FDM 13-15-1 Economic Analysis

August 8, 1997

1.1 Introduction

It is desired practice to keep headwater at a minimum. However, economic design in many instances requires that the pipe flow at least full or with some headwater. Full-flow structures or structures designed to flow full under certain conditions are subject to close study. Full-flow culverts that are so designed to increase headwater and reduce the size of the culvert, and therefore reduce the cost, result in a savings for the conduit itself; but many effects that cannot be accurately determined enter into the economic design of culverts with headwater. Each individual location should be analyzed to determine the allowable headwater for a specific design frequency.

The economic design of culverts with headwater for a specific design frequency requires that consideration be given to the following effects:

1. Hydraulic uplift or buoyancy, which is especially significant for large pipes in permeable soils and/or pipes with no headwalls. This danger is augmented when the culvert entrance becomes blocked with debris.
2. Accuracy of the estimate of design discharge. When determining allowable headwater depth, the designer should keep in mind that the estimate of design discharge is an approximation.
3. Exfiltration from pipes due to pressure.
4. Erosion of the embankment due to receding headwater.
5. Danger of transverse seepage through fills, especially in side hill locations.
6. Debris protection.
7. Maintenance.
8. Damage to property.
9. Hazards to life.
10. Public image.
11. Flooding of land affected by headwater. It must be understood that raising headwater over the levels of former flooding is to be avoided.
12. The installation cost includes the pipe, structure excavation, backfill, and other special features, and occasionally maintenance costs that occur on a regular, predictable basis, or specific material features that offer additional resistance to such things as silting, sliding, rupture, or corrosion.

FDM 13-15-5 Design Criteria

August 8, 1997

5.1 Introduction

In this procedure the criteria for the hydraulic design of culverts are discussed under two broad headings--Culvert Location, and Structure Size Selection. When designing culverts, the hydraulic design engineer should employ these criteria along with FDM 13-15-10, "Culvert Hydraulics," of this manual.

A Structure Survey Report containing the site data information should be submitted to the Structures Design Section in the Bureau of Highway Development for the design of all cast-in-place culverts (refer to Bridge Manual Chapter 6 for reporting procedures). In addition, each cast-in-place culvert requires a Hydraulic Report as described in Bridge Manual Chapter 8.

5.2 Culvert Location

The culvert location should be selected so the culvert passes the expected discharge with as little interruption as practical. Where water is confined in a channel, the culvert should be located at or near the point where the channel reaches the project and as much in line with the channel as possible. Where other considerations indicate a less desirable location, the roadbed and special ditch must be protected against turbulence generated by the change in direction of flow.

When a highway is to be reconstructed essentially on the location of the existing highway, the engineer shall evaluate old culvert locations for possible culvert replacement. This will aid in minimizing changes in existing drainage conditions on private lands.

When a highway is to be constructed on relocation, the designer shall provide a culvert wherever there is an appreciable natural draw or depression. If there are no significant draws or depressions, culverts shall be placed so as not to collect and concentrate a large drainage flow.

5.3 Structure Size Selection

In general, pipe drainage structures shall be selected in accordance with the current culvert selection standard (refer to FDM 13-1-15). The size of culvert may be chosen knowing the following data:

1. Estimated runoff (Q).
2. Approximate length and slope of culvert.
3. Allowable headwater depth in feet, which is taken as the vertical distance from the conduit flow line at the entrance to the water surface in the channel.
4. Entrance type. The type of entrance must be predetermined by the designer.
5. Barrel cross-sectional shape. Determined considering available headroom.
6. Barrel roughness factor. The roughness factor that produces the largest size pipe should be used when alternate materials are allowed at the contractor's option.
7. Tail-water conditions known or computed. Tail water is defined as the distance in feet from the outlet invert to the water surface in the outlet channel.

Following is a detailed discussion of the minimum required data for culvert design along with a discussion of additional design criteria required to perform a thorough hydraulic analysis of a culvert.

5.3.1 Minimum Pipe Size

In accordance with Department of Transportation practice, the minimum size of pipe for culvert cross drains shall be 24 inches, except that on multi-lane highways in fill of 10 feet or more, the minimum size shall be 30 inches.

