	299	5.2
12.5					175	3.5	203	4.0	230	4.4	256	4.7	282	5.0	308	5.3
13.0					177	3.4	207	3.9	235	4.4	263	4.7	290	5.1	317	5.3
13.5							210	3.9	240	4.3	269	4.7	298	5.1	326	5.4
14.0							213	3.8	245	4.3	275	4.7	305	5.1	334	5.4
14.5							215	3.7	249	4.3	281	4.7	312	5.1	342	5.4
15.0									252	4.2	286	4.7	318	5.1	350	5.5
15.5									255	4.1	290	4.7	324	5.1	357	5.5
16.0									256	4.0	294	4.6	330	5.1	364	5.5
16.5											297	4.5	335	5.0	371	5.5
17.0											300	4.4	339	5.0	377	5.4
17.5													343	4.9	382	5.4
18.0													346	4.9	387	5.4
18.5													348	4.7	392	5.3
19.0															396	5.3
19.5															398	5.2
20.0															400	5.0

d_n	Span 32'		Span 34'		Span 36'		Span 38'		Span 40'		Span 42'		Span 44'	
	A	r	A	r	A	r	A	r	A	r	A	r	A	r
0.5	16	0.4	17	0.4	18	0.4	19	0.4	20	0.4	21	0.4	22	0.4
1.0	32	0.9	34	0.9	36	0.9	38	0.9	40	0.9	42	0.9	44	0.9
1.5	47	1.3	50	1.3	53	1.3	56	1.3	59	1.3	62	1.3	65	1.3
2.0	62	1.7	66	1.7	70	1.7	74	1.7	78	1.7	82	1.7	86	1.7
2.5	78	2.0	83	2.0	88	2.1	93	2.1	98	2.1	103	2.1	108	2.1
3.0	93	2.4	99	2.4	105	2.4	111	2.4	117	2.5	123	2.5	129	2.5
3.5	107	2.7	114	2.7	121	2.7	128	2.8	135	2.8	142	2.8	149	2.8
4.0	122	2.9	130	3.0	138	3.0	146	3.1	154	3.1	162	3.1	170	3.2
4.5	136	3.2	145	3.3	154	3.3	163	3.4	172	3.4	181	3.5	190	3.5
5.0	150	3.5	160	3.5	170	3.6	180	3.6	190	3.7	200	3.7	210	3.8
5.5	164	3.7	175	3.8	186	3.8	197	3.9	208	4.0	219	4.0	230	4.1
6.0	178	3.9	190	4.0	202	4.1	214	4.2	226	4.2	238	4.3	250	4.3
6.5	191	4.1	204	4.2	217	4.3	230	4.4	243	4.5	256	4.5	270	4.6
7.0	204	4.3	219	4.4	233	4.5	247	4.6	261	4.7	275	4.8	289	4.8
7.5	217	4.5	233	4.6	248	4.7	263	4.8	278	4.9	293	5.0	308	5.1
8.0	230	4.6	246	4.7	262	4.9	279	5.0	295	5.1	311	5.2	327	5.3
8.5	243	4.8	260	4.9	277	5.0	294	5.2	311	5.3	328	5.4	345	5.5
9.0	255	4.9	273	5.1	291	5.2	310	5.3	328	5.5	346	5.6	364	5.7
9.5	267	5.0	286	5.2	306	5.3	325	5.5	344	5.6	363	5.8	382	5.9
10.0	279	5.1	299	5.3	319	5.5	340	5.6	360	5.8	380	5.9	400	6.0
10.5	290	5.2	312	5.4	333	5.6	354	5.8	375	5.9	397	6.1	418	6.2
