Chapter 7 Drainage

The main factors to consider in roadway drainage design are traffic safety, potential for property damage from flooding, roadway functionality, environmental impacts, and maintenance. Bridges, box and pipe culvert crossings, channels, gutters, storm sewer systems and stormwater best management practices are some of the design elements used to collect, manage, remove water from the roadway and convey it across the right of way. The information in this chapter provides an overview of the most important aspects regarding drainage of transportation facilities.

7.1 Drainage Considerations for Strategic Transportation Corridors

Roadways that have been identified as Strategic Transportation Corridors (STC) may require more rigorous drainage design criteria than expected based solely on their functional classification, thus it is critical to coordinate with the hydraulics engineer when setting the initial roadway grade. The criteria for these STC may require larger drainage structures for larger design storm events, may affect the required minimum and maximum roadway vertical grade, may require extending the project limits, and may result in the need for additional right of way acquisition. Design for STC functional standards may also result in additional environmental impacts, an increased cost estimate, or a combination of any of these factors.

Refer to the *NCDOT Strategic Transportation Corridor* site for more information regarding STC classification and STC maps.

7.2 PDN Process and Drainage Design

Maintain ongoing communication with the hydraulics engineer throughout the different stages of the NCDOT PDN process, since roadway design changes may affect the hydraulic design, and vice versa.

7.2.1 Alignment Defined PDN Stage 2

Coordinate early in the process with the hydraulics engineer when establishing the horizontal and vertical roadway alignment. The hydraulics engineer will prepare the preliminary hydraulic recommendations which include any preliminary bridge or culvert reports, or a hydraulics memo stating whether the proposed roadway grade is hydraulically controlled. For instance, if the existing hydraulic structure is at or below the existing base flood elevation, raising the existing roadway grade may have significant effects on the existing base flood elevations upstream and cause flooding. A larger proposed hydraulic opening may mitigate for raising the grade, but this is not guaranteed. Getting to an acceptable roadway grade and proposed structure combination is an iterative process.

In addition, consider the type of permits and the agencies that will be involved with the project to include any additional time required for the permit application processes when developing the project schedule. Environmental permitting involving jurisdictional streams, wetlands and riparian buffers, Coastal Area Management Act (CAMA) permits, Federal Emergency Management Agency (FEMA) and North Carolina Floodplain Mapping Program (NCFMP) permitting are some of the permit applications that may take a significant amount of time for approval. For example, streams crossings not included in a FEMA study may only require approval from the NCDOT Hydraulics Unit. Whereas stream crossings included in a FEMA

study may need to be coordinated through NCDOT's Highway Floodplain Program and may also need approval from NCFMP or FEMA. These NCFMP/FEMA permit approvals may take 4 to 6 months and sometimes longer.

7.2.2 Plan-in-Hand PDN Stage 3

Discuss with the hydraulics engineer any revisions to the roadway design, since these may affect drainage design and environmental permit drawings. Coordinate with the erosion control designer regarding the anticipated location and size of erosion control basins since this information is crucial for the development of right of way plans which include permanent and temporary construction easements. At this time, the transportation management plan is being finalized and any on-site temporary detours, if present, will require appropriate temporary detour drainage and erosion control measures, and potential modifications to hydraulic structures. The environmental permit drawings commence once the hydraulic design is approved.

7.2.3 Plans, Specifications and Estimate PDN Stage 4

During Stage 4, any hydraulics and erosion control open tasks are finalized, and the permit drawings are secured. Maintain ongoing communication with the hydraulics engineer and erosion control designer and inform them of any changes in roadway design that may affect both disciplines and the environmental permit drawings.

7.3 Vertical Clearance and Other Grade Considerations

7.3.1 Cut Ditch Sections

In cut ditch sections, a roadway grade flatter than 0.3 percent may be used as long as the ditches have a ditch slope greater than 0.3 percent. Maintenance is more important on flat gradients on uncurbed pavements to prevent the build-up of vegetation or debris along the edge of pavement that could result in a spread ponding situation.

