CHAPTER 4

DESIGN OF CULVERTS

4.3 Engineering Design Criteria

The design of a culvert should take into account many different engineering and technical aspects at the culvert site and adjacent areas. The following design criteria should be considered for all culvert designs as applicable.

Frequency Flood – The design storm for a culvert for all roads is the 100-year storm using future development land use conditions, assuming no detention. The design of lateral systems shall be based on a 25-year storm event, using future development land use conditions assuming no detention. The 100-year frequency storm shall be routed through all culverts to be sure building structures (i.e., houses, commercial buildings) are not flooded or increased damage does not occur to the highway or adjacent property for this design event.

Velocity Limitations – Both minimum and maximum velocities should be considered when – designing a culvert. The maximum velocity should be consistent with channel stability requirements at the culvert outlet. The maximum allowable velocity for corrugated metal pipe is 15 feet per second. These is no specified maximum allowable velocity for reinforced concrete pipe, but outlet protection shall be provided where discharge velocities will cause erosion problems, to ensure self-cleaning during partial depth flow, a minimum velocity of 2.5 feet per second, for the 2-year flow velocity, when the culvert is flowing partially full is required.

Buoyancy Protection – Headwalls, endwalls, slope paving or other means of anchoring to provide buoyancy protection should be considered for all flexible culverts.

Length and Slope – The culvert length and slope should be chosen to approximate existing topography, and to the degree practicable: the culvert invert should be aligned with the channel bottom and the skew angle of the stream, and the culvert entrance should match the geometry of the roadway embankment. The maximum slope using concrete pipe is 10% and for CMP is 14% before pipe restraining methods must be taken. Maximum drop in a drainage structure is 10 feet.

Debris Control – In designing debris control structures it is recommended that the Hydraulic Engineering Circular No. 9 entitled "Debris – Control Structures" be consulted.

Headwater Limitations – The allowable headwater elevation is determined from an evaluation of land use upstream of the culvert and the proposed or existing roadway elevation. Headwater is the depth of water above the culvert invert at the entrance end of the culvert.

The following criteria related to headwater should be considered:

- The allowable headwater for design frequency conditions should allow for the following upstream controls.

- 18 inch freeboard.

- Minimize upstream property damage.

- Elevations established to delineate flood plain zoning.

- Low point in the road grade that is not at the culvert location.

- Ditch elevation of the terrain that will permit flow to divert around culvert.

- Following HW/D criteria:

  For drainage facilities with cross-section area equal to or less than 30 sq. ft.
  HW/D =to or < 1.5.

  For drainage facilities with cross-section area greater than 30 sq. ft.
  HW/D = to or < 1.2.

- The headwater should be checked for the 100-year flood to ensure compliance with flood plain management criteria and for most facilities the culvert should be sized to maintain flood-free conditions on major thoroughfares with 18 inches freeboard at the low-point of the road.

- The maximum acceptable outlet velocity should be identified (see Section 5.3 in Open Channel Hydrology chapter). Either the headwater should be set to produce acceptable velocities or stabilization or energy dissipation should be provided where these velocities are exceeded.

- Other site-specific design considerations should be addressed as required.

- In general the constraint which gives the lowest allowable headwater elevation establishes the criteria for the hydraulic calculations.

Tailwater Considerations – The hydraulic conditions downstream of the culvert site must be evaluated to determine a tailwater depth for a range of discharge. At times there may be a need for calculating backwater curves to establish the tailwater conditions. The following conditions must be considered:

- If the culvert outlet is operating with a free outfall, the critical depth and equivalent hydraulic grade line should be determined.

- For culverts which discharge to an open channel, the stage-discharge curve for the channel must be determined. See Open Channel Hydrology chapter.

- If an upstream culvert outlet is located near a downstream culvert inlet, the headwater elevation of the downstream culvert may establish the design tailwater depth for the upstream culvert.

- If the culvert discharges to a lake, pond, or other major water body, the expected high water elevation of the particular water body may establish the culvert tailwater.

Storage – If the storage is being assumed upstream of the culvert, consideration should be given to:

- The total area of flooding,

- The average time that bankfull stage is exceeded for the design flood up to 48 hours in rural areas or 6 hours in urban areas, and

- Ensuring that the storage area will remain available for the life of the culvert through the purchase of right-of-way or easement.

Culvert Inlets – Hydraulic efficiency and cost can be significantly affected by inlet conditions. The inlet coefficient K_e, is a measure of the hydraulic efficiency of the inlet, with lower values indicating greater efficiency. Recommended inlet coefficients are given in Table 4-2.