5.4 Allowable Headwater

As noted previously, existing field conditions and channel geometry will determine a maximum depth of water that can be tolerated at the entrance of a culvert. This depth of water is known as the maximum allowable headwater depth. The information that has been accumulated during the field review of the culvert crossing can now be used to determine the maximum allowable headwater depth for the structure. When the highway profile is established, the headwater depth may also be controlled by the low point in the roadway subgrade or by high points in the roadway ditches. Generally, the maximum high-water elevation should not be higher than the subgrade shoulder point.

Sometimes field conditions will dictate a depth of headwater that is too low to allow an economical design for the culvert crossing. When this occurs, the engineer may consider the use of artificial conditions that will allow a greater depth of headwater to develop. These artificial means are berms or dikes at the inlet ends of culverts, or a depressed profile for the culvert. These artificial means of forcing a headwater depth should not cause any appreciable increase of existing flooding conditions upstream from the culvert.

5.5 Design Freeboard and Headwater-to-Depth Ratio

The headwater depth at the inlet of a pipe culvert is normally expressed as a ratio (HW/D) where HW is the total depth of water (measured from the invert of a culvert) and D is the interior height of the culvert barrel.

The design ratio can be as high as 1.50 for the culverts under 15 feet in diameter or rise. The design ratio for culverts in excess of 15 feet in diameter or rise should be 1.00. Smaller ratios for pipes less than 15 feet may be justified by safety factors of flooding conditions, velocities, scouring, economy, etc. If damage to the culvert is anticipated, or if adverse flooding conditions will be caused upstream of the culvert from the accumulation of ice and debris, the headwater-depth ratio shall be reduced. The reduction of the ratio shall be sufficient to allow an increase in the design flow capacity and freeboard (if needed) at the entrance of the structure to eliminate flood damage or to reduce it to within acceptable limits.

Since the advent of the large sections for round pipe, it has become economical in special cases to design for these culverts with a low headwater to depth ratio. In essence, the headwater to depth ratio plays no part as a control for the design of these culverts, but instead economics is the major controlling factor. To illustrate this

point, a large flow rate with a shallow allowable headwater may dictate using two or more corrugated structural plate pipes or round pipes side by side. The headwater-depth ratio of these pipes would be equal to one. A more economical design may be the use of a large round pipe with the water using a small portion of the cross-sectional area of the pipe and with the hydraulics of the stream channel flow being satisfied. In this case, a close analysis of the economics of the situation would be the controlling factor and not the headwater to depth ratio.

Note: Except in special cases where debris and ice are a problem or possible upstream flooding cannot be tolerated, allowing a freeboard is not necessary for pipes up to 20 feet in span. A two-foot freeboard is desirable for single pipe drainage with structures greater than 20 feet in span (bridges). For freeboard requirements over navigable waterways the designer is referred to the Wisconsin Administrative Code, Chapter NR 320, "Bridges and Culverts in or Over Navigable Waterways."

5.6 Inlet Treatments

The shape, geometry, and skew of an inlet all affect culvert capacity. As stated in Hydraulic Design Series (HDS) No. 5 (1): The inlet edge configuration is a major factor in inlet control performance and it can be modified to improve performance.

In outlet control, the type of inlet has some affect on capacity but generally the edge geometry is less important than in inlet control. The skew of the entrance has some affect on capacity but the result is minor.

For culverts flowing with inlet control, the constriction at the inlet may limit the flow that the culvert can carry in comparison to its potential barrel capacity. Performance curves can be used to advantage, as explained in HDS No. 5 (1), to obtain the most efficient balanced design for a given culvert size. Considerable improvements may sometimes be made in a culvert's performance by using a depressed and/or improved inlet. Performance curves are particularly useful in comparing the desirability of alternate culvert designs and the ability of the culverts to accommodate flows in excess of the design discharge.

