OFFICE OF STRUCTURES
MANUAL FOR HYDROLOGIC AND HYDRAULIC DESIGN

CHAPTER 13 CULVERTS

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Chapter 13 Culverts

Table of Contents

CHAPTER 13 CULVERTS

FOREWARD

The Office of Structures is currently working with the Federal Highway Administration and various other state and federal agencies to develop an improved design approach for facilitating the passage of aquatic organisms (AOP) and wildlife through culverts. The findings and recommendations resulting from this work will be incorporated in updated versions of Chapter 13 as it becomes available.

Please note that the traditional term, "Passage of Fish and Wildlife" has been expanded to include other aquatic organisms as well as fish, such as amphibians. The information presented in this section is to be used in the design of culverts for the Office of Structures. AOP is a relatively new acronym used to refer to Aquatic Organism Passage. Special features may need to be incorporated into the design and construction of a culvert to accommodate passage of fish as well as other aquatic animals such as amphibians. These features may be different from the features required for fish passage.

Please refer to Section 13.3, Passage of Aquatic Organisms and Wildlife for current guidance on this matter.

13.1 Introduction

Various definitions for a culvert are used by the Office of Structures, depending upon the purpose of the definition:

- Any structure designed hydraulically as a culvert, regardless of size, is considered as a culvert for purposes of this chapter

- Any structure that has a paved bottom is defined by the Maryland Department of the Environment as a culvert, and this definition is used by SHA in preparing permit applications.

- Structures 20 feet or wider in centerline length between extreme ends of openings are considered as bridges for purpose of the bridge inventory. These bridges may include structures designed as culverts and are therefore treated as culverts for purposes of this chapter.

- Small structures are defined as structures from 5 feet up to 20 feet in centerline length between extreme ends of openings. These may be either bridges or culverts.

- Structures designated as "bottomless arch culverts" are typically modeled for hydraulic flow conditions using HEC-RAS (Reference 13) and are evaluated for scour using the bottomless culvert module in the OOS ABSCOUR Program. Information regarding the application of this program is presented in Chapter 11, Appendix C of the OOS Manual for Hydrologic and Hydraulic Design. (Reference 1)

OOS uses the hydraulic design procedures for culverts set forth in the publications and software of the Federal Highway Administration. However, there are other important considerations that enter in the location and design of a culvert. These other environmental and geomorphological considerations affecting culvert design will be presented in this chapter.

The design of a highway stream crossing involves consideration and resolution of a number of issues and concerns in order to achieve the design objectives for the site. The designer should list and prioritize these objectives at the beginning of the location/design process. This exercise will provide an opportunity to evaluate the type of design best suited for a particular location. It will also serve to highlight the need for any compromises required to achieve, to a reasonable degree, the desired objectives for a given site. *In this regard, safety should always be the primary concern of the engineer and should not be compromised to achieve other objectives.*

The design approaches to achieving the objectives listed below have evolved over the last 50 years or so as engineers have become better informed regarding the effect of the highway on the stream crossing and the effect of the stream crossing on the highway. During the early years of the Interstate Program, emphasis was placed on safety, both for the highway user and abutting

13.1 Introduction Continued)

property owners, and on the cost-effectiveness of the structure. Over time, procedures evolved to address other significant issues as well. These are all important design objectives that should be evaluated for every culvert installation:

SAFETY OBJECTIVES

- Provide for the safety of the traveling public; structure to remain stable for worst-case flood conditions.
- Meet requirements for flood plain management and the safety of abutting property owners

STREAM STABILITY AND ENVIRONMENTAL OBJECTIVES

- Maintain the natural stream channel stability of dimension, pattern and profile so that over time the channel features are maintained and the channel neither aggrades nor degrades. (Select culvert installation to maintain bankfull geometry of width and depth).
- Control scour, erosion and degradation of bed and banks at culvert inlet and outlet and in downstream channel; minimize deposition of material in culvert barrel.
- Passage of aquatic organisms (AOP) and wildlife
- Maintain and enhance habitat for aquatic organisms and wildlife

STRUCTURAL DESIGN AND MAINTENANCE OBJECTIVES

- Provide a cost-effective and maintainable design
- Meet OOS requirements for strength and durability
- Minimize potential for hydraulic uplift, piping and pressure forces on culverts
- Minimize maintenance problems with inorganic and organic debris (trees).
- Create an aesthetic design

This chapter provides an approach to the location and design of culvert installations based on the evaluation of the relative significance and priorities of the objectives listed above. In addition, each location is likely to have special features that will need to be evaluated and dealt with on the basis of engineering judgment.

Additional information regarding general design policies and procedures of the Office of Structures affecting culverts is set forth in the following chapters of the OOS Manual for Hydrologic and Hydraulic Design:

Chapter 3 – Policy
Chapter 8 – Hydrology
Chapter 9 - Channels
Chapter 10 - Bridges
Chapter 11 – Scour
Chapter 14 - Stream Morphology

13.2 Policy

The following policies of the Office of Structures apply to culverts.

- Culverts shall be located and designed to minimize hazards to traffic and people. Design considerations shall include appropriate measures for headwall and endwall designs, along with scour countermeasures, to protect the culvert from uplift, piping and scour.
- All culverts shall be hydraulically designed. Hydraulic design procedures for culverts shall be based on the publications and software of the Federal Highway Administration. (HY-8 and associated design publications)
- The design flood shall be selected in accordance with the criteria set forth in Chapter 10, for the classification of the highway on which the culvert is located. The 100-year, overtopping and check flood shall be used to evaluate the worst-case conditions for culvert and embankment stability due to flooding and scour (Hydrology Chapter 8).
- The culvert installation shall be designed, to the extent practicable, to meet the objectives in this chapter regarding stream stability, passage of aquatic organisms (AOP) and wildlife and other environmental concerns.
- Culvert outlet velocities are to be computed and the culvert design modified as necessary to achieve velocities consistent with the site conditions, or to dissipate high velocities.
- Any culvert founded on spread footings or deep foundations shall be evaluated for resistance to scour in accordance with Chapter 11 and Chapter 11 Appendix C
- Material selection shall include consideration of service life and the effects of corrosion and abrasion.
- The detail of documentation for each culvert site shall be commensurate with the risk and importance of the structure and the site conditions. Design data and calculations shall be assembled in an orderly fashion, presented in a formal report, both written and electronic, to the Office of Structures and retained for future reference as provided for in Chapter 5, Documentation. A Hydrology and Hydraulics Summary Sheet shall be completed for each culvert and included with the PS&E plans for the project (Chapter 4, Documentation).
- Consideration shall be given to the potential problems of debris and silting up of culvert barrels.
- Where practicable, means shall be provided for personnel and equipment access to facilitate maintenance.
- Culverts shall be regularly inspected and maintained.

There are many culvert types and combinations of culvert types currently available for installation at a stream crossing. A traditional engineering approach for culvert selection has been to specify the design requirements for acceptable alternatives. This allows the contractor to select from among approved alternative designs on the basis of cost. This approach works best for small pipe culvert installations. The selection process becomes more complex as the size of the stream increases due to the increasing number of factors to consider and the individual performance characteristics of different types of culverts. Because of this complexity, the

13.2 Policy (Continued)

SHA Office of Structures will normally specify the culvert type and size to be installed. For design-build projects, early coordination is necessary to reach agreement on the selection of the culvert type. SHA typically provides detailed instructions with regard to the installation procedures to be followed for culvert construction.

Chapter 13 introduces the concept of using a combination of main channel and flood plain culverts, when applicable, to accomplish the design objectives in Section 13.2. Such designs must be approved by the Office of Structures on a case by case basis. For the most part, however, the OOS will continue to use main channel culverts without flood plain culverts when such designs can be expected to substantially meet the design objectives in this chapter.

These policies, along with location and design guidance used to implement the policies are discussed at greater length in the following sections of this chapter and in other referenced chapters of the Manual as well.

13.3 Passage of Aquatic Organisms (AOP) and Wildlife

The Office of Structures has been working with the Federal Highway Administration and various other state and federal agencies to develop an improved design approach for facilitating the passage of aquatic organisms (AOP) and wildlife through culverts. The findings and recommendations resulting from this work will be incorporated in updated versions of Chapter 13 as it becomes available.

Please note that the traditional term, "Passage of Fish and Wildlife" has been expanded to include other aquatic organisms as well as fish, such as amphibians. The information presented in this section is to be used in the design of culverts for the Office of Structures. AOP is a relatively new acronym used to refer to Aquatic Organism Passage. Special features may need to be incorporated into the design and construction of a culvert to accommodate passage of fish as well as other aquatic animals such as amphibians. These features may be different from the features required for fish passage.

Until the findings and recommendations of these new studies become available and are incorporated in this manual, the Office of Structures will be assessing AOP and wildlife passage needs and developing appropriate designs on a project by project basis.