Inlets with Headwalls – Headwalls may be used for a variety of reasons including increasing the efficiency of the inlet, providing embankment stability, providing embankment protection against erosion, providing protection from buoyancy, and shorten the length of the required structure. Headwalls are required for all metal culverts and where buoyancy protection is necessary. If high headwater depths are to be encountered, or the approach velocity in the channel will cause scour, a short channel apron should be provided at the toe of the headwall. This apron should extend at least one pipe diameter upstream from the entrance, and the top of the apron should not protrude above the normal streambed elevation.

Wingwalls and Aprons – Wingwalls are used where the side slopes of the channel adjacent to the entrance are unstable or where the culvert is skewed to the normal channel flow.

Improved Inlets – Where inlet conditions control the amount of flow that can pass through the culvert, improved inlets can greatly increase the hydraulic performance at the culver.

Table 4.3-1

Inlet Coefficients

Type of Structure and Design of Entrance	Coefficient K_e
Pipe, Concrete	
Projecting from fill, socket end (grove-end)	0.2
Projecting from fill, square cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end)	0.2
Square-edge	0.5
Rounded [radius = 1/12(D)]	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45°	0.2
Side- or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal[1]	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to fill slope, paved or unpaved slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45°bevels	0.2
Side- or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of [1/12(D)] or beveled edges on 3 sides	0.2
Wingwalls at 30° to 75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of {1/12(D)] or beveled top edge	0.2
Wingwalls at 10° or 35° to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side- or slope-tapered inlet	0.2

[1]Although laboratory tests have not been completed on K_e values for High Density Polyethylene (HDPE) pipes, the k_E values for corrugated metal pipes are recommended for HDPE pipes.

*Note: End Section conforming to fill slope, made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control.

Table 4.3-2

Manning's n Values

Type of Conduit	Wall & Joint Description	Manning's n
Concrete Pipe	Good joints, smooth walls	0.012
	Good joints, rough walls	0.016
	Poor joints, rough walls	0.017
Concrete Box	Good joints, smooth finished walls	0.012
	Poor joints, rough, unfinished walls	0.018
Corrugated Metal Pipes and Boxes Annular Corrugations	2 2/3 by 1/2 inch corrugations	0.024
	6 by 1 inch corrugations	0.025
	5 by 1 inch corrugations	0.026
	3 by 1 inch corrugations	0.028
	6 by 2 inch structural plate	0.035
	9 by 2 1/2 inch structural plate	0.035
Corrugated Metal Pipes, Helical	2 2/3 by 1/2 inch corrugated 24 inch plate width	0.012
Corrugations, Full Circular Flow Spiral Rib Metal Pipe	3/4 by 3/4 in recess at 12 inch spacing, good joints	0.013
High Density Polyethylene (HDPE)		
	Corrugated Smooth Liner	0.015
	Corrugated	0.020
Polyvinyl Chloride (PVC)		0.011

Note: For further information concerning Manning n values for selected conduits consult Hydraulic Design of Highway Culverts, Federal Highway Administration, HDS No. 5, page 163

Material Selection – Reinforced concrete pipe (RCP) shall be used (1) under a roadway, (2) when pipe slopes are less than 1%,. Reinforced concrete pipe (RC P) and fully coated corrugated metal pipe (CMP) and High Density Polyethylene can be used in all other cases. Table 4.3-2 gives recommended Manning's n values for different materials.

Culvert Skews – Culvert skews shall not exceed 45 degrees as measured from a line perpendicular to the roadway centerline without approval.

Culvert Sizes – The minimum allowable pipe diameter shall be 18 inches.

Weep Holes – Weep holes are sometimes used to relieve uplift pressure. Filter materials should be used in conjunction with the weep holes in order to intercept the flow and prevent the formation of piping channels. The filter materials should be designed as underdrain filter so that it will not become clogged and so that piping cannot occur through the previous material and the weep hole.

Outlet Protection – See Energy Dissipation chapter for information on the design of outlet protection. Outlet protection should be provided for the 25-year storm.

Erosion and Sediment Control – Shall be in accordance with the latest approved Soil Erosion and Sediment Control ordinance for Gwinnett County. See also the Manual For Erosion and Sediment Control in Georgia for design standards and details related to erosion and sediment control.

Environmental Considerations – Where Compatible with good hydraulic engineering, a site should be selected that will permit the culvert to be constructed to cause the least impact on the stream or wetlands. This selection must consider the entire site, including any necessary lead channels

END OF SECTION 4.3