Further reference is made to the design of the entrance for the various types of culverts in chapter III of HDS No. 5 (1) The entrance loss coefficient (K_e) varies from 0.2 to 0.9 depending on the type of structure and the configuration of the entrance; 0.2 applies to concrete pipe with the socket end projecting from fill, and 0.9 applies to a corrugated metal pipe or pipe arch projecting from the fill with no headwall (refer to Attachment 5.1).

5.7 Improved Inlets

An improved inlet is a means of increasing the capacity of a given culvert pipe size without raising the headwater. Their use has resulted in considerable savings on various projects throughout the United States. These savings have resulted primarily when inlets are used with reinforced concrete box structures. When used with corrugated metal structures, the savings have been very small. The cost savings for a single pipe installation will not usually be as great as for a large box culvert. However, the potential cost savings in achieving balanced designs on many pipe culverts by using improved inlets may be very significant. The savings in these structures are a result of reducing the size of the barrel of the structure by using a more efficient inlet. Conventional culvert inlet configurations are as listed on page 5 of HDS No. 5 (1) (for example, projecting from fill, end section conforming to fill slope, etc. Improved inlet configurations include bevel-edged, side-tapered, and slope-tapered inlets.

The bevel-edged inlet is the most economical method of improving the capacity of a conventional culvert. The addition of bevels to a conventional culvert with a square-edged inlet increases culvert capacity by five to 20 percent.

Note: Bevels should be used on all cast-in-place culvert entrance headwalls, both conventional and improved inlet types.

The side-tapered inlet consists of an enlarged face area with the transition to the culvert barrel accomplished by tapering the sidewalls. The inlet face has the same height as the barrel, and its top and bottom are extensions of the top and bottom of the barrel. This type of inlet increases flow capacity of a conventional culvert with a square-edged inlet by 25 to 40 percent.

The slope-tapered inlet increases the flow capacity of a side-tapered inlet by also providing a fall within the enclosed entrance section. This means that more head is available at the throat section (point at which the improved inlet joins the culvert barrel). This type of inlet can have over a 100 percent greater capacity than a conventional culvert with square edges.

Since culverts operating in outlet control are usually flowing full, an improved inlet will not increase its capacity. However, culverts in inlet control lie on relatively steep slopes and flow only partly full, and will exhibit marked increases in capacity with the use of an improved inlet.

Improved inlets are not prefabricated or precast; therefore, an expensive cast-in-place, rectangular, side-tapered

inlet would be a logical alternate. Obviously, the increased cost of using an improved inlet may outweigh the increased cost of using a larger culvert size. Therefore, when proposing an improved inlet, a thorough economic analysis of all feasible designs must be performed. In general, improved inlets can be economically justified for long culverts and for existing culverts that require more capacity.

Note: Reducing the structure size by utilizing improved entrance design is generally not practiced; but its practice is appropriate in very large, very long or very costly culvert installations.

For further information on improved inlets, refer to HDS No. 5 and FHWA Technical Advisory T 5140.6, "Improved Inlets for Culverts-Example Structural Plans," January 16, 1979.

5.8 End Protection

Preformed metal, aluminum, or reinforced concrete apron endwalls should be used at the inlet and discharge end of all single installation culvert pipe 84 inches and under in diameter, and pipe arch 72 inches and under in span. This applies to all cross drains, private entrances, and median installations. For larger pipe sizes or installations of two or more pipes, use concrete masonry endwalls as shown in SDD, "Concrete Masonry Headwalls."

5.9 Type, Shape, and Roughness of Culvert

Culverts are comprised of different types of material and different shapes, both of which have differing degrees of roughness. The predominant types of material for culverts are corrugated steel, precast concrete, and cast-in-place concrete.

The factor that describes roughness of culverts is usually expressed as "Manning Roughness Coefficients," designated by the letter "n." Table XIV on page 84 of "Design and Construction of Sanitary Sewers," ASCE and WEF, sixth printing, 1991 gives a listing of roughness coefficients (Darcy-Weisbach, Manning, and Hazen-Williams) to be used for conduits.