The project development steps for hydrology and hydraulics design for an Office of Structures project usually consists of the following (See Chapter 5 Project Development):

- Hydrology Studies Report
- Preliminary Studies Geomorphology Report*
- Existing Condition Hydraulics Study*
- Detailed Stream Morphology Report*

*Please note that a preliminary assessment of AOP and Wildlife passage is to be included in the development of the Existing Condition Study and the Stream Morphology Reports. During the initial preliminary studies, the Office of Structures typically initiates coordination with environmental and regulatory agencies, and participates in inter-agency reviews. Information from these meetings will be helpful in making preliminary assessments about AOP and wildlife passage.

The information obtained from these studies is used during the selection of the structure type. If a culvert is selected for the stream crossing, additional studies of AOP and Wildlife passage are to be initiated. The Detailed Stream Morphology Report can serve as a starting point to address concerns about the existing conditions for AOP and wildlife passage and how they might be enhanced by the project. For example, to facilitate fish passage under low flow conditions, it may be reasonable to change the plan and profile of the reach of the stream affected by the project so that the culvert will sit in a pool rather than on a riffle. In addition, if the main culvert is designed in a pool, an auxiliary culvert may need to be provided at a higher elevation to accommodate passage of other forms of aquatic life.

13.3 Passage of Aquatic Organisms (AOP) and Wildlife (Continued)

A supplemental hydrology report will also be needed to determine the range of flows within which fish passage can take place. This range is defined as Qlow and Qhigh, The minimum design flow for Qlow is one cfs. The value of Qhigh will depend on the site conditions and in particular the size of the drainage area for the culvert.

The Federal Highway Administration and Washington State University (WSU) are collaborating to produce Hydraulic Engineering Circular 26: "Design of Fish Passage for Bridges and Culverts"; a comprehensive manual for the design or retrofit of a stream crossing to meet fish passage requirements. The Office of Structures is using this manual as a guide for the hydrology recommendations only.

Further guidance on conducting AOP and wildlife studies will be provided on a project by project basis until a more detailed methodology is developed.

13.4 Location Studies

13.4.1 Location Studies

Office of Structures engineers are represented on study groups convened by the Office of Planning and Preliminary Engineering to assure that highway stream crossings are located, to the extent practicable, at appropriate locations (See Chapter 5).

Preliminary field and office studies and evaluations are made of the location of proposed culvert installations early in the project development process to enable the Office of Structures to make informed decisions regarding the proposed crossing locations and the types of structures to be built.

These preliminary studies normally include consideration of the proposed line, grade and typical section of the highway, the hydrology of the watershed and the geomorphology of the stream and its flood plain. The extent of such location studies should be dependent upon the importance of the proposed structures and the flood hazards and environmental concerns involved with the site. These considerations and concerns are outlined below.

13.4.2 Highway Geometry and Stream Plan Form

Favorable crossing locations are those that:

- are located on a relatively straight and stable section of the stream, typically a pool.

- provide for a highway alignment generally normal to the flow in the channel and flood plain, avoiding locations of sharp bends, severe meanders, confluences or other areas of converging or diverging flow patterns and associated turbulence. Culvert skew should not exceed 45^0.

- are maintaining stable stream conditions in the reach of the stream affected by the highway crossing.

It may not be feasible to obtain an optimum highway alignment for every stream crossing; nevertheless, it is important that efforts be made at this early stage of project development to select the structure location and type that best fits the particular site conditions.

13.4.3 Hydrology Studies

Hydrology studies shall be performed in accordance with the policies and procedures set forth in Chapter 8 (See also Reference 18). These studies provide the information to develop a flood frequency plot for the crossing site for flows from the bankfull stage (approximately 1.5-year flood for natural channels) to the 500-year flood. Hydrology studies should be initiated early in

13.4 Location Studies

the project development process so that information on flood flows will be available for consideration when decisions are made regarding the location of the highway stream crossing and the selection of structure type.

13.4.4 Stream Morphology Report

A Stream Morphology Report is to be prepared in accordance with Chapter 14. The stream should be classified in accordance with the Rosgen classification system (References 7 and 8). :

13.4.5 Selection of Structure Type (Culvert vs. Bridge)

It is helpful to develop alternative design concepts for further evaluation for both a culvert installation and a bridge unless the choice of the appropriate structure to meet site conditions is obvious (extensions of existing structures, magnitude of flood discharge, etc). Table 2 below provides a comparison of the advantages and disadvantages of bridges and culverts.

TABLE 1 -BRIDGE vs. CULVERT

Part 1 - Bridges

Advantages	Disadvantages
Less susceptible to clogging with drift, ice and debris	Requires more structural maintenance and rehabilitation over design life than do culverts
Waterway area increases with rising stage of stream until water begins to submerge superstructure	Spill-through slopes susceptible to erosion damage from highway and bridge runoff
Scour increases waterway opening, reducing backwater.	Piers and abutments susceptible to failure from scour
Roadway widening does not usually affect hydraulic capacity	Susceptible to ice and frost formation on deck
Less of an impact on aquatic environment and wetlands when natural channel/flood plain relationships maintained.	Bridge railing and parapets hazardous to motorists as compared to recovery areas generally provided by culverts
Easier to maintain the natural stream channel width/depth ratios under the bridge.	Deck drainage may pose a hazard to motorists; scuppers may require frequent clean out
Easier to maintain bed load (coarse sediment) transport.	Buoyant, drag and impact forces are hazards to bridges
Easier to maintain passage of AOP and wildlife.	Susceptible to damage from stream meander migration
Channel under bridge can enhance habitat via scour holes at piers and abutments, etc.	
Channel under bridge may get more sunlight	

13.4 Location Studies

Part 2 – Culverts

Advantages	Disadvantages
Provides an uninterrupted view of the road.	Silting in one or more cells of multiple cell installations and/or accumulation of debris and ice can be a problem requiring frequent maintenance(*These problem can be reduced through the careful application of the criteria in this design guide*)
Roadway recovery area can be provided	Waterway area is fixed, once water rises above the soffit of the culvert, until overtopping occurs. May discharge flood flows to downstream channel at a higher velocity than would occur in the natural channel
Grade raises and widening projects can sometimes be accommodated by extending culvert ends	Roadway susceptible to overtopping and possible breaching of embankment if culvert clogs with drift, ice or debris
Most culverts require very little, if any, structural maintenance	Many require special designs to accommodate AOP and wildlife passage to minimize effects of high velocities, inadequate low flow depths, blocking of sunlight, etc.
Frost and ice usually do not form on the traveled way before other areas experience the same problem	Susceptible to erosion of fill slopes and scour at outlets due to high exit velocities; may require energy dissipation at outlets
Capacity increases with stage, and can be increased with improved inlets	Susceptible to damage from abrasion or corrosion; Susceptible to failure by piping and/or infiltration
Usually quicker and easier to build	Culvert extensions may reduce culvert capacity
Scour is localized, more predictable and easier to control	Inlets of flexible culverts susceptible to failure by buoyancy; rigid culverts susceptible to failure from separation of joints
Can be used to control headcutting or other vertical channel instabilities	Backwater caused by culvert may cause silting of upstream channel.
Storage can be used to reduce peak discharges in small channels (at interchanges, etc.) for storm water management.	Loss of sunlight and changed flow conditions can significantly reduce viability of stream for habitat within the limits of the culvert.
	May require stream diversions during construction
	May cause degradation of downstream channel through redistribution, collection and concentration of flood flows at culvert outlet.

13.5 Design Criteria

The criteria in Chapter 13 apply to culverts with "paved bottoms." Bottomless arch culverts should be designed using the procedures set forth in Chapter 11, Evaluating Scour at Bridges, Appendix C.

13.5.1 Hydraulic Design of Culverts. Culverts shall be hydraulically designed using the procedures of the Federal Highway Administration. The culvert width should be selected so as to maintain the width of the upstream bankfull flow through the culvert.

13.5.2 Passage of Fish and Wildlife. Design criteria for passage of fish and wildlife will be determined for each crossing site as indicated in Section 13.3 Fish Passage.

13.5.3 Culvert Headwalls and Endwalls
Culverts ends shall be protected with walls designed to meet the site conditions (straight headwall or endwall, use of wing walls, etc.). A cutoff wall shall be provided below the culvert invert at the headwall and at the endwall (including wingwalls) to prevent problems of undermining, piping, scour and erosion of the culvert bedding material and the culvert fill, and to protect against downstream scour and degradation in the channel. *The cutoff wall should extend below the elevation of computed or estimated scour and degradation.* Use a minimum toe wall of 3 feet for all culverts. Confer with the designer on the need for increasing the toe wall depth for large culverts (inside clear widths of 10' or more), particularly for locations that will experience high outlet velocities and/or where downstream degradation is anticipated. Culvert end sections should be designed as hydraulically efficient openings, should be structurally designed to resist buoyancy and uplift forces acting on the culvert, and should match the geometry of the roadway embankment. See SHA PPM D84-29 (4) dated July 26, 1994, Reference 3); Structural Standard BC (6.01)-75-1, Box Culvert Headwall and Toe Wall Details)

13.5.4 Culvert Entrances The channel upstream of the culvert shall be shaped to provide for a smooth transition to the flow and riprap protection shall be provided as necessary to minimize any upstream degradation due to the culvert installation. This will be particularly important when the culvert inlet is set below the existing bottom of the channel.