7.3.2 Curb and Gutter Sections

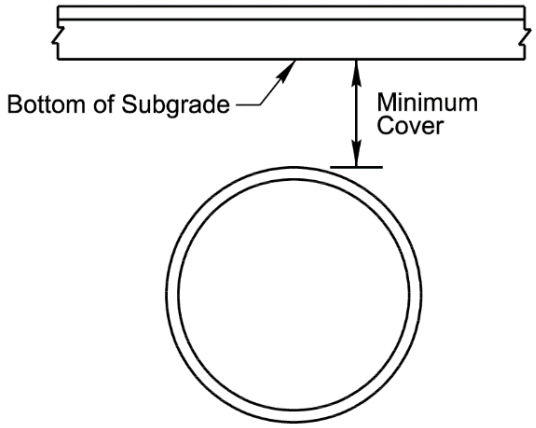
For curb and gutter sections (and along median barrier sections), maintain a minimum grade of 0.3 percent at the edge of pavement. Although not desirable, minimum grades for drainage can be maintained in very flat terrain by use of a rolling profile or by warping the cross slope to achieve rolling gutter profiles. Superelevation and widening transitions at roadway intersections can result in a gutter profile that is very different from the centerline profile, creating sumps or ponding areas along the gutter. Identify and eliminate these areas early on in coordination with the hydraulics engineer.

7.3.3 Vertical Clearance for Pipes

Refer to the *NCDOT Pipe Material Selection Guide* for vertical clearance information for most commonly used pipes. The hydraulics engineer will verify the required minimum and maximum fill heights for other less commonly used pipe sizes not listed in the guide, such as corrugated steel or aluminum pipe arches, structural plate steel pipes, elliptical and arched concrete pipes.

Refer to Figure 7-1 for illustration of minimum pipe cover.

Figure 7-1 Minimum Pipe Cover Requirements



7.3.4 Vertical Clearance for Box Culverts

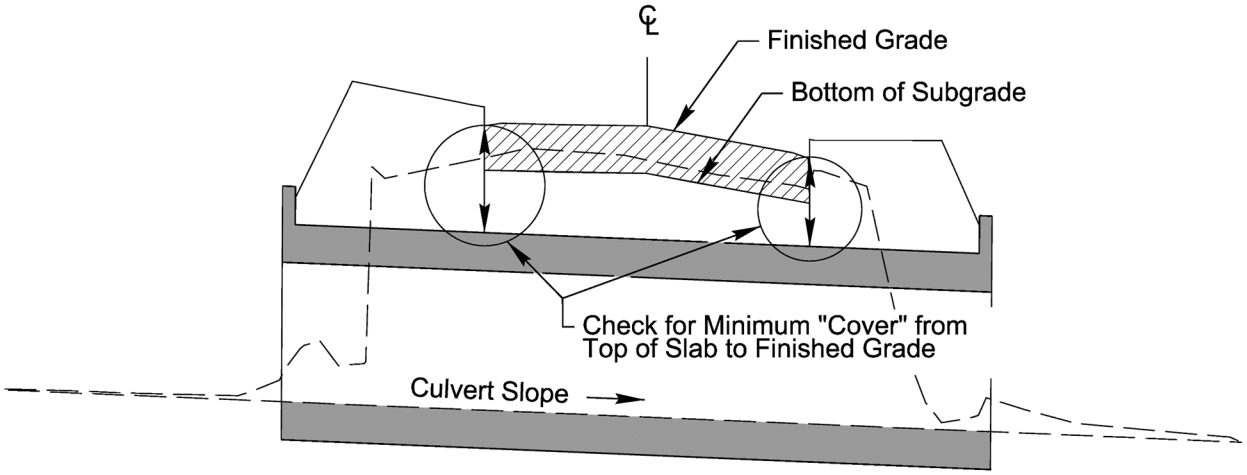
For NCDOT box culverts, the desired cover is 3 feet or more, measured from the top of the roof slab to the finished grade. For those instances when meeting the 3-foot cover criteria is not practical or cannot be met, provide as a minimum for full depth of pavement at all critical spots along the box culvert. Pay special attention to low spots on skewed pipe and box culverts.

Top slab thicknesses can vary, depending on the fill height. For example, under a given condition a 10-inch slab thickness may be needed whenever the cover is equal to 3 feet or more. However, design loads based on AASHTO typically increase as the depth of cover gets closer to 0 feet. The increased loading may result in an increased slab thickness, as thick as 18 inches in some cases. Increasing the slab thickness will further encroach upon the depth of cover as measured from the top of the roof slab to the finish grade.

Coordinate with both the structures and hydraulics engineers whenever low fill conditions may be encountered. A grade revision, alternate hydraulic structure, modified structural design, or a combination of all three options may be needed to find an appropriate solution. Also coordinate closely when temporary detours may limit vertical clearance requirements.

Refer to Figure 7-2 for illustration of minimum cover for boxes.

