Highway Drainage Manual Design Guidelines

Culverts

I. Policy

The following policies are specific to culverts.

- All culverts shall be hydraulically designed unless otherwise directed by the Chief, Highway Hydraulics Division.
- The overtopping flood shall be consistent with the class of highway and commensurate with the risk at the site.
- Site information shall consider topographic features, channel characteristics, aquatic life, high-water information, existing structures, soil and water chemical characteristics, abrasion potential and other related site specific information.
- Culvert location in both plan and profile shall be investigated to avoid sediment buildup in culvert barrels.
- When for environmental reasons culverts are required to provide for a natural bottom, length, slope and effects upon stream down cutting must be considered. The assumption, unless structural means are used to maintain the stream bottom, is that the culvert capacity is determined using the full pipe cross sectional area.
- The cost savings of multiple uses (utilities, stock and wildlife passage, land access, and fish passage) shall be weighed against the advantages of separate facilities.
- Culverts shall be designed to accommodate debris or proper provisions shall be made for debris maintenance.
- Where practicable, means shall be provided for personnel and equipment access to facilitate maintenance
- Material selection shall include consideration of service life. The expected service life is dependant on numerous variables such as; soil characteristics, water chemistry, bedload, groundwater levels, and use of various protective coatings. The design service life of a drainage facility is defined as the expected maintenance free service life of each installation.
- Total Life-Cycle Cost, including maintenance, rehabilitation and replacement costs, shall be considered in an evaluation of alternatives.
- Culverts shall be located and designed to minimize hazards to traffic and people.
- Soil and water testing for pH and resistivity shall be performed at all stream crossings to ensure proper pipe material selection.
- All pipes shall be installed with bedding and backfill materials suitable for the particular pipe material used.
- No asphalt coatings may be used on pipes within stream systems as the coating may abrade and enter the stream environment.

- All pipe outfalls shall be protected from scour.
- Transverse pipes may not be smaller than 18 in. diameter (or equivalent). Where the length of pipe exceeds 60 ft, the minimum diameter is 24 in.
- The detail of documentation for each culvert site shall be commensurate with the risk and importance of the structure. Design data and calculations shall be assembled in an orderly fashion and retained for future reference.
- Culverts 60" diameter or greater are part of the Small Structures Program and may be subject to review by the Office of Bridge Development. Consult the Office of Bridge Development "Manual for Hydrologic and Hydraulic Design, Chapter 13 – Guidelines for the Selection and Design of Culvert Installations
- Structures with openings between 3 feet and 5 feet are also considered to be small structures if the height of fill above them is less than their width.
- Multiple pipe installations with a total span greater than 20 ft are considered bridges.
- Culvert installations shall be designed, to the extent practicable, to maintain stream stability and to provide passage of fish and wildlife.
- Equal consideration in the selection of pipe materials is required where alternate products are judged to be of satisfactory quality and equally acceptable on the basis of engineering and economic analysis.
- Hydraulic design procedures for culverts are based on the publications and software of the Federal Highway Administration. These procedures are discussed in Appendix B.
- Post installation inspection as specified in Section 303 of the Standard Specifications is required to determine deflection, joint alignment and cracking.
- Where design criteria cannot or should not be met, a design exception must be obtained from the Chief, Highway Hydraulics Division.

II. Criteria

A. Allowable Headwater

The maximum allowable headwater shall:

- Not encroach upon upstream property improvements,
- Be below the outside edge of the shoulder for the design flood frequency,
- Be below the edge of shoulder of the low point in the road grade,
- Not exceed an HW/D ratio of 1.5 without concurrence of Chief, Highway Hydraulics Division (HHD),
- Not divert flow into adjacent watersheds, and
- Regardless of the Design Flood, the 100 year floodplain outside of the Right-of-way shall not be increased above the elevation which existed prior to construction.

B. Flood Frequency

The flood frequency used to design or review culverts shall be based on:

- The roadway classification,
- The level of risk associated with failure of the crossing, increasing backwater, or redirection of the floodwaters,
- Location of mapped floodplains and
- An economic assessment or analysis to justify the flood frequencies greater or lesser than the minimum flood frequencies listed below.