13.5.5 Culvert Outlets Evaluate culvert outlet velocities and provide for appropriate measures for the following conditions for fish passage, stability and to minimize the potential for a catastrophic failure with resulting safety hazards to vehicular traffic and downstream property owners. (See Sections 13.3, 13.6 and 13.9)

- low flows designated for evaluating fish passage (See Section 13.3)
- bankfull flow: evaluate the effect of the structure on the channel
- design flow: assure that the highway embankment and the structure remains stable, and that the roadway does not overtop.

13.5 Design Criteria Continued)

- overtopping flow, 100-year or 500-year flow as appropriate (See Chapter 8): minimize the potential for culvert failure with attendant safety hazards to vehicular traffic and downstream property owners.

13.5.6 Culvert Slopes Culvert slopes shall be selected in consideration of the multiple objectives of (1) maintaining the existing channel grade; (2) providing for fish passage; (3) maintaining flow velocities for bankfull flows in the culvert that are reasonably consistent with the upstream and downstream channel velocities, and (4) maintaining self-cleaning velocities so that the culvert does not silt up. Considerations for minimizing the silting of culverts is discussed in Section 13.9

13.5.7 Debris and Ice Blockage Highway culverts should be located so as to avoid areas that have a high potential for blockage by the deposition of stream sediments and debris. Because of Maryland's location and climate, ice jams have not been a significant state-wide problem in the operation of highway culverts. Debris, on the other hand is a continuing problem, and the consequences of debris accumulation should be considered in the location and design of the culvert. Wherever practicable, access should be provided for personnel and equipment to clean the culvert entrance.
Debris deflectors and control structures have not been used extensively in Maryland, and they are not generally recommended for inclusion on new construction. Information on the use of debris structures is included in Section 13.10

13.5.8 Structural Requirements

Cast-in-place structures such as box culverts are individually designed for the given site conditions in accordance with the policies and procedures of the Office of Structures

Pre-cast boxes, pipes and pipe arch structures are to be designed in accordance with the criteria specified by the manufacturer, including provisions for minimum cover. The minimum cover for concrete and metal round pipe is three feet. The manufacturers fill height tables and specifications should be consulted when determining minimum and maximum cover for other culvert shapes and materials.

Specialized designs, such as long span culverts, are evaluated on a case by case basis.

An important requirement for metal culvert installations is to assure that the culvert is properly anchored in the headwall to resist buoyancy and up-lift forces.

13.5 Design Criteria Continued)

13.5.9 Durability Requirements

The minimum service life for a culvert designed by the Office of Structures is 75 years. On a case by case basis, a longer service life of up to 100 years may be specified where the construction of a replacement structure would result in extraordinary costs or involve an extended period of disruption of traffic service. An example of this case would be a culvert under a high fill on a major arterial or Interstate highway.

The design service life of a culvert is defined as the expected maintenance free service life of each installation. The Office of Structures has adopted the durability requirements in the Highway Drainage Manual, Chapter 9, Culverts, (Reference 1) for all concrete and metal pipe culverts. For structural plate pipe, ellipses and arches, the maintenance free service life, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of perforation at any location. (It is noted that metal pipe with 75% or more of the invert intact can be rehabilitated in some instances by means of a concrete or vitrified paved invert to extend the useful service life for years without replacement.)

For reinforced concrete structures, maintenance-free service life, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of exposed reinforcement at any point on the culvert.

All culverts are subject to deterioration from corrosion and abrasion. Corrosion may result from active elements in the soil, water and/or atmosphere. Mechanical wear depends upon the frequency, duration and velocity of flow, and the amount and character of bed load.

To assure that the maintenance-free service life is achieved, culvert materials and thicknesses should be designed for the environmental conditions existing at the site:

- Measurements of the pH and resistivity of the soil and the water at proposed culvert structures serve to provide this information. Consideration should also be given to chlorides, such as in salt-water crossings, and to sulfides. An evaluation should also be made of the potential for abrasive wear of the invert by the bed load of the stream.

- Once a site survey has been conducted, the Highway Drainage Manual can be consulted to determine the types and extent of protection needed to provide for durability of concrete and corrugated metal pipes for the site conditions.

- For structural plate pipe culverts (round, pipe-arch, and ellipse), increase the thickness of the invert plates required for structural strength by two gages in thickness.

- Use of steel pipe is generally not recommended for salt-water locations.

13.5 Design Criteria Continued)

- For severe conditions where the pH or resistivity of the stream or adjacent soil falls outside the limits specified in the Highway Drainage Manual, additional evaluation of the potential for corrosion is warranted. Alternative considerations include provision of a very heavy gage at the pipe invert, or factory or field paving of the invert. For severe conditions of acid flow, as from a mine, use of vitrified clay lining to accommodate corrosive low flows may provide a solution to the problem.

- Additional protection of the culvert invert to resist abrasion is recommended where the velocity of flow for the bankfull flow exceeds 7 fps and bed load is present. In streams carrying very heavy bed loads, it may be difficult to maintain a culvert invert in an acceptable condition for the desired service life. For such cases, consider alternative designs such as:
    - placement of steel rails along the invert of the culvert,
    - burying the invert of the structure by the scour depth, or
    - use of an alternative structure type such as a bridge or bottomless culvert

- Concrete Structures

    Where the pH or resistivity of the soil or water at the site is outside of the limits specified in the Highway Drainage Manual, additional protection from corrosion should be provided for concrete structures. This protection may consist of extra thickness of concrete cover over the steel reinforcement, high-density concrete, and/or other protective coatings. In general, cast-in-place structures should be provided with additional protective paving or coatings in environments with a low pH since they are more vulnerable to corrosion.

13.5.10 Traffic Safety Requirements

Culverts shall be designed in accordance with the AASHTO Roadside Design Guide, Reference 10, to minimize hazards to vehicles that leave the travelled way. For culverts designed by the Office of Structures, provision for traffic safety is normally accomplished in one of two ways:

- Placement of culvert headwalls and endwalls at an appropriate safe distance from the travelled way as determined from Reference 10, or,

- Shielding the obstruction or hazard presented by the culvert with an appropriate roadside barrier.

SHA PPM D78-15 (4) dated July 31, 1990 entitled Length and Treatment of Culverts (Reference 4) provides additional information on the end treatment of culverts. Placement of bars or grids at

13.5 Design Criteria (Continued)

culvert ends to provide for a traversable design is not generally recommended for large culvert installations. Where the culvert installation is similar to a bridge, the appropriate bridge barrier rail design is to be used.

13.5.11 Construction Details

Please refer to Chapter 19 of this Manual for further information on construction details. The design plans for the culvert will need to contain complete information with regard to construction details. This will include:

- Bedding conditions,
- Requirements for water tightness,
- Location and description of weep holes, when used,
- Structural strength requirements, pipe class and wall thicknesses for pipe installations,
- Details of end sections including:
  - measures to anchor flexible pipe to the headwalls for protection against uplift and buoyancy,
  - strengthening of the weak leading edge of flexible pipe, particularly for a mitered condition,
  - use of bevels or improved inlets to increase hydraulic efficiency,
  - alignment of the endwalls with the roadway and embankment fill.
- Riprap protection of the culvert endwalls,
- Special designs to facilitate fish passage in the culvert barrel,
- Roadside barriers, when required.

A construction plan will need to be developed as a part of the design plans for the culvert. Elements of the construction plan should include:

- An estimate of the area to be disturbed and the activities associated with the culvert construction. This will include the staging area, materials storage, stock and spoil piles, construction access and traffic detour routes, and sediment control measures (traps, basins, earth dikes, silt fences, etc.).

- A plan for accommodating and maintaining stream flow through the project area during the construction of the culvert.

- A plan to control sediment discharge into the stream being crossed.

- A construction schedule designed to avoid disturbances to and blockages of stream flow during spawning periods.

13.6 Guidelines for Consideration of Stream Morphology

13.6.1 Introduction

Please note that this section of Chapter 13 discusses the concept of using a combination of main channel and flood plain culverts, when applicable, to accomplish the design objectives in Section 13.1. Such designs must be approved by the Office of Structures on a case by case basis as indicated in Section 13.3. For the most part, however, the OOS will continue to use main channel culverts without flood plain culverts when such designs can be expected to substantially meet the design objectives in Table 1 and the policy objectives in Section 13.2

The Office of Structures is involved with structures on streams having a drainage area of one square mile or more. Culvert designs for such locations may involve multi-cell boxes or multiple pipe installations. The concepts presented below represent approaches to achieving the design objectives for Types B, C, and E streams as defined by Rosgen (Reference 7). Special considerations for other stream types are discussed in Section 13.7.