11.0	302	5.3	324	5.5	346	5.7	369	5.9	391	6.1	413	6.2	435	6.4
11.5	313	5.4	336	5.6	359	5.8	383	6.0	406	6.2	429	6.4	453	6.5
12.0	323	5.5	348	5.7	372	5.9	397	6.1	421	6.3	445	6.5	470	6.7
12.5	334	5.6	359	5.8	385	6.0	410	6.2	436	6.4	461	6.6	486	6.8
13.0	314	5.6	371	5.9	397	6.1	424	6.3	450	6.5	477	6.7	503	6.9
13.5	354	5.7	382	5.9	409	6.2	437	6.4	464	6.6	492	6.8	519	7.0
14.0	363	5.7	392	6.0	421	6.3	450	6.5	478	6.7	507	6.9	535	7.1
14.5	373	5.8	403	6.0	433	6.3	462	6.6	492	6.8	522	7.0	551	7.2
15.0	381	5.8	413	6.1	444	6.4	475	6.6	505	6.9	536	7.1	567	7.3
15.5	390	5.3	422	6.1	455	6.4	487	6.7	518	6.9	550	7.2	582	7.4
16.0	398	5.8	432	6.2	465	6.5	498	6.7	531	7.0	564	7.3	597	7.5
16.5	406	5.8	441	6.2	475	6.5	510	6.8	544	7.1	578	7.3	611	7.6
17.0	413	5.8	450	6.2	485	6.5	521	6.8	556	7.1	591	7.4	626	7.6
17.5	420	5.8	458	6.2	495	6.5	531	6.9	568	7.2	604	7.4	640	7.7
18.0	427	5.8	466	6.2	504	6.6	542	6.9	579	7.2	617	7.5	654	7.8
18.5	433	5.8	473	6.2	513	6.6	552	6.9	591	7.2	629	7.5	667	7.8
19.0	439	5.8	480	6.2	521	6.6	562	6.9	601	7.3	641	7.6	681	7.9
19.5	444	5.7	487	6.2	529	6.6	571	6.9	612	7.3	653	7.6	693	7.9
20.0	448	5.6	493	6.1	537	6.6	580	6.9	622	7.3	664	7.6	706	7.9
20.5	452	5.6	499	6.1	544	6.5	588	6.9	632	7.3	675	7.6	718	8.0
21.0	454	5.5	504	6.0	551	6.5	596	6.9	641	7.3	686	7.7	730	8.0
21.5			508	6.0	557	6.5	604	6.9	650	7.3	696	7.7	742	8.0
22.0			511	5.9	562	6.4	611	6.9	659	7.3	706	7.7	753	8.0
22.5			513	5.7	567	6.4	618	6.8	667	7.3	716	7.7	764	8.0
23.0					571	6.3	624	6.8	675	7.3	725	7.7	774	8.0
23.5					574	6.2	629	6.7	682	7.2	733	7.6	784	8.0
24.0					576	6.0	634	6.7	689	7.2	742	7.6	794	8.0
24.5							638	6.6	[illegible]	[illegible]	749	7.6	803	8.0
25.0							641	6.5	700	[illegible]	757	7.6	812	8.0
25.5									705	7.0	763	7.5	820	8.0
26.0									708	6.9	769	7.5	827	7.9
26.5									711	6.7	774	7.4	835	7.9
27.0											779	7.3	841	7.8
27.5											782	7.2	847	7.8
28.0											784	7.0	852	7.7
28.5													856	7.6
29.0													859	7.5