Figure 7-2 Minimum Box Culvert Cover Requirements

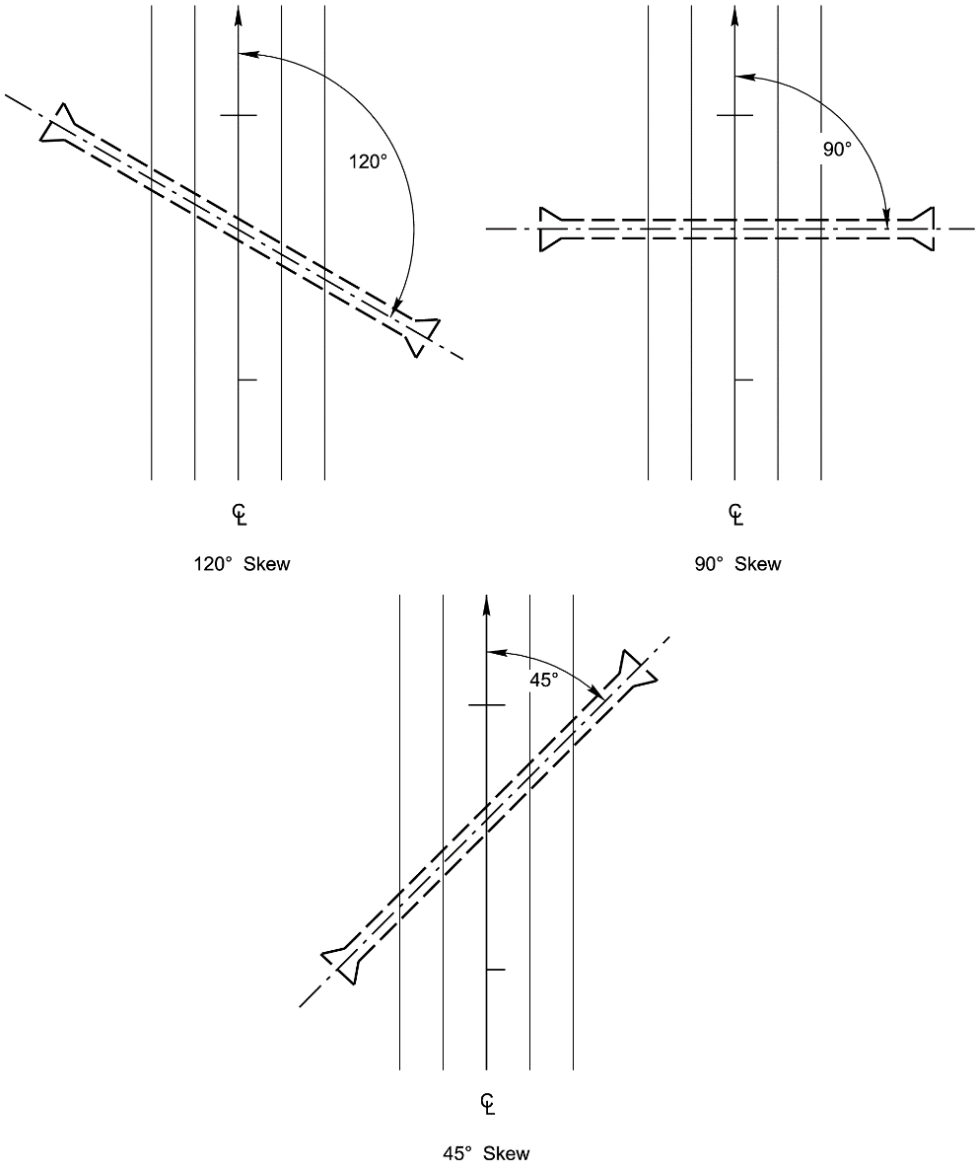


7.4 Skew Angle

The angle that a crossing pipe, bridge, box culvert, or other structure makes with the centerline of the roadway is measured in a clockwise direction from the centerline, line ahead. Refer to Figure 7-3 for illustration of skew angle designation.

- For box culverts and cross pipes, round to the nearest whole or half degrees preferably. Angle designation will vary as needed for hydraulics design and site restrictions.
- For bridges over streams, round to the nearest 5 degrees preferably.
- For cored slab or box beam bridges round to the nearest 15 degrees so that standard NCDOT bridge plans may be utilized.