AASHTO Classification	*Highway Needs Inventory Classification*	*Flood Frequency*
Expressways	*I. Principal Arterials*	*100 year storm*
Arterials	*II Intermediate Arterial*	*50 year storm*
	III Minor Arterials	*50 year storm*
Collectors	*IV Major Collectors*	*25 year storm*
	V Minor Collector	*25 year storm*
Local Roads & Entrances	*VI Local Streets*	*10 year storm*
Ramps		*Higher classification of the intersecting road*

- Regardless of the design flood frequency, culverts requiring a permit for "Construction on Non-Tidal Waters and Floodplains" shall be analyzed using the ultimate discharge for the 100 year storm. The ultimate discharge is that discharge which would occur if the watershed was fully developed in accordance with existing zoning.

C. Location

- Culvert length and slope shall 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.
- Culvert skew shall not exceed 45 degrees as measured from a line perpendicular to the roadway centerline without the approval of the Chief, Highway Hydraulics Division.
- Culverts determined to be located within and affecting non-tidal waters and floodplains shall be designed in accordance to COMAR 26.17.04.06; specifically:
    - The length of culverts shall be limited to a maximum of 150 feet unless it can be demonstrated through an environmental study that any adverse impacts will be adequately mitigated.
    - Culverts shall have at least one cell placed at least 1 foot below the invert of the stream.

D. Sizing

- Acceptable design methods include:
    - FHWA Hydraulic Design Series No. 5 HDS-5,
    - HY-8,
    - HEC-RAS,
    - SHA Drainage Manual Charts and
    - Proprietary software approved by the Chief, Highway Hydraulics Division.
- Minimum sizes:
    - 18 inch diameter (or equivalent) minimum.
    - 24 inch if length exceeds 60 feet
    - 24 inch under expressways
    - 15 inch for driveways and side drains.
- Maximum sizes:
    - All pipes greater than 96” diameter require approval from Office of Bridge Design.
- Multiple Pipes:
    - Shall be avoided where the approach flow is high velocity, particularly if supercritical
    - The minimum spacing between spans is
        - 2 ft for spans 48” or less,
        - ½ span or 3 ft, whichever is less for spans greater than 48”
    - Shall be avoided if bankfull flow is adversely affected.
    - One pipe should fit dominant channel with minor widening of the channel so as to avoid conveyance loss through sediment deposition in some of the barrels. The other pipes may be within the floodplain.

E. End Treatment

All culvert ends shall be protected. Consideration shall also be given to safety since some end treatments can be hazardous to errant vehicles. If the culvert cannot be extended to the clear zone, the use of end grates may be required as per AASHTO Roadside Design Guide. Unless specified, culvert end treatment visible from the roadway shall be oriented parallel to the roadway; otherwise place perpendicular to the pipe.

- Headwalls
    - Are used to anchor pipes to prevent uplift,
    - Must extend beyond the clear zone or be protected,
    - May be beveled, as appropriate, to increase the hydraulic performance of the culvert (inlet control).
    - Improved inlets such as side-tapered and slope-tapered inlets can increase the hydraulic performance of the culvert, but may also add to the total culvert cost. Therefore, they should only be used if practicable.
- Wingwalls
    - Are use to contain roadway fill for culverts ≥ 48 in. rise.
    - Are used where the side slopes of the channel are unstable.
    - Are used where the culvert is skewed to the normal channel flow.
    - Can affect hydraulic efficiency if the flare angle is < 30° or > 60°.
- End Sections may only be used if;
    - No base flow is present,
    - No backwater conditions are anticipated,
    - Span is less than 36 inch, 30 inch within the clear zone.
    - Pipe slope and flow velocity do not affect stability.
- Safety Considerations
  Traffic shall be protected from culvert ends as follows:
    - Small culverts 30" (750 mm) diameter or less shall use an end section or a sloped headwall unless beyond the clear zone.
    - Culverts greater than 30" (750 mm) diameter shall receive one of the following treatments.
        - Extend to the appropriate "clear zone" distance per AASHTO Roadside Design Guide.
        - Provide a grate if the consequences of clogging and causing a potential flooding hazard are less than the hazard of vehicles impacting an unprotected end. If a grate is used, an open area shall be provided between the bars of 1.5 to 3.0 times the area of the culvert entrance.
        - If the culvert cannot be extended and a grate is not desirable, shield with a traffic barrier

F. Outfall Protection

- Outfalls shall be protected from erosion.
- Outlet velocity shall be calculated and at a minimum, outfall protection be provided for the same design storm as the culvert. Where conditions indicate that greater outfall velocity may occur at a lesser storm event, provide protection for that event.
- Riprap outfalls may be used when the outlet Froude number (Fr) is less than or equal to 2.5. In general, riprap aprons prove economical for transitions from culverts to overland sheet flow at terminal outlets, but may also be used for transitions from culvert sections to stable channel sections. Stability of the surface at the termination of the apron shall be considered.