Section 13.6 is generally applicable to culverts located on a riffle and on comparatively straight channel reaches. Additional considerations regarding the special problems involved in locating culverts on bends, confluences and in pools are also discussed in Section 13.7.

The design process involves the following considerations:

- design of the main channel culvert to accommodate bankfull flow with minimum change in the hydraulic characteristics of unit discharge, width, depth and velocity,
- design of an upstream transition to the culvert entrance to achieve, within practical limits, a streamlined continuity of the flow and to maintain sediment transport characteristics of velocity and shear so as to avoid deposition of material or scouring,
- design of the culvert installation, including additional flood plain culverts as appropriate, to accommodate the design discharge in the channel and on the flood plain, and
- design of the main channel culvert outlet to minimize impacts to the downstream channel and to stabilize flow conditions for passage of fish.
- provide for flood plain culverts, where appropriate, to relieve scour and erosion problems in the downstream channel.

There is no single "standard" design method applicable to all streams. The discussion below should be considered as a guide for addressing the various objectives presented in Section 13.1 to be achieved in the culvert design process, consistent with the site conditions.

13.6 Guidelines for Consideration of Stream Morphology (Continued)

13.6.3 Upstream Transition Section

The purpose of the transition section is to provide a channel section where the flow can transition smoothly from the stream channel to the culvert entrance. A properly designed transition section is important in achieving various objectives of the culvert installation:

- Maintaining the natural stream channel stability of dimension, pattern and profile so that over time channel features are maintained and the channel neither aggrades nor degrades,
- Minimizing scour, erosion or deposition at the culvert inlet and in the culvert barrel,
- Maintaining or enhancing fish and wildlife passage and habitat, and
- Creating an aesthetic design

Additional rights-of-way may be required to properly design the transition. This need must be recognized early in the project development stage and coordinated with the Office of Real Estate. When additional ROW will be required for channel transitions, early contact should be made with affected property owners to explain the nature of the proposed work and how such work will enhance the stream quality in the transition section (See Section 13.6).

Work in the channel may be necessary to modify the channel cross-section and slope. This need must be recognized and agreed to early in the project development stage by personnel from other agencies who will review the project plans. Stream modifications can serve to provide an attractive design that enhances habitat.

13.6.4 Design Procedure

From the stream morphology study (Chapter 14), note the stream type of the approach channel and obtain data on the bankfull depth, width, velocity and slope. The recommended general approach is to design the culvert width to match the (stable) bankfull width of the upstream approach channel. For B, C and E Rosgen-type channels, this approach will tend to stabilize the channel since the culvert invert will serve to control the upstream channel elevation. In such cases, there may not be a need for much of a transition section between the culvert and the upstream channel other than to minimize any abrupt changes in the channel elevation between the channel thalweg and the depressed culvert invert. Some adjustments to the channel banks are normally required to construct the culvert and its wingwalls or headwalls. Riprap is commonly provided in the immediate vicinity of the culvert to transition to the channel banks. In some cases, such as for sand or silt channels, it may be desirable to provide riprap on the channel bed in the transition to the depressed culvert invert to limit any upstream effect of the culvert on the approach channel or adjacent wetlands. These upstream transitions are generally short, being on the order of 25 feet or less.

13.6 Guidelines for Consideration of Stream Morphology (Continued)

For Rosgen Type A, D, DA, F or G channels, there is likely to be special site conditions that will need to be taken into consideration in the design of the approach section as well as in the design of the culvert itself (See section 13.6).

There will be situations where there is inadequate ROW available to construct much of a transition section. In such cases, the culvert should be sized so that the depth and velocity at the culvert entrance for bankfull flow should approximate the depth and velocity of the flow in the approach channel. This will help to maintain the natural flow conditions at the bankfull discharge and provide for a short but functional transition section.

The design of the main channel culvert is described in the following sections. The design of the transition section and the culvert installation should be done concurrently.

13.6.5 Main Channel Culvert

Select a trial size of the main channel culvert:

- The culvert width should be about the same as the bankfull width for the reference section. Where practicable, accommodate the bankfull flow in a bottomless arch, a single pipe (up to 15’ to 16’ span) or a single box culvert cell (up to a 20’ span). If the bankfull width is too great to carry in a single cell, provide a multi-cell box or pipe installation that minimizes disruption of bankfull flow. Box culverts have an advantage over pipe installations in this regard since the spacing between the box culvert cells is kept to a minimum (Figure 3). In cases where a two cell box is placed in the channel, consider the use of a “W” weir upstream of the culvert entrance. Some modification of the standard weir dimensions may be needed to fit the culvert site. The weir serves to divide the flow into two thalwegs while increasing the approach velocity to the culvert to accomplish the following:
  - reduced bar deposition and/or bank scour,
  - increased capability for coarse bed transport,
  - reduced debris accumulation at the center wall

- Where provision is to be made for fish passage, refer to Section 13.3

- Use HEC-RAS to run the water surface profile for the bankfull discharge; adjust culvert slope, type, roughness and dimensions by a trial and error process to maintain continuity, to the extent practicable, of bankfull flow widths, depths and velocities upstream of, through and downstream of the culvert. Plot the bankfull depths along the reach of the stream in which the culvert is located. If a depressed section is selected for the culvert (See Section 13.3) adjust the invert elevations to maintain the selected depression depth in the culvert.
  - From the stream stability study, check the width/depth ratios and the stream type for the reference reach for agreement with the values at the culvert site.

13.6 Guidelines for Consideration of Stream Morphology (Continued)

- assume that the depressed culvert section will fill in naturally so that the channel bed in the culvert will be continuous with the upstream and downstream channel elevations for the bankfull condition (This assumption will need to be reviewed using the procedures in Section 13.8). Filling of the culvert depression with stream bed material during construction should not be necessary. A composite "n" value
- should be used for the culvert, based on the stream bed material and the culvert material above the stream bed.

- since the culvert geometry and roughness will differ from the stream channel, it is unlikely that any culvert selection will be able to match exactly the conveyance properties of the existing channel. The objective should be to design the culvert *system* so as to match, to the extent practicable, the existing water surface elevations for the bankfull flow upstream and downstream of the culvert

- assume no scour hole occurs at the culvert outlet for the HEC-RAS run, unless the evaluation involves an existing culvert with an existing significant outlet scour hole such as a "blow hole". This assumption will need to be checked later on in the design process.

- where the continuity of bankfull flow conditions can be maintained through the culvert, the foregoing design procedure can be expected to provide reasonable assurance of fish passage for low flows. However, (1) if bankfull flow velocities in the culvert are significantly higher than in the adjacent channel or (2) if it appears that channel bed load will be swept out of the culvert for bankfull flow, design modifications (changes in culvert type or slope, addition of
- baffles, downstream grade control structures, etc.) should be considered as discussed in Sections 13.8 and 13.9

13.6 Guidelines for Consideration of Stream Morphology (Continued)

13.6.6 Flood Plain Culverts

The culvert is a cost-effective hydraulic structure since it serves to collect flood flows upstream of the highway crossing from the channel and flood plains, convey the flow under the highway and discharge it into the downstream channel. However, this action of collecting the upstream flow and discharging it in a concentrated jet into the downstream channel may have an effect on the stream morphology. A small culvert that severely constricts the flow can initiate degradation and lead to the creation of an unstable channel downstream of the highway.

One way to minimize this effect is to install additional culverts on the flood plain to convey the flood plain flows from one side of the highway to the other and thereby reduce the collection and concentration of flow by the main channel culvert into the downstream channel. However, flood plain culverts typically are not hydraulically efficient, and it may not be practical at some sites to install flood plain culverts.

An alternative approach would be to design a bridge for the crossing. However, the costs of such a solution may be high in comparison with the benefits to be obtained. Stream channels are dynamic and can adjust over time to changing conditions brought about by a highway culvert installation when careful attention is given to the stream morphology in the design of the structure. The engineer needs to determine the best method of accommodating the flood flows for the particular site conditions.

The flood plain culverts may also serve to accommodate passage of wildlife. The need to provide for such passage, and the clearance or size requirements to encourage wildlife to use the culverts should be pursued with environmental specialists during the location/environmental phase of project development (See Chapter 13, Section 3).

The following guidance is provided with regard to the design of the flood plain culverts. The guidance is based on the design for a box culvert, but a similar approach can be used for other culvert types and shapes as well.