Figure 7-3 Skew Angle Designations



7.5 Pipe End Treatment

Pipe ends within the clear zone are considered a hazard for motor vehicles without an appropriate end treatment approach. The criteria to be used depends on the facility type and the design speed. Coordinate with the hydraulics engineer to discuss the pipe end treatment approach to be used for each road in the project.

Verify the pipe end treatments used are appropriate for the project after the hydraulics design is complete. Discuss with the hydraulics engineer any specific locations where a clear zone guardrail warrant can be eliminated by lengthening of pipes/culverts.

Refer to *NCDOT Roadway Standard Drawings* Std. Nos. 310.02, 310.03, 310.04, and 310.05 for parallel pipe and cross pipe end sections. Also refer to RDM Part I Chapter 4 Section 4.6.1.

These guidelines apply to new construction and major reconstruction projects on Interstate, US, and NC routes. They do not apply to resurfacing or secondary roads (SR). Pipe end treatment on those type of projects (including private pipe installation) will be the same as existing pipes unless accident history warrants special consideration.

Providing a clear roadside recovery area is desirable in all locations, but the design will be more compatible on projects with minimum access points. (For example, partial control of access projects or projects on new locations.) The RDG also provides guidance, but many of the recommended treatments are not typically used by NCDOT.

Sections 7.5.1 and 7.5.2 below apply to projects on the primary system and do not apply to those projects on the secondary road system. Recommendations are listed in order of preference; use the first recommendation under each heading if practical. Use engineering judgement to determine if a different but more appropriate treatment is necessary.

7.5.1 Pipe End Treatment for Cross Pipes

Refer to *NCDOT Roadway Standard Drawings*, Std. Nos. 310.03 and 310.05.

7.5.1.1 Cross Pipes Outside the Clear Zone

- For pipes 36 inches in diameter and greater, use endwall on inlet end unless the hydraulics engineer specifies otherwise. Equalizer pipes in wetlands and outside the clear zone area do not require headwalls.
- Pipes 30 inches in diameter and smaller do not require headwalls on either end unless the hydraulic engineer specifies otherwise.

7.5.1.2 Cross Pipes Inside the Clear Zone

- For pipes 36 inches in diameter and greater, extend pipe beyond the clear zone recovery area when feasible and use endwall on inlet end unless hydraulics engineer specifies otherwise. Consider any impacts to jurisdictional areas when extending pipes beyond clear zone. Any additional backfill material necessary to extend this pipe is covered under Section 300 of the *NCDOT Standard Specifications for Roads and Structures*.

  If extending the pipe beyond the clear zone recovery area is not feasible, use guardrail with endwall on the inlet end. Protect with guardrail on the outlet end.

- For pipes 30 inches in diameter and smaller, extend pipe beyond the clear zone recovery area when feasible. If extending the pipe beyond the clear zone recovery area is not feasible, use a cross pipe end section with a 4:1 slope.

7.5.2 Pipe End Treatment for Parallel Pipes

Refer to *NCDOT Roadway Standard Drawings* Std. Nos. 310.02 and 310.04.

7.5.2.1 Parallel Pipes at Median Crossovers

- Use a grated drop inlet with 10:1 or flatter slopes.
- Use pipes 30 inches in diameter and smaller with parallel pipe end sections, and 6:1 slopes at existing locations without sufficient depth for a drainage structure.

7.5.2.2 Parallel Pipes at Grade Intersections

Multilane roadways with design speed greater than 50 mph

Recommendations are listed in order of preference.

- Place all pipes beyond the clear zone and use an endwall on the inlet end of pipes 36 inches in diameter and greater accordingly unless the hydraulics engineer specifies otherwise. Transition the roadway ditch accordingly.
- When placing pipes beyond the clear zone is not feasible, use a grated drop inlet with 6:1 or flatter slopes on the approach ends where practical and where existing or proposed drainage systems are available. Trailing ends do not require special treatment other than endwalls on the inlet end of pipes 36 inches in diameter and greater unless the hydraulics engineer specifies otherwise.
- When using a grated drop inlet on the approach ends is not feasible, then use a parallel pipe end section with 6:1 slope for pipes 24 inches in diameter and smaller and use guardrail for pipes 30 inches in diameter or greater. Trailing ends do not require special treatment other than endwalls on the inlet end of pipes 36 inches in diameter and greater unless the hydraulics engineer specifies otherwise.

Multilane roadways with design speed less than 50 mph and all two-lane roadways

Multilane roadways with design speed less than 50 mph and all two-lane roadways do not require special end treatment other than the use of an endwall on the inlet end for pipes 36 inches in diameter and greater unless hydraulics engineer specifies otherwise.