  Riprap aprons may be designed using Charts in Appendix 2

  - No. 405.8 "Design of Outlet Protection Minimum Tailwater Condition" is for use where:
    - Tailwater is less than ½ the culvert height and the culvert outlets onto flat areas with no defined channel.
    - Tailwater is less than ½ the culvert height and the receiving stream is wide enough to accept divergence of the flow.
  - No 405.9 "Design of Outlet Protection Maximum Tailwater Condition" is for use where:
    - Tailwater is greater than ½ the culvert height.
    - Culvert discharges into a confined channel.
- Riprap lined preformed scour holes may also be used when the outlet Fr is less than or equal to 2.5. They are generally used for transitions from culverts to stable channels. Since they function by creating a hydraulic jump to dissipate energy, performance is impacted by tailwater conditions.
- Riprap Culvert Outlet Basin (CSU Basin as modified by SHA) is available for download as an Excel spreadsheet.
- Energy dissipators may be designed according to HEC-14, *Hydraulic Design of Energy Dissipators for Culverts and Channels* or using the Energy Dissipator subroutine included in HY-8. Some preferred types of dissipators include:
  - Preformed scour hole (CSU Basin)
  - USBR Type VI Hanging Baffle Energy Dissipator
- Evaluate downstream channel stability and provide appropriate erosion protection.
- Outlets determined to be located within and affecting non-tidal waters and floodplains shall be designed in accordance to COMAR 26.17.04.06; specifically:
  - Adequate protection shall be provided to prevent damage due to scour. Protective measures may not prevent the passage of fish.
  - The outlet velocity of culverts which is associated with the dominant discharge may not exceed the existing stream channel velocity associated with the dominant discharge. A higher than existing stream

channel velocity may be allowed at a culvert outlet when or if measures are incorporated into the design to prevent increases in stream channel erosion.

- The maximum allowable Froude number, associated with the 100-year frequency flood event as calculated through the bridge opening or at the outlet of the culvert, shall be as follows:
  - 0.9, if the presently existing Froude number is less than or equal to 0.9; or
  - (b) The presently existing Froude number, if the presently existing Froude number is greater than 0.9.

G. Cover

- The minimum cover for rigid pipe (concrete) is
  - 0.75 ft from top of pipe to top of sub-base (bottom of aggregate base), or
  - 1.0 ft in non-traffic areas.
- The minimum cover for flexible pipe (thermoplastic, corrugated metal) is 1 ft to top of sub-base. During construction, a minimum 2 ft temporary cover must be maintained.
- Maximum Cover is dependent upon pipe material and loading.
  - Consult appropriate height of fill tables in the Highway Drainage Manual
  - AASHTO Section 26 for corrugated metal pipe
  - AASHTO Section 27 for reinforced concrete pipe
  - AASHTO Section 30 for plastic pipe
- When cover criteria cannot be met, a structurally adequate design must be developed and a design exception request must be approved by the Chief, Highway Hydraulics Division.

H. Service Life

The design service life for drainage facilities for all projects shall be as follows:

- Expressway – 100 years.
- Roadbed widths greater than 27 ft or greater than 10 ft of cover - 75 years
- All pipes within SHA right-of-way shall have a minimum 50-year service life

It is desirable that the design of drainage related facilities conform to SHA criteria set forth in these guidelines. Roadways and other projects in undeveloped areas should meet all criteria. However for some projects, meeting the criteria is not practicable due to existing constraints such as utilities, Right-of-Way limitations, budgetary limits and where the project would be surrounded by facilities not meeting the criteria. The design should be appropriate to the type of project and surroundings. When the design criteria cannot or should not be met a design exception request must be approved by the Chief, Highway Hydraulics Division.

I. Private Development

Work performed by private developers within SHA right-of-way under permit shall meet the criteria and conform to the "Guidelines for Development Adjacent to State Highways".