Location

Where practicable, the flood plain culvert should be positioned on the flood plain well beyond the channel banks. This location avoids the higher velocity and boundary shear stress in the near bank region of the flood plain, and moves the culvert away from the area of convergence of the flood plain flow into the culvert. (However, SHA has successfully constructed “flood plain” culverts immediately adjacent to the main channel culvert). It also minimizes the chance for clogging with debris that is carried in the main channel. The upstream flood plain culvert invert is to be set at the water surface elevation of the bankfull flow for concrete conduits or buried at least 6 inches for metal conduits. On wide flood plains, flood plain culverts should be used on both sides of the channel. If the flood plain is constricted, place the culvert(s) on the inside of the channel bend to avoid convergence and high velocity flows on the outside of the bend (See also Section 13.9).

Size

The culvert installation is to be sized to meet the state flood plain requirements. Since the flood plain culvert(s) and the main channel culvert will have different invert elevations, the dimensions of the various culverts must be determined by a trial and error solution.

Main channel culvert: the culvert width is determined by the procedure discussed in Section 13.4.5 to match the bankfull width; the height of the culvert needs to be established as described below.

Flood plain culvert: both the width and height of the culvert need to be determined by the procedure described below.

Culvert design software packages such as the FHWA HY-8 program or the Corps of Engineers HEC-RAS program can be used to select the culvert sizes (See References). A primary goal is to design the main channel culvert installation to convey the main channel flows and the flood plain culvert installation(s) to convey the flood plain flows. Judgment must be used to determine the best way to handle the flow for a specific location and flood discharge.

The following guidance is offered in establishing culvert size and heights:

- Provide for freeboard for *bankfull flow* in the main channel (Freeboard should be equal to the thalweg or maximum depth in the channel for bankfull flow – See Figure 6).

- For pressure flow conditions, an appropriate ratio should be maintained between the main channel culvert and the flood plain culverts. As a first step where conditions warrant, it is suggested that the soffit or crown of the flood plain and main channel culverts be set at the same elevation.

- Match the existing water surface profile of the existing structure. For a structure on new location, meet the flood plain requirements set forth in Chapter 9.

- The energy line elevation for the design discharge should not exceed the elevation of the upstream edge of traffic lanes.

13.6 Guidelines for Consideration of Stream Morphology (Continued)

- A minimum cover between the pavement and the top of the box should be provided as discussed in Section 13.10.

One of the most important decisions about this aspect of the design is whether the culvert installation will share a single headwall and endwall, or whether each culvert will be protected with its own headwall and endwall. It is important to place the flood plain culverts away from the active channel to minimize the potential for undermining by degradation or migration of the main channel into the area of the flood plain culvert. If flood plain culverts can be located away from the main channel and still serve to effectively convey flood plain flows, then it is reasonable to provide for separate entrance and outlet protection for the flood plain culvert. If site conditions necessitate placing the flood plain culverts near the banks of the main channel, they become more vulnerable to undermining. Under this condition, consider combined headwalls and endwalls for the main channel and flood plain culverts to protect the culvert installation at its inlet and outlet. In some cases, the size of such a combined headwall can become massive and render this concept as impractical.

Protection of the culvert ends needs careful consideration, taking into account the likelihood of lateral migration of the upstream channel or degradation and scour of the downstream channel over the design life of the culvert installation. The stream morphology study (Chapter 14) should be reviewed to consider channel characteristics such as the potential for lateral channel movement and downstream degradation.

13.6.7 Hydraulic Analysis

After selection of trial sizes and arrangements of the culvert installation to best fit the channel morphology, the culvert installation needs to be analyzed for hydraulic capacity to convey flood flows so as to meet State requirements. As noted earlier, the FHWA hydraulic manuals are to be used for the hydraulic analysis in conjunction with the HEC-RAS Program.
The design recurrence interval for various classes of highways is set forth in Chapter 10, Bridges.

Water surface profiles should be prepared using HEC-RAS. Adjustments may be needed in sizing the culvert to meet State requirements. In making these adjustments, it should be kept in mind that the width of the main channel culvert should be selected to accommodate the bankfull flow. Where adjustments in capacity are required, consider increasing the area of the flood plain culverts or the height of the main channel culvert. Try to minimize changes to the width of the main channel culvert.

Field checks should be made of the development in the flood plain to assure that the culvert headwater elevations determined by the hydraulic analysis are consistent with State regulations.

13.6 Guidelines for Consideration of Stream Morphology (Continued)

13.6.8 Culvert Outlet Designs for Main Channel Culverts

The design of the main channel culvert outlet is a critical aspect of the culvert installation with regard to minimizing the impact of the culvert on the stream. A stream morphology study (Chapter 14) should be made of the stream channel downstream of the proposed highway crossing to determine its characteristics and to evaluate its stability. If the downstream channel is steep or unstable, special considerations may need to be taken in the design of the culvert outlet. Of particular importance is the occurrence of any downstream "nick points" or channel drops which indicate that an instability downstream of the culvert is working back towards the culvert outlet. If the channel reach in the vicinity of the culvert is unstable, an early decision will need to be made as to whether restoration efforts to stabilize the stream are necessary. If so, such restoration measures should be designed and constructed as a part of the culvert installation

Culvert outlet protection needs to be tailored for the specific conditions at the site, and no single "standard" method will be appropriate for all locations. This guide provides an overview of factors to consider in the design and provides for several examples to illustrate how the outlet protection can be designed to fit the site conditions.

Case 1 Outlets

Case 1 outlets are defined in this chapter as outlets into a downstream channel that is stable and has a relatively flat slope such as a C-Type or E-Type Stream. Velocities in the main channel culvert can be expected to be higher than in the upstream approach channel for the design discharge. In addition, the downstream channel banks and bed are likely to be vulnerable to scour and erosion. The typical design concept for this condition is to pass the flow through the culvert and to dissipate the outlet velocity in the downstream channel using a riprap installation designed to resist the scouring velocities.

If outlet velocities are high, a second approach might be to install the OOS riprap basin at the outlet with a pool depth designed for energy dissipation. Basins serve to dissipate energy and to redirect the outlet flow so that it spreads out and redistributes itself into the downstream channel. In some developed areas, however, basins may represent a nuisance and safety hazard.

Where appropriate, consideration can also be given to designing the stream itself at the culvert outlet as a pool using the dimensions of pool width, depth, length and other characteristics obtained from the stream inventory and classification study (Chapter 14).

In some cases, it may be necessary to provide for a grade control installation on the downstream end of the basin. The purpose of the control is to maintain the outlet scour pool at an elevation to enable fish passage through the structure. (See Section 13.3)

13.6 Guidelines for Consideration of Stream Morphology (Continued)

Case 2 Outlets - Structural Energy Dissipators

There are a number of structural design measures that can be used to dissipate energy where there is a very high outlet velocity from a culvert. The FHWA publication HEC-14 contains details regarding outlet protection. Such devices are generally not recommended for use if there are other design approaches that can be used to reduce the outlet velocity. Alternative considerations include use of other culvert materials and shapes, modification of culvert slopes or design of a bridge in lieu of a culvert. The H&H Manual contains recommendations for sizing the OOS riprap basins at such a site. (See the Outlet Basins for Culverts Excel Spread Sheet in the Chapter on OBD Software in this manual).

13.7 Special Design Considerations

In some cases, particularly for A, DA, F and G (Rosgen) Type streams, stream morphology becomes of paramount importance to the culvert design, requiring the services of engineers with specialized experience and knowledge. The discussion below addresses possible considerations affecting the design of culverts on these streams. The primary consideration for such specialized design problems should be to obtain the services of engineers with experience in working with these stream types. As noted elsewhere in this chapter, extensive work outside of the normal highway rights-of- way represents a departure from traditional design practices. Such specialized designs will need to be justified on a case by case basis.

Additional rights-of-way may be required to modify the stream. This need must be recognized early in the project development stage to obtain approval of the concept and to coordinate the work with the Office of Real Estate. When additional ROW will be required for channel modifications, early contact should be made with affected property owners to explain the nature of the proposed work and how such work will enhance the stream quality.

Work in the channel may be necessary to modify the channel cross-section and slope. This need must be recognized and agreed to early in the project development stage by personnel from other agencies that will review the project plans. Stream modifications can serve to provide an attractive design that enhances habitat.

13.7.1 Type A Streams

The A-type stream is a steep, entrenched and confined channel with stream slopes in the range of 4 to 10% or more. In Maryland, this stream type tends to occur mostly in small drainage basins. The recommended general concept for a highway structure on an A type stream is to span the entire channel, placing the structure footings beyond the limits of the channel banks. This approach minimizes the effect of the structure on the stream and on bankfull flow conditions. Use of a bottomless culvert, rigid frame or bridge may avoid the need for any work in the stream channel, including energy dissipation at the outlet of the structure. Typically, such structures can be constructed as a single span. If the abutment footings are located within the limits of the 500-year flood plain, appropriate measures will need to be taken to protect the abutments from damage from scour. For stream types A3, A4 and A5, particular attention should be given to evaluating the need for a grade control structure at the culvert outlet. If a culvert installation is used on a Type A stream, the culvert should be located in the area of steps, rapids or chutes.