7.5.2.3 Driveways

Where feasible, locate the driveway pipe outside the clear roadside recovery area and transition the roadway ditch accordingly. Refer to Figure 7-4 for illustration of pipe location and clear roadside recovery area.

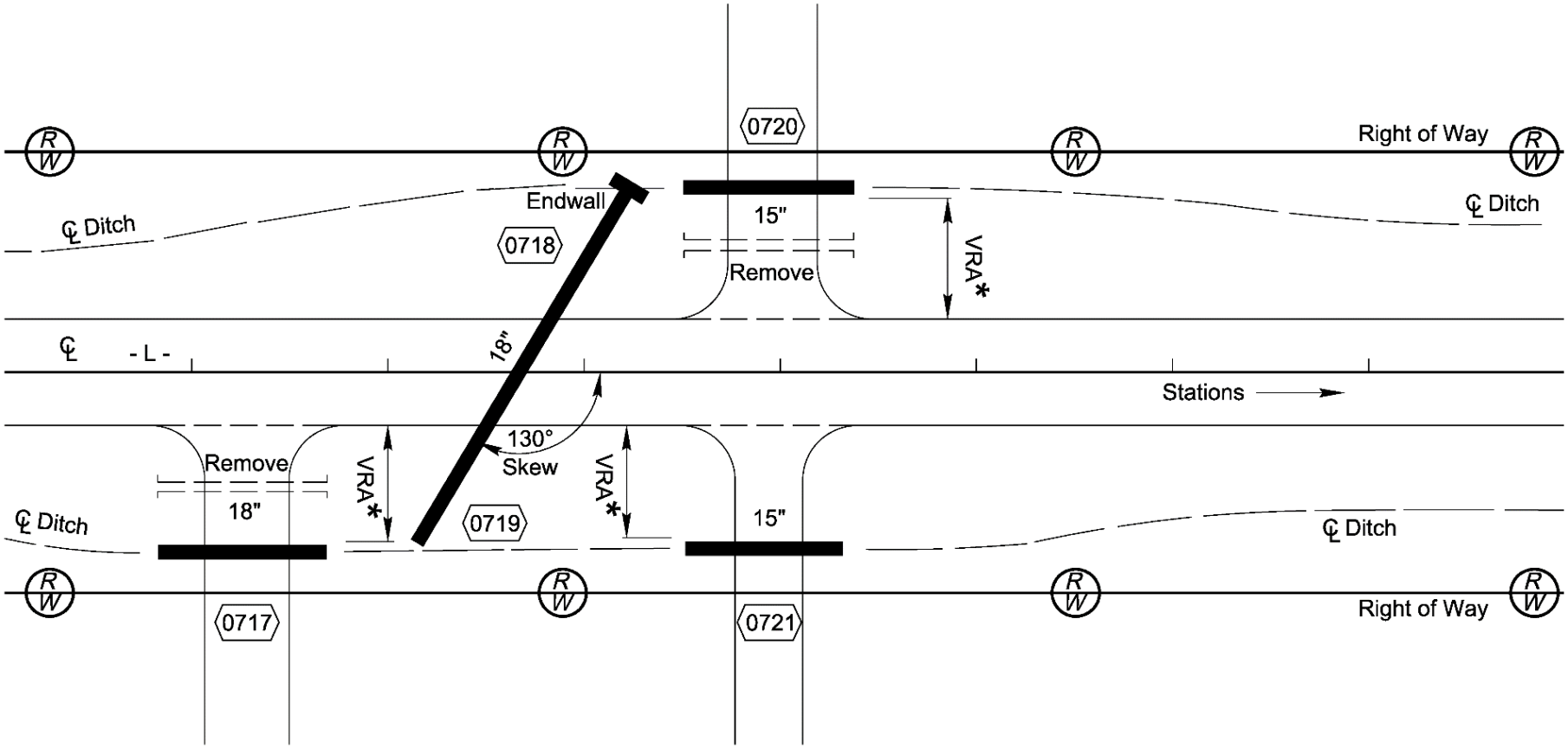
7.5.3 Endwalls

Construct the endwalls perpendicular to the centerline of the pipe unless specific site conditions warrant construction of an endwall parallel to the roadway. Coordinate with Hydraulics Unit for approval. Extend the pipe to allow the end of the endwall to tie into the toe of the fill.