III. Materials

The selection of pipe material is dependant upon various factors: soil type, soil chemistry, soil saturation, baseflow, abrasion potential, height of fill, cover, replacement costs, outlet velocities, service life requirements and other potential factors.

A. Approved materials. The following pipe materials are approved as noted. It is the designer's responsibility to ensure that that the selected material meets all of the required needs.

Reinforced Concrete Pipe (RCP), Reinforced Concrete Pressure Rated Pipe (RCPP and Horizontal Elliptical Reinforced Concrete Pipe (HERCP)

- Specification: M-170, Class IV minimum
    - Joints shall have rubber gaskets conforming to M-315
- Specification: C-361 Low-Head Pressure rated pipe is required for pond spillways subject to Code 378
- Specification: M-207 Horizontal Elliptical only
    - Sizes: up to 53" X 34"
    - Joints shall be sealed conforming to M-198
- If water soluble chlorides exceed 400 ppm, protective measures are necessary.
- If soils, as indicated in the Soil Survey, have a high corrosion potential, additional protective measures may be necessary. *[These ratings depend on texture, occurrence of organic horizons, pH, and the amounts of magnesium and sodium sulfate or sodium chloride in the saturation extract. (NRCS Soil Survey Manual)]*

Corrugated Metal Pipe (CMP), Pipe-Arch (CMPA) and Spiral Rib Pipe (SRP)

- Steel (CSP, CSPA and SRP)
    - Specification: M-36
    - Minimum Thickness: 14 gage roadway, 16 gage under entrances.
    - Coatings: Aluminized (Type 2) as per M-274 is to be used within roadway. Additional/alternative protective coatings may be used on a case-by-case basis
    - Joints shall have rubber O-ring gaskets and be silt tight
    - Sizes: 15" to 54"
    - 60" and larger must be approved by Office of Bridge Development
    - Soil and water pH testing is required. Acceptable pH range from 5.5 to 8.5. Minimum soil resistively shall be in excess of 1500 ohm-cm.
    - Where baseflow is anticipated, abrasion must be considered in the Service Life computations.
    - Bedding shall be loose granular material with a maximum particle size less than one-half the corrugation depth.
    - Backfill materials shall be granular, free of organic matter and rock fragment greater than 3 in. in greatest dimension and meet the requirements of A 145 A-1, A-2, or A-3, Selected Backfill or Select

Borrow. Flowable Backfill may be used provided adequate flotation resistance can be achieved.
- When comparing costs to other materials, include cost of bedding and backfill material if in-situ material does not meet specification.
- Not for use as pond spillways.

- **Aluminum (CAP, ASRP and CAPA)**
  - Specification: M-196
  - Joints shall have rubber O-ring gaskets
  - Sizes: 15" to 54"
  - 60" and larger must be approved by Office of Bridge Development
  - Bedding shall be loose granular material with a maximum particle size less than one-half the corrugation depth.
  - Backfill materials shall be granular, free of organic matter and rock fragment greater than 3 in. in greatest dimension and meet the requirements of A 145 A-1, A-2, or A-3, Selected Backfill or Select Borrow. Flowable Backfill may be used provided adequate flotation resistance can be achieved.
  - When comparing costs to other materials, include cost of bedding and backfill material if in-situ material does not meet specification.
  - Not for use as pond spillways.

Structural Plate Pipe and Pipe Arch

- Steel (SPP and SPPA)
  - Specification: M- 197
  - Sizes: 60" to 96"
  - Bottom plate shall be 1 gage thicker than the rest of the structure.
  - Larger than 96" must be approved by Office of Bridge Development
  - Bedding shall be loose granular material with a maximum particle size less than one-half the corrugation depth.
  - Backfill materials shall be granular, free of organic matter and rock fragment greater than 3 in. in greatest dimension and meet the requirements of A 145 A-1, A-2, or A-3, Selected Backfill or Select Borrow. Flowable Backfill may be used provided adequate flotation resistance can be achieved

- Aluminum (APP, APPA)
  - Specification: M-219
  - Sizes: 60" to 96" must be approved by Office of Bridge Design.
  - Bottom plate shall be 1 gage thicker than the rest of the structure.
  - Bedding shall be loose granular material with a maximum particle size less than one-half the corrugation depth.
  - Backfill materials shall be granular, free of organic matter and rock fragment greater than 3 in. in greatest dimension and meet the requirements of A 145 A-1, A-2, or A-3, Selected Backfill or Select