13.7.2 Type DA Streams

The DA stream types are highly interconnected channel systems developing in gentle relief terrain areas exhibiting wetland environments with stable channel conditions. The stream channels have highly variable width to depth ratios, flat slopes (< 0.005), low bedload and stable banks.

In Maryland, such streams are encountered mostly in the coastal physiographic regions. The recommended general concept for a highway structure on such streams is to maintain the existing channel system to the extent feasible and to locate the culverts in convergence regions. This can be accomplished by providing:

- a combination of bridges and culverts at the crossing (preferred approach),
- culverts to carry each of the individual stream channels under the highway, or
- a bridge to span the entire channel system.

13.7.3 Type F Streams

The F stream type is an entrenched, meandering riffle/pool channel on a low gradient with a high width to depth ratio. Type F streams tend to be laterally unstable with high bank erosion rates. Studies by Rosgen have shown that the unstable nature of F type streams can lead to a reestablishment of a functional flood plain inside the confines of a channel that is consistently increasing its width within the valley. Because of the potential for the lateral instability of the F channel, an investigation should be made of the stream reach upstream and downstream of the proposed highway crossing. Consideration needs to be given to the potential for a continuing evolutionary cycle of the F channel with accompanying downcutting of the channel thalweg and building of a new flood plain level. Design alternatives for a highway stream crossing include:

1. A stream rehabilitation project to modify the Type F channel to a more stable channel form such as a Type C channel. While this approach may require additional ROW purchases or easements, it may also achieve offsetting cost savings in the form of a smaller main channel culvert or bridge (to match the lower width to depth ratio of the re-established channel). Another anticipated benefit would be lower maintenance costs associated with a stable channel. The re-established channel will be more efficient in transporting sediment, and can be designed to accommodate fish passage in the reach of the stream affected by the highway crossing.

2. A bridge to span the main channel with abutments set back from the channel banks and, if necessary, placement of circular piers in the channel. A clear span without piers is preferred, since further downcutting and shifting of the channel may increase the scour potential at the piers. If the bridge width provided is of adequate length, the stream may eventually re-establish a second stage channel within the limits of the original F channel.

13.7 Special Design Considerations_ (Continued)

3. A culvert installation. The most feasible approach would be to consider the evolutionary cycle of the F channel and to design the installation with a main channel culvert (to match the lower width to depth ratio of the re-established channel) and with flood plain culverts (Alternative 1 above). If this approach cannot be worked out, a wide culvert should be considered, having a width equal to or greater than the bankfull width of the F channel. The culvert should be of adequate size to convey the design flow assuming that an evolutionary channel will form inside the F channel and culvert. The geometry and arrangement of the culvert cells should anticipate bankfull flow in a second stage channel so that one or more of the cells can function as a future main channel culvert. Stabilization of the steep F channel banks may be needed to protect against further lateral movement of the channel that would result in outflanking of the culvert and subsequent erosion of the highway embankment).

13.7.4 Type G Streams

The “G” or gully stream type is an entrenched narrow and deep step/pool channel with a low to moderate sinuosity. Channel slopes generally range from 2% to 4% although “G” channels may be associated with gentler slopes where they occur as “down-cut” gullies in meadows. With the exception of channels containing bedrock and boulders, the “G” stream types have very high bank erosion rates and a high sediment supply. Channel degradation and sideslope rejuvenation processes are typical.

A culvert design on a “G” type stream should be approached with caution in recognition of the potential problems with bank erosion and sediment discharge. A bridge may be a better alternative in some cases and it is recommended that a bridge alternative always be evaluated for “G-3 to G-6” Type streams.

Prior to selecting a culvert installation for a “G” type stream, a detailed study should be conducted of the stream reach to determine whether work is necessary to stabilize the channel upstream and downstream of the culvert.

- The upstream approach channel may require stabilization in order to control bank erosion and the development and movement of meanders towards the highway. Without stabilization, the stream may outflank the culvert and attack the highway embankment. Stabilization efforts may include consideration of the conversion of the “G” channel to a “B” type channel. This is done by increasing the width to depth ratio as well as the entrenchment ratio

- Upstream stabilization may require a right-of-way easement including an access road (beyond the channel banks) to maintain the channel stabilization measures.

- The design of the upstream transition section should be made with careful attention to the energy slope of the flow to minimize any deposition of bed load at the culvert entrance.

- The depth and velocity of flow for bankfull flow conditions in the culvert should be consistent with depth and flow velocity in the upstream (stabilized) channel. Accordingly, culvert longitudinal slopes should be similar to the upstream channel slopes. Any significant flattening of the culvert slope or the energy line of the flow through or upstream of the culvert may result in silting up of the culvert barrel or the approach transition section.

- Culvert outlet velocities should be consistent with existing flow velocities in the channel to the extent feasible. Significant increases in outlet velocities coupled with the formation of an outlet jet into the channel can create problems with downstream channel instability. This can result in channel degradation and headcutting leading to the undermining of the outlet and possible failure of the entire culvert installation.

- Stabilization of a downstream channel reach may be necessary to control degradation on G-3 to G-6 streams. Stabilization efforts may be required beyond the highway right-of-way limits. In some cases, the construction of two or three step/pools can serve effectively to stabilize the downstream channel.

In general, the stability problems with "G" type channels become more difficult as the culvert length increases. A bridge alternative has the advantage of spanning the stream entirely, thereby avoiding changes to the stream regime. Bridge abutments should be placed well back of the channel banks taking into account the potential for future channel widening and an evolution to an F ($G_c \rightarrow F$) or B ($G \rightarrow B$) type stream (Figure `17).

13.7.5Stream Crossings at Bends, Pools and Confluences

The foregoing discussion regarding the location and design of culverts is based on the assumption of a favorable crossing location of the stream such as a straight reach on a riffle. In some cases, however, it may be necessary to construct a culvert in a bend or a pool or to deal with a stream confluence. These situations introduce a number of other considerations in the design process.

Bends

Bend locations can present a number of challenges to a culvert design. It is important to assure that the reach upstream and downstream of the bend, as well as the bend itself, be reasonably stable. If it is not, consider designing upstream or downstream transition sections to reestablish a stable channel. Align the culvert entrance and outlet with the stream channel to provide for a streamlined flow pattern and accompanying efficiency in the conveyance of sediment and flood flows. To achieve the design objectives in bends, it may become necessary to adjust the location of the channel in the vicinity of the culvert inlet or outlet. Such adjustments should be made so as to maintain, to the extent practicable, the existing pattern, profile and dimension of the stream and avoid straightening of the channel. Because of the additional problems and costs associated with designing a large culvert with a radius of curvature, this approach is not generally recommended. In some cases, however, use of a curved culvert may serve to minimize problems associated with disruption of the existing channel.

Pools

When a culvert is to be located in an existing pool, the culvert design should be directed at maintaining the characteristics of the pool. The geometry of the pool can be obtained from the stream inventory data. The culvert width should be based on the average bankfull width in the pool. The bankfull depth will be much greater in the pool than it is for a riffle section. Fish passage is facilitated in a pool and the culvert invert may not need to be depressed below the stream thalweg in the pool. If the culvert extends beyond the pool into the downstream riffle, it may remove the existing control, which established the glide and the run at the end of the pool. To the extent practicable, the pool depth should be extended into the downstream riffle beyond the outlet area of the culvert a sufficient distance in order to reestablish a control for the glide and the run.

Pools and riffles tend to move downstream over time. In the event that an upstream riffle moves down into the culvert, consider a design that will still provide for sufficient flow depth for fish passage. Downstream grade control structures can be used to maintain the pool elevation.

Confluences

A recurring problem in culvert design is the treatment of a stream confluence that lies within the limits of the proposed highway alignment. The general rule for such cases is to maintain separately the natural flow pattern of each stream channel even if this involves construction of two culverts. (Bridging of the confluence is *not* generally recommended because of problems with scour, erosion or sedimentation.) The site conditions for each location will need to be evaluated to determine the best location of the confluence relative to the highway.

Relocating the stream confluence immediately upstream of the highway culvert may create future problems with sediment deposition at the confluence and culvert entrance. It is usually preferable to relocate the stream confluence downstream of the highway crossing, especially if

13.7 Special Design Considerations

the streams are different sizes and types   For example; a small tributary G Type stream emptying into a larger E Type stream is liable to carry a significant sediment load that will be deposited at the confluence and the culvert entrance. Moving the confluence downstream of the highway will require the construction of two separate main channel culverts. Where the two streams share a common flood plain, the hydraulic design will need to be developed considering the total flow in the flood plain system and the characteristics of the hydrographs (time to peak, etc.) of the two streams. If both tributaries are of the same type and approximate size, it may be feasible to locate the confluence upstream from the culvert, provided that sediment transport can be maintained through the culvert. For this case, lateral stabilization of the channel banks may be needed upstream of the culvert.