The various shapes of culverts are round, oblate, oval, and rectangular. The most efficient shape of culverts hydraulically may not be the most efficient shape economically. The preference for use of one shape over another will depend on the structural capabilities and the type of material composition of the culvert. Also, the hydraulic efficiency of the various shapes of culverts with or without coatings or linings and the final economic analysis of the various combinations of shapes, roughness factors, and hydraulic efficiencies will determine the final selection of the culvert for a specific location.

5.10 Design Tail Water

A culvert that is designed to flow under outlet control is affected by a tail-water at the outlet. Tail-water depth is the depth of water at the outlet of a structure that will affect the flow of water through a structure. The information regarding the tail water recorded during the field review of the drainage areas will now be used in the design of the culvert, either as a controlling factor or as a check factor, to ensure that the culvert is flowing under inlet control.

For the controlling cross section of an outlet channel, the tail-water depth may be approximated by the normal depth of flow as computed by Manning's Equation.

The design formulas and charts that will be needed by the engineer to design a culvert with a tail-water control are given in HDS No. 5 (1) and discussed in FDM 13-15-10.

5.11 Allowable Velocity

Culverts shall be placed, if possible, at or near the critical slope, as determined from FHWA "Open Channel" charts, in order to obtain maximum capacity. Culvert outlet velocities shall be computed for all pipes to determine whether scour will occur. These computed velocities should then be compared with outlet velocities of alternate culvert design, existing culverts in the area, or the natural stream velocities to determine the need for channel protection. In addition, the designer is referred to Chapter III-Culvert Outlet Velocity and Chapter V-Outlet Scour Computation of H.E.C. #14 (3).

5.12 Depth of Flow

For inlet control, the depth of flow in the pipe may be determined by using Manning's Equation:

$$V = \frac{1.49\, R^{2/3}\, S^{1/2}}{n}$$

However, the determination of flow depth by this formula involves a process of trial and error, and hence the depth of flow and velocity is determined through the use of the design charts in HDS #3 (3).

For outlet control, the depth of flow determined by the above formula may be drowned out by the tail-water depth; that is, the computed depth may apply near the inlet end of the conduit, but near the outlet end the depth will be higher than the computed depth.

5.13 Check Discharges

Check discharges are used during the design of culvert crossings and should be investigated for all drainage structures. The use of a check discharge is to determine the safety factor or lack of a safety factor being incorporated into the culvert crossing. When definite danger to the safety of the traveling public or extensive and costly property damage can develop from surcharging a pipe with flood flows equivalent to the check discharge, necessary precautions must be taken to alleviate the possible dangers

5.14 References

1. U.S. Department of Transportation Federal Highway Administration, Hydraulic Design of Highway Culverts Hydraulic Design Series No. 5, 2001, 348 pp

2. U.S. Department of Transportation, Federal Highway Administration, Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular #14, Washington, D.C., 2006

3. U.S. Department of Transportation Federal Highway Administration, Design Charts for Open-Channel Flow Hydraulic Design Series #3, Washington, D.C., 1961, 105 pp.

LIST OF ATTACHMENTS

FDM 13-15-10 Culvert Hydraulics

March 9, 1998

10.1 Introduction

The designer must be aware of the design aids available for designing hydraulic structures operating with inlet or outlet control, or with improved inlets. In addition, selecting the most economical and feasible hydraulic structure for a particular stream crossing is facilitated by constructing a performance curve for each of the viable hydraulic structures. This procedure gives references for the required design aids, a general discussion of inlet-outlet control along with sample problems, a short discussion on where to find literature and design aids for improved inlets, and a general discussion on using the culvert performance curve.

10.2 Available Design Aids

The hydraulic design aids used in this manual are contained in Hydraulic Design Series (HDS) #5 (1) and Hydraulic Design Series (HDS) #3. It is recommended that any designer using these charts should first thoroughly study the above-listed publications.

Culvert designs can be accomplished by using the following types of charts: the capacity charts the inlet and outlet control nomographs from critical depth charts. They are grouped by type and shape pipe in HDS #5 (1).

A direct solution of the Manning Equation for rectangular open channels and closed circular pipe channels can be obtained with the aid of HDS #3 (2), Charts 1 to 14, and Charts 35 to 51, respectively.