Borrow. Flowable Backfill may be used provided adequate flotation resistance can be achieved

Corrugated Polyethylene Pipe (CPP-S)

- Specification: M-294, Type 'S' (smooth interior) and Type 'D' (smooth interior and exterior)
- Sizes: 15" to 60"
- Joints shall be bell and spigot with internal gaskets meeting F 477.
- Watertight joints as per D3212 and F1417 may be specified.
- 1' minimum cover from top of the outside diameter to the top of subbase
- Bedding and backfill materials shall meet the requirements of A 145 A-1, A-2-4, A-2-5 or A-3, Selected Backfill or Select Borrow. Flowable Backfill may be used provided adequate flotation resistance can be achieved.
- Structural Backfill envelope shall extend from 4 in. below pipe to 12 in. above pipe.
- When comparing costs to other materials, include cost of bedding and backfill material if in-situ material does not meet specification.

Polyvinyl Chloride Profile Wall (PPWP)

- Specification: F-949
- Sizes: 15" to 36"
- Joints shall be bell and spigot with internal gaskets meeting F 477
- Watertight joints as per D3212 and F1417 may be specified
- 1' minimum cover from top of the outside diameter to the top of subbase
- Bedding and backfill materials shall meet the requirements of A 145 A-1, A-2-4, A-2-5 or A-3, Selected Backfill or Select Borrow. Flowable Backfill may be used provided adequate flotation resistance can be achieved.
- Structural Backfill envelope shall extend from 4 in. below pipe to 12 in. above pipe.
- When comparing costs to other materials, include cost of bedding and backfill material if in-situ material does not meet specification.

Non-Asbestos Fiber-Cement Storm Drain Pipe (FCP)

- Specification: C 1450
- Sizes: 15" to 48"
- Class IV minimum
- Rubber gasket joints conforming to M-315
- Not for use within the roadway unless specifically approved by Chief, Highway Hydraulics Division

B. Service Life

The prediction of design service life of drainage facilities is difficult because of the large number of variables, continuing changes in materials, wide range of environments, and use of various protective coatings. The design service life of a drainage facility is defined as the expected maintenance free service life of each installation.

For corrugated metal pipe culverts (CMP), 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 on the culvert.

For reinforced concrete pipe culverts (RCP), 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, or a 0.3 mm or larger crack develops at any point on the culvert.

The service life for thermoplastic pipe culverts (CPP-S and PPWP) is based upon the growth of circumferential cracking in the smooth waterway liner of the pipe wall

Concrete and metal culverts are subject to deterioration from corrosion, abrasion, or both. 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 bedload.

To assure that the maintenance free service life is achieved, metal pipe may require added thickness and/or protective coatings. Concrete pipe may require extra thickness of concrete cover over the steel reinforcement, high density concrete, and/or protective coatings.

It is the responsibility of the designer to verify that the chosen pipe material meets the assumed service life.

Actual Service Life of pipe culvert materials may be estimated using the figures in Section IV of the Culvert Guidelines

1. 100-year service life

No pipe material is assumed to meet the 100-year service life criteria. It is the designer's responsibility to consider the environmental conditions and demonstrate that the material is adequate and/or what additional protective measures should be implemented to provide an expected 100-year life.

2. 75-year service life

The following pipe materials are assumed to meet at least a 75-year service life.

- Reinforced Concrete, Class IV except where:
  - Chloride concentrations exceed 500 ppm,
  - Sulfate concentrations (as SO_4) exceed 150 ppm,
  - pH is below 4.5.
- Corrugated Polyethylene
- Polyvinyl Chloride Profile Wall

3. 50-year service life

The following pipe materials are assumed to meet at least a 50-year service life.

- Non-Asbestos Fiber-Cement

4. Other

- Corrugated Steel/ Spiral Rib/ Structural Steel Plate; actual service life to be computed using the charts in Appendix 1
- Corrugated Aluminum/ Aluminum Plate; actual service life to be computed using the charts in Appendix 1

Other pipe materials will be considered on a case-by-case basis subject to approval by Chief, Highway Hydraulics Division.

IV. Reference

A. Service Life Computation

- Service Life for corrugated steel pipe is dependant upon soil resisitivity and pH and may be estimated using the figures, tables, or formulae developed for the Florida Drainage Manual which are attached in Appendix 1.