13.8 Applications – Case Histories

The guidelines and criteria in this chapter provide an overview of the concepts to be applied in the design of a culvert installation in order to meet the design objectives. Since each stream crossing is unique, having its own set of conditions and considerations, it is not feasible to provide a step by step process that would serve equally well for every culvert location. However, the SHA has now constructed several culvert installations that have been designed utilizing the Rosgen stream classification system and the basic concepts presented in this chapter. Designers are encouraged to review the hydraulic reports for these culvert installations to note how the environmental, morphological, hydraulic and hydrologic conditions were evaluated and taken into account in the culvert design.

These culvert installations include:

1. Route 50 Salisbury Bypass over Wicomico River (combined bridge and culvert installation for a Rosgen DA stream type,

2. Route 25 over Beaverdam Run, Baltimore County (Rosgen C4 Channel),

3. Route 382 over Full Mill Branch and Spice Creek, Prince Georges County (Rosgen E6 channel),

4. Arena Drive over Tributary to Southwest Branch, Prince Georges County (Rosgen G4 channel),

5. Route 191 over Tributary to Cabin John, Montgomery County (Rosgen C3/B3 Channel)

13.9 Outlet Velocities, Degradation and Scour

Section 13.5, Culvert Design Procedures, presents general recommendations for the sizing and hydraulic analysis of culvert installations and their outlets. The hydraulic analyses serve to provide a reasonable estimate of the culvert outlet velocity for selected discharges.

Where adequately sized flood plain culverts are provided, the culvert outlet velocity in the main channel should be reasonably consistent with channel velocities for existing conditions. For culverts on mild slopes, modest increases in velocities of less than 20 percent normally will be dissipated by the formation of the outlet scour hole. Culverts on steep slopes, however, can represent more of a problem. This section expands on the guidance in Section 13.5 for the condition where there is a need to study the scour potential in greater detail. Use of an outlet riprap basin (See the chapter on OBD software in this Manual) generally will serve in dissipating this outlet energy.

Evaluation of the following flows is recommended: flow for AOP passage (Section 13.3); bankfull flow; design flow; and incipient overtopping flow. Information required for the analysis includes:

- Information on the stream channel, its slope and composition of channel bars as determined from the stream inventory and classification (As noted in Section 13.5, particular attention needs to be given to the stability of the downstream channel section and any tendency towards degradation of the channel bed in this section.)

- Composition of the bed material in the outlet channel,

- Flow velocity, slope and depth at the culvert outlet and at various locations in the downstream channel.

Bankfull Flow Conditions

Compute the Manning's "n" value (bankfull flow) and critical shear stress for the bed material using the information presented in References 7 and 8, Shield's criteria or other references. Estimate the size of bedload being transported at or near the bankfull stage by sampling nearby channel bars. Compute the shear stress at several locations downstream of the culvert outlet ($\tau = \gamma RS$) where the channel is stable. By a comparison of existing and proposed conditions determine the "zone of influence" in the downstream channel where velocities and shear stresses of proposed conditions are higher than for existing conditions.

Based on the above information, determine whether outlet flow conditions are acceptable. If not, consider either (1) a redesign of the culvert or (2) use of one or more riprap basins with accompanying grade control structures in the downstream channel to dissipate energy. These pools may require construction of a step-pool type of control using rock weirs, with careful attention given to passage of fish at the weirs

<u>13.9 Outlet Velocities, Degradation and Scour (Continued)</u>

Where significant problems are encountered with regard to the effect of high outlet velocities on the stability of a downstream channel, it may be prudent to evaluate an alternative design rather than to acquire easements and to construct elaborate outfall structures.

<u>Design Flow Condition</u>

Any culvert outlet control feature used to control bankfull flow will need to be evaluated for the design flow to assure that it will not fail and endanger the stability of the culvert. The evaluation process is similar to that used for bankfull flow. However, the estimation of Manning's "n" may need to be modified to account for the effect of vegetation and other conditions of flood flows. *It is essential that the culvert and its outlet protection system remain stable for conditions of the design flow*.

<u>Incipient Overtopping Condition</u>

In some cases, the incipient overtopping condition may be the design condition. In other cases, this condition may occur only for a very rare flood well in excess of a 100-year or 500-year flood. The probability of occurrence needs to be given primary consideration in the evaluation of this flood event. The incipient overtopping condition is used as a worst case scenario for evaluating culvert outlet conditions. If this flow condition will create catastrophic results due to extreme outlet velocities, a reevaluation of the culvert design is warranted.

13.10 Silting of Culverts

Main Channel Culverts

The design procedure in Section 13.5 is based on the assumptions that:

- the culvert is aligned with the upstream channel,
- the upstream channel is stable and is neither aggrading or degrading,
- the depressed culvert invert will remain filled with bed load material from the upstream channel, and
- silting of the main channel culvert installation above the invert depression provided for fish passage will be unlikely if the culvert is designed to maintain the dimension, pattern and profile of the stable channel morphology associated with the bankfull flow.

An important objective of the stream inventory and classification study, Section 13.4.4, is to determine the site conditions and to identify potential problems with sedimentation (stream bed aggradation or degradation, bank erosion, etc.). There will be various situations where the above assumptions will not apply. Two examples are discussed below:

Example one involves flow through a box culvert on a steep slope where the Manning's "n" value in the culvert is lower than in the approach channel. In this case, there is a concern that the bed material may be swept out of the culvert, resulting in a lower "n" value and a resultant high culvert velocity. If fish passage is a design objective for this culvert, special features may need to be incorporated in the design of the culvert barrel to reduce culvert velocities and to provide resting places for fish. Alternatively, a different type of structure may be required.

Example Two involves a location where a steeper approach channel flattens out just upstream of the culvert. This is not a desirable culvert location; yet, constraints sometimes require that a culvert be located in a less than ideal stream reach. In this instance, there is a concern that the culvert will be unable to convey the bed load from the upstream channel and will silt up.

The concepts presented in Chapter 14, Stream Morphology, can be applied to this condition for estimating sediment conveyance capacity and deposition potential in culverts.

Flood Plain Culverts

The design procedure in Section 13.5 is based on the concept that (1) the bed load carried by a stream is concentrated in the main channel and (2) that very little bed load is carried by overbank

13.10 Silting of Culverts (Continued)

flow. This concept is applicable to many locations since the higher roughness values and lower depths of flow on the flood plain result in shear stress values that are lower than the critical shear material are conveyed out of the stream bed and deposited on the flood plain or along the riverbank. These locations typically introduce a major change in the sediment transport conditions due to the highway crossing or the natural flow conditions in the stream. Placement of flood plain culverts should be made with this thought in mind. Examples include:

- Formation of bars on the inside of bends,
- Goose neck bends where flood flows and sediment are transported across the flood plain neck separating the channels,
- Stream confluences,
- Diversion of flood flow due to blockage of culverts or bridges by sediment and debris.

13.11 Effects of Ice and Debris

Highway culverts should be located so as to avoid areas that have a high potential for blockage by the deposition of stream sediments and debris. Because of Maryland's location and climate, ice jams have not been a significant state-wide problem in the operation of highway culverts. Debris, on the other hand is a continuing problem, and the consequences of debris accumulation should be considered in the location and design of the culvert. Wherever practicable, access should be provided for personnel and equipment to clean the culvert entrance.

Debris is defined as any material moved by a flowing stream. This includes a combination of floating material, suspended sediment and bed load. A stream's propensity for carrying debris is based upon watershed land uses and its stream and flood plain characteristics. Debris is likely to be a problem in mountainous or steep regions. The site investigations of a proposed stream crossing should include evaluation of the following conditions:

- Stream velocity, slope and alignment,
- Presence of eroding banks and the types of trees or shrubs on the banks vulnerable to being undermined and washed away,
- Watershed land uses, particularly logging, cultivation and construction,
- Watershed response to storms, such as flash flooding in steep terrain,
- Storage of debris and materials on the flood plain (logs, lumber yards, etc.),

Debris can accumulate at a culvert inlet or become lodged in the inlet or barrel. Severe blockages can lead to the ponding of water upstream of the culvert with damage to developed properties, overtopping of the roadway and subsequent destruction of the entire culvert installation.

Some debris accumulation can be anticipated at most culvert installations. Routine maintenance operations including removal of the debris will serve in most cases to minimize the hazard of blockages. If the site reconnaissance reveals a significant potential for debris accumulation, consideration should be given to minimizing the problem and its effect on the safe operation of the highway. Alternative approaches include use of a single cell (vs a multiple-cell culvert installation) or selection of a bridge. The use of flood plain culverts will serve to provide relief openings for conveyance of the flood flows in the event the main channel culvert becomes blocked.