Culvert design can also be accomplished through the use of computer programs. HY8, which is part of FHWA's hydrain package, is a suggested computer program to use for designing:

1. Pipe arch culvert.
2. Elliptical pipe culvert.
3. Circular pipe culvert.
4. Concrete box culvert and other culvert shape.

Moreover, the HY8 computer program can design one or more of the inlet configurations that follow:

1. Conventional Inlet.
2. Bevel-Edged Inlet.
3. Side-Tapered Inlet (circular or rectangular).
4. Slope-Tapered Inlet.

Further literature on the HY8 computer program and other HYDRAIN computer programs, can be found in the

HYDRAIN. Integrated Drainage Design Computer System, Version 5.0, Volumes I to VII, January 1994 manual.

10.3 Inlet-Outlet Control

Laboratory tests and field observations show two major types of culvert flow: (1) flow with inlet control and (2) flow with outlet control. For each type of control, different factors and formulas are used to compute the hydraulic capacity of a culvert.

The controlling factors for inlet control are:

1. Inlet Area.
2. Inlet Shape.
3. Inlet Edge Configuration.
4. Allowable Headwater.

The controlling factors for outlet control are:

1. Inlet Area.
2. Inlet Shape.
3. Inlet Edge Configuration.
4. Allowable Headwater.
5. Tail Water Elevation.
6. Slope of Culvert.
7. Roughness of Culvert.
8. Length of Culvert.
9. Area of Barrel.
10. Barrel Shape.

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 (HW) is the vertical distance from the culvert invert at the entrance to the energy line of the headwater pool (depth and velocity head). Because of the low velocities in most entrance pools and difficulty in determining the velocity head for all flows, the water surface and the energy line at the entrance are assumed to be coincident.

See Attachment 10.1 for a graphical depiction of the energy balance on a culvert pipe in outlet control. The letters in Attachment 10.1 that are not easily self-explanatory are defined as follows:

He = entrance loss

Hf = friction loss

Hv = velocity head

Inlet Control Problem:

Given: Culvert Length = 200 feet

Culvert Slope = 2 percent

Allowable Headwater = 7.5 feet

Design Discharge = 190 cfs

Find: The minimum required pipe sizes for corrugated metal pipe and concrete pipe.

Solution: Refer to Attachment 10.2 for the solution that follows:

Corrugated Metal Pipe

1. Headwater Depth for metal pipe culverts with inlet control, HDS No. 5 Chart 2.

   a. Assume projecting entrance

   b. Try a 66” metal pipe using chart 2. HDS No. 5.

      HW/D = 1.25

      HW = 1.25 x 5.5 ft. = 6.9 ft.

Concrete Pipe

See Attachment 10.2 for the solution, which follows the same methodology used for the corrugated metal pipe solution.

Assume groove end projecting

try a 60" concrete pipe using chart 1. HDS No. 5.

HW/D = 1.3

HW = 1.3 x 5 = 6.5 ft.

Conclusions:

At this drainage crossing, either one of the following designs can be used:

1. A 66-inch CMP with a projecting entrance that produces a headwater of 6.9 feet or,
2. A 60-inch concrete pipe with a grooved edge projecting entrance that produces a headwater of 6.5 feet

The final selection should be based on an economic analysis and/or established policy and/or outlet protection required.

Outlet Control Problem:

Given: Culvert Length = 200 feet
Culvert Slope = 0.2 percent
Allowable Headwater = 7.0 feet
Design Discharge = 190 cfs
(322.8 m3/min)

Find: The minimum required pipe sizes for corrugated metal pipe and concrete pipe.

Solution: Refer to Attachment 10.2 for the solution that follows:

Corrugated Metal Pipe

1. Head for standard metal pipe culverts, n = .024 Chart number 6, HDS number 5

1. assume projecting entrance
2. entrance loss coefficient (K_e = .9)
3. from chart 6, HDS number 5, 84 in. pipe, 200 feet long H = 1.4 feet
4. from chart 4, HDS number 5, critical depth (d_c) is 3.6
5. h_o equals (d_o+ D)/2 equals 5.3, or TW equals 3, whichever is greater
6. actual HW equals H + h_o- L_{so} equals 6.3 feet

Concrete Pipe

See Attachment 10.2 for the solution, which follows the same methodology used for the corrugated metal pipe solution.