A= Cross Sectional Area of the Water at Depth d_n

r= Hydraulic Radius of Culvert at d_n

Height= 2/3 of the Span

Use Manning's Formula to Calculate the Velocity

KY DEPT HWYS
DIV of DESIGN
DRAINAGE SECTION

d_n	Span 6'		Span 7'		Span 8'		Span 9'		Span 10'		Span 12'		Span 14'		Span 16'		Span 18'		Span 20'		Span 22'		Span 24'		Span 26'	
	A	r	A	r	A	r	A	r	A	r	A	r	A	r	A	r	A	r	A	r	A	r	A	r	A	r
0.50	2.99	.43	3.49	.44	3.99	.44	4.49	.45	4.99	.45	5.99	.46	6.99	.47	7.99	.47	9.00	.47	10.00	.48	11.00	.48	12.00	.48	13.00	.48
1.00	5.89	.73	6.90	.76	7.92	.78	8.93	.81	9.93	.83	11.94	.85	13.95	.87	15.96	.89	17.96	.90	19.97	.91	21.97	.92	23.97	.92	25.97	.93
1.50	8.61	.92	10.17	1.01	11.71	1.06	13.25	1.10	14.77	1.13	17.81	1.18	20.84	1.22	23.86	1.25	26.87	1.28	29.89	1.30	32.90	1.32	35.91	1.33	38.91	1.34
2.00	11.04	1.06	13.20	1.17	15.31	1.26	17.39	1.32	19.45	1.38	23.55	1.46	27.61	1.53	31.66	1.58	35.70	1.62	39.73	1.65	43.76	1.68	47.78	1.71	51.79	1.73
2.50	13.01	1.09	15.87	1.26	18.61	1.39	21.28	1.49	23.92	1.57	29.11	1.70	34.24	1.79	39.34	1.87	44.41	1.93	49.47	1.97	54.52	2.02	59.56	2.05	64.60	2.08
3.00	14.14	.91	18.02	1.27	21.51	1.46	24.84	1.60	28.09	1.71	34.44	1.88	40.68	2.01	46.85	2.12	52.98	2.20	59.09	2.26	65.17	2.32	71.24	2.37	77.30	2.41
3.50			19.24	1.07	23.82	1.44	27.94	1.64	31.88	1.80	39.48	2.03	46.87	2.20	54.16	2.33	61.37	2.44	68.54	2.52	75.68	2.60	82.79	2.66	89.89	2.72
4.00					25.13	1.22	30.42	1.61	35.18	1.83	44.16	2.13	52.78	2.34	61.22	2.51	69.55	2.65	77.81	2.76	86.02	2.85	94.19	2.93	102.33	2.98
4.50							31.81	1.37	37.80	1.78	48.39	2.18	58.34	2.45	68.00	2.66	77.49	2.83	86.86	2.96	96.16	3.08	105.41	3.17	114.62	3.26
5.00									39.27	1.53	52.05	2.19	63.48	2.53	74.43	2.78	85.13	2.98	95.66	3.14	106.09	3.28	116.43	3.39	126.72	3.49
5.50											54.94	2.12	68.10	2.56	80.47	2.86	92.44	3.10	104.17	3.29	115.75	3.45	127.22	3.59	138.61	3.71
6.00											56.55	1.83	72.09	2.54	86.02	2.91	99.36	3.19	112.35	3.42	125.13	3.61	137.75	3.77	150.27	3.91
6.50													75.22	2.45	91.01	2.92	105.83	3.25	120.15	3.52	134.18	3.74	147.99	3.92	161.67	4.08
7.00													76.97	2.14	95.30	2.88	111.78	3.28	127.53	3.59	142.86	3.84	157.91	4.05	172.78	4.24
7.50															98.66	2.78	117.11	3.28	134.41	3.64	151.13	3.92	167.48	4.17	183.57	4.37
8.00															100.53	2.44	121.67	3.23	140.73	3.65	158.93	3.98	176.63	4.26	194.00	4.49
8.50																	125.25	3.11	146.38	3.63	166.21	4.01	185.35	4.32	204.05	4.58
9.00																	127.23	2.75	151.21	3.57	172.87	4.01	193.56	4.36	213.66	4.66
9.50																			154.99	3.44	178.82	3.98	201.20	4.38	222.79	4.71
10.00																			157.08	3.05	183.90	3.90	208.19	4.37	231.39	4.74
10.50																					187.87	3.76	214.42	4.33	239.38	4.74
11.00																					190.07	3.36	219.74	4.24	246.69	4.72
11.50																							223.90	4.09	253.19	4.67
12.00																							226.19	3.67	258.74	4.57
12.50																									263.07	4.41
13.00																									265.46	3.97

A = Cross Sectional Area of the flow prism at Depth d_n

r = Hydraulic Radius of Culvert at d_n

Height = 1/2 Span (Semi-Circle)

Use Manning's Formula to Calculate the Velocity