Debris deflectors and control structures have not been used extensively in Maryland, and they are not generally recommended for inclusion on new construction. Where debris accumulation has become a continuing maintenance problem and safety hazard at an existing culvert, a debris control structure or deflector should be considered as one way of lessening the extent of the problem. Design information for commonly employed debris control structures and deflectors can be found in the FHWA Publication HEC-9, Debris Control Structures, Reference 5.

13.12 Structures on Small Watersheds

The Structure H&H Division is currently assisting SIRE and the SHA District Offices in the conduct of studies for rehabilitation of structures on streams with the following site characteristics:

1. Small watershed areas (typically less than one square mile),
2. No improved properties located in the vicinity of the stream crossing,
3. No proposed changes to the roadway profile,
4. No District concerns related to the frequency of roadway overtopping.
5. No significant downstream degradation.

The primary objective of the simplified studies discussed in this section is to rehabilitate existing structures that are reaching the end of their service life. In some cases, for locations with the above noted site characteristics, it may be necessary to replace the existing structure with a structure providing for equal or better performance.

After receiving a request from SIRE for assistance, the Structure H&H Division will initiate a study of the structure and verify that the structure crossing has not been a concern with regard to flooding of the highway.

Office of Structures Project Development Procedure for Rehabilitation (or Possible Replacement) of Structures on Small Watersheds

1. Contact the District Office regarding any concerns about the frequency of road overtopping.
2. Notify all affected property owners of the proposed project, if there is a need to access the property
3. SIRE will usually recommend the option of rehabilitating corrugated metal culverts with a lining. Study this option if the above noted site characteristics conditions have been met.
4. Evaluate the liner installation option by computing the conveyance $((1.49/n)*A*R^{0.667})$ of the existing pipe and the conveyance of the proposed lined pipe. If the conveyance of the lined pipe is equal to or greater than the conveyance of the existing pipe, the lined pipe can be considered as a replacement in kind, subject to MDE approval. Submit a letter to MDE requesting their concurrence with the proposed culvert rehabilitation plan. (See Example letter in Attachment A below).
5. Companies that install liners in culverts include:

- CONTECH CONSTRUCTION PRODUCTS, INC. – www.contech-cpi.com
- SNAP-TITE- www.*culvert*-rehab.com

6. If the liner installation option described in Step 4 above is not appropriate or if other factors indicate that rehabilitation of the existing culvert is not feasible, design a replacement structure using the procedure outlined below:

   A. Conduct a Hydrology Study
   - Run a single area TR-20 for existing and ultimate development conditions Use a time of concentration either as estimated by GIS-HYDRO or by manual computations
   - Use TR-20 ultimate development discharges in the HEC-RAS models (The FHWA HY-8 program may be an acceptable alternative approach for some cases).
   - If the watershed area is within the range used to develop the fixed-region regression equations, follow the recommendations of the Hydrology Panel (See Chapter 8).

   B. Conduct a Hydraulic Study
   - Use mapping that is already available for a particular watershed such as LiDAR, or 200 scale county maps.

   - Supplement these maps with four field-surveyed cross-sections (two upstream and two downstream of the crossing) .Include structure and roadway geometry (See Chapter 4) and the roadway profile. Field surveys performed by H&H personnel with an assumed datum are acceptable to MDE.

   - Establish reliable tailwater elevations by one of two methods:

     - Repeat the first (field surveyed) cross-section further downstream at selected intervals. Make appropriate elevation adjustments based on the channel slope.

     - As an alternative approach, use available mapping for the floodplain and impose a channel geometry. The channel can either be field-measured (preferred) or estimated based on the regional bankfull geometry curves prepared for the Maryland SHA by the U. S Fish and Wildlife Survey.

   - Select a concrete pipe or box size that is equal to or larger than the existing culvert

   - Bury the proposed culvert at least one foot below the elevation of the existing channel

   - Run HEC-RAS or a combination of HEC-RAS and HY-8 for existing and proposed conditions.

- Verify that the proposed headwater changes (between existing and proposed conditions) at the SHA right of way line does not exceed 0.5 ft. If this value is exceeded, select a larger culvert size so that the increase in elevation is no greater than 0.5 feet.

7. Provide for any special provisions that should be considered in the design of the replacement structure:

   - Improvements to facilitate passage of aquatic organisms (AOP) and wildlife (Chapter 13 Culverts)
   - Standard inlet and outlet protection, as necessary
   - Protection of stream channel and banks,
   - Provisions for protecting the culvert from clogging by debris
   - Other specific concerns that may be present at the existing culvert.

8. Prepare a combined H/H report for MDE review and approval

ATTACHMENT A

Letter of Request to MDE for Waiver from Performing H&H Studies

Martin O'Malley, *Governor*
Anthony G. Brown, *Lt. Governor*

SHA State Highway Administration
Maryland Department of Transportation

Beverley K. Swaim-Staley, *Secretary*
Neil J. Pedersen, *Administrator*

April 22, 2011

Subject: Request for Waiver from
Performing H&H Studies
MD 349 over Branch of Dennis Creek
Structure No. 22078X0
4.0' X 3.0' Box Culvert

Mr. William Seiger
Maryland Department of the Environment
1800 Washington Blvd.
Baltimore, Maryland 21230-1708

Dear Mr. Seiger:

The Maryland State Highway Administration is proposing to install a one inch HDPE smooth sheet liner on the existing walls and bottom of box culvert (Structure No.22078X0). The sheet liner will be installed on the dry surface of the box culvert with epoxy anchors and 2.0" anchor washers. Extrusion welding joints at the bottom and sides of the box culvert will be done with silicone caulk. The existing crossing is located in Wicomico County. We checked with the SHA District and have been told that there is no record of flooding at this site. The "n" values for the existing and proposed (with liner) culvert are based on a conservative approach. Since the existing concrete box culvert is in bad condition the "n" value has been increased to 0.018 to take this condition into account. The proposed HDPE liner "n" value has been increased from the Snap-Tite value of 0.0094 to 0.012 to account for possible abrasion over time due to sediment flow.

With the use of tables and the formula we have computed the conveyance in both the existing structure and the structure with the HDPE liner. The conveyance values are:

K= 1.49/n AR 2/3 = Conveyance

	n	1.49/n	A	P	R = A/P	R 2/3	K
Existing	0.018	55.555	12	14	0.8571	0.9023	601.55
With Liner	0.012	83.333	10	14	0.7143	0.7990	665.87

We are requesting a waiver from performing H&H studies as outlined in the DNR-WRA Operational Policy Guidelines, since the conveyance (flow) through the box culvert with the

Mr. William Seiger
April 15, 201
Page 2

smooth HDPE liner will be better than the present condition of the box culvert. To account for increase of velocity in flow due to this action we intend to install riprap at the outlet of the culvert.

If you have any questions, please contact Mr. Leonard Podell at (410) 545-8363 or Mr. Andy Kosicki at (410) 545-8340.

Very truly yours,

Earle S. Freedman, Director
Office of Structures

ESF/LNP/cd
FILE:N_2011/MD349_22078X0.LTR

Cc: Mr. Rod Thornton
Mr. Steve Hurt, McCormick Taylor

13.12 References

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2. Maryland SHA Highway Drainage Manual, December 1981

3. Maryland SHA Highway Drainage Manual, December 1981, Chapter 9, Culverts

4. Maryland SHA Office of Structures PPM D84-29(4) dated July 26, 1994 entitled End Treatment for Pipe Culverts.

5. Maryland SHA Office of Structures PPM D78-15(4) dated July 31, 1990 entitled Length and Treatment of Culverts.

6. AASHTO Highway Drainage Guidelines, Chapter 4, Hydraulic Design of Highway Culverts, 2007

7. AASHTO Model Drainage Manual, 2006, Chapter 9, Culverts

8. Federal Highway Administration, Hydraulic Design Series No. 5, Hydraulic Design of Highway Culverts, 2005 (FHWA-NHI-01-020).

9. Federal Highway Administration, HY-8, FHWA Culvert Analysis Program, Version7, 2007.

10. Federal Highway Administration, Hydraulic Engineering Circular HEC-9, Debris Control Structures, 2005 (FHWA-IF-04-016)

11. Federal Highway Administration, Hydraulic Engineering Circular HEC-14, Hydraulic Design of Energy Dissipators for Culverts and Channels, 2006 (FHWA-NHI-06-086).

12. Rosgen, Dave, Applied River Morphology, Wildland Hydrology, 1996

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14. U.S. Army Corps of Engineers, HEC-RAS River Analysis System, Version 4.0.0, March 2008.

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16. Rosgen, David, Informal communications with the Maryland SHA, December 1998.

17. Rosgen, David, Geomorphology Applications to the Design of Waterway Crossings, instructional material for a workshop presented to the Maryland SHA, May 1998.

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18. U. S. Geological Survey, Maryland Stream Survey, 1999.

19. Maryland SHA and Maryland Department of the Environment, Application of Hydrologic Methods in Maryland, August 2006 Revision.