Conclusions:

At this drainage crossing, either one of the two following designs can be used:

1. An 84-inch cmp with a projecting entrance that produces a headwater of 6.3 feet; or,
2. A 60-inch concrete pipe with a groove-edged projecting entrance that produces a headwater of 6.8 feet.

The final selection should be based on an economic analysis and/or established policy and/or outlet protection required.

10.4 Discharge Velocity

A culvert pipe, because of its hydraulic characteristics, increases the velocity of flow over that in the natural channel. The erosive potential of this discharge velocity can be ascertained by comparing this velocity with existing culverts in the area or the natural stream velocities. Normally, changing the culvert size will not appreciably change the discharge velocity.

For culverts with supercritical flow (culverts in inlet control), the outlet velocity can be calculated by using Manning's Equation:

$$V = \frac{1.49\ R^{2/3}\ S^{1/2}}{n}$$

For culverts with subcritical flow (normally culverts in outlet control), the discharge velocity is equal to the discharge divided by the cross-sectional area of flow at the outlet. This flow area can be either that corresponding to critical depth, if $d_c > tw$; tail water depth, if $tw > d_c$ and $tw < d$; and diameter of pipe, if $d < tw$.

For a more detailed discussion of culvert discharge velocities, the designer is referred to FHWA H.E.C. #14 (3).

Discharge Velocity Problems

Inlet Control: See Attachment 10.2 (Inlet) for all pertinent data.

1. From the above equation, for Q equals 190 cfs,, D equals 66 inches, and n equals 0.024, flow velocity in the pipe is 11 fps from chart, HDS number 5, the critical depth d_c is 6 feet.

Outlet Control: See Attachment 10.2 (Outlet) for all pertinent data.

1. For an 84-inch cmp, dc equals 3.6 feet tw equals 3.0 feet, and d equals 7.0 feet. Therefore, the critical depth of 3.6 feet is used to compute the cross-sectional flow area at the outlet of the pipe.
2. D flowing/Diameter equals 3.6/7.0 equals 0.51. From Attachment 10.3, with d/D equals 0.51, read A/A_{full} equals 0.51.
3. A equals A_f x .51 equals π x $(7/2)^2$ x .51 equals 19.63 s.f.
4. V equals Q/A equals 190 cfs/19 63 s.f. equals 9.7 fps

10.5 Improved Inlets

For a further discussion of improved inlets, the designer should read the section on improved inlets contained in FDM 13-15-5 of this manual.

For further information on improved inlets, including sample problems, the designer is referred to FHWA HDS number 5 (1). In addition to manual methods for designing improved' inlets, the designer may elect to use the previously mentioned computer program entitled “HY8.”

10.6 Culvert Performance Curve

A performance curve for a culvert is a plot of discharge versus headwater depth or elevation (stage). It is a means of ascertaining at a glance how a particular culvert will operate over a range of discharges. In particular, the performance curves of alternate culvert designs are used to evaluate the potential for damage to the highway and adjacent property from floods greater than the design discharge.

See Attachment 10.3 for a schematic performance curve for a culvert with either a side-tapered or slope-tapered inlet. HDS number 5 (1) explains this performance curve as follows:

> "Each potential control section (face, throat, and outlet) has a performance curve, based on the assumption that a particular section controls the flow. Calculating the plotting the various performance curves results in a graph similar to (figure 3)," containing the face control, throat control and outlet control curves. The overall culvert performance is represented by the hatched line.

In a like manner, for conventional culverts in the lower discharge range, inlet control governs; and in the higher discharge range, outlet control governs.

10.7 References

1. U.S. Department of Transportation, Federal Highway Administration, Hydraulic Design of Highway Culverts, Hydraulic Design Series #5 McLean, Virginia, 1985, 235 pp.

2. U.S. Department of Transportation Federal Highway Administration, Design Charts for Open Channel Flow, Hydraulic Design Series #3, Washington, D.C., 1961, 105 pp.

3. U.S. Department of Transportation, Federal Highway Administration, Hydraulic Design of Energy Dissipaters for Culverts and Channels, Hydraulic Engineering Circular #14, Washington, D.C., 1983.

LIST OF ATTACHMENTS

FDM 13-15-15 Special Hydraulics

August 8, 1997

15.1 Introduction

For the purpose of this manual, special hydraulics is defined as hydraulic structures that are considered unique by highway engineers because of their limited use in highway engineering. This procedure contains general discussions on drainage disposal by pumping, and siphons and sag culverts.

15.2 Drainage Disposal by Pumping

15.2.1 General Practices

1. Drainage disposal by pumping should be avoided where gravity drainage is reasonable. Because pumping installations have high initial cost, maintenance expense, power costs, and the possibility of power failure during a storm, large expenditures can be justified for gravity drainage. In some cases this can be accomplished with long runs of pipe or continuing the depressed grade to a natural low area.
2. Horizontal pumps in a dry location should be specified for ease of access, safety, and standardization of replacement parts.
3. Whenever possible, drainage originating outside the depressed area shall be excluded.
4. Stand-by power installations for pumping plants shall be made only in special cases.

15.2.2 Surface Inlets

Grate and combination inlets should be used for surface drainage. If conditions dictate the use of a side-opening inlet, a trash rack should be provided.

15.2.3 Maintenance Access

Access to the pumping plant for maintenance from the lower roadway should generally consist of a stairway or paved ramp adjacent to the pumping plant. A stairway or ramp should generally extend from the top of cut slope to the toe of cut slope. Parking space for maintenance vehicles shall be provided in the vicinity of the pumping plant. Access to the pump room should be through a vertical doorway with the bottom at or near floor level, and never through a hatch.

15.3 Siphons and Sag Culverts

15.3.1 General Notes

There are two kinds of conduits called siphons: the true siphon and the inverted siphon or sag culvert. The true siphon is a closed conduit, a portion of which lies above the hydraulic grade line. This results in less than atmospheric pressure in that portion. The sag culvert lies entirely below the hydraulic grade line; it operates under pressure without siphonic action.

Under the proper conditions, there are hydraulic advantages and cost economies to be obtained by using the siphon principle in culvert design.

15.3.2 Sag Culverts

This type is most often used to carry an irrigation canal under a highway when the available headroom is insufficient for a normal culvert. The top of a sag culvert should be at least 4.5 feet below the finished grade where possible to ensure against damage from heavy construction equipment. The culvert should be on a straight grade and sumps provided at each end to facilitate maintenance. Sag culverts should not be used:

1. When any other alternative is possible at reasonable cost.
2. For intermittent flows where the effects of standing water are objectionable.
3. When the flow carries trash and detritus in sufficient quantity to cause heavy deposits.

15.4 Type of Conduit

Siphons should have water-tight joints. Gaskets are required to be water-tight at the pipe joints. The following are kinds of pipes used for siphons and sag culverts to prevent leakage:

1. Reinforced concrete pipe.
2. Ductile iron pipe.
3. Welded smooth steel pipe.

Siphons that are subjected to internal pressure should have watertight joints. Welded smooth steel pipe with internal ceramic coating as well as precast reinforced concrete pressure pipe, ductile iron pipe, or reinforced plastic mortar pressure pipe are commonly used. Jointed pipe require gaskets to ensure water tightness. Inverted siphons must be able to withstand the internal hydrostatic head measured to the centerline of the siphon.

Methods for designing siphons can be found in the following recommended hydraulics design book, such as "Handbook of Hydraulics," Horace Williams King; "Design and Construction of Sanitary and Storm Sewers," ASCE and WPCF; "Handbook of Concrete Culvert Pipe Hydraulics," Portland Cement Association; and "Roadway Drainage Manual," AASHTO.