Refer to Figure 7-5 for illustration of typical endwall treatment. Additional backfill material necessary to extend this pipe is covered under Section 300 of the *NCDOT Standard Specifications for Roads and Structures*.

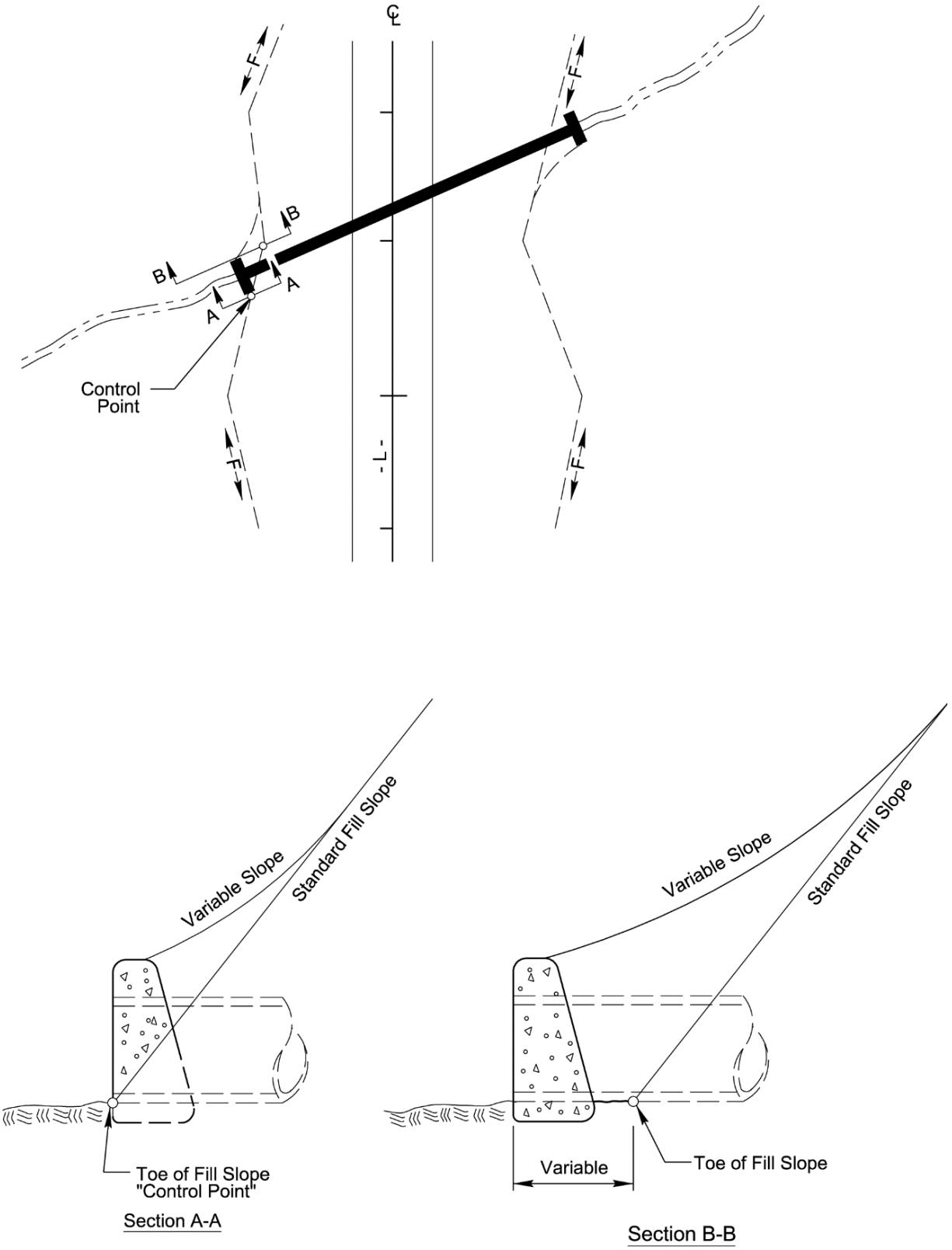
The quantities for the endwalls constructed perpendicular to the centerline of the pipe are based on a 90-degree skew rather than the skew of the pipe. On multiple pipe installations, provide additional pipe length such that a line projected along the face of the endwall is perpendicular to the centerline of pipes.

Figure 7-4 Clear Roadside Recovery Area for Access Roads



Note: VRA = Vehicle Recovery Area. Refer to RDM Part I Chapter 4 Section 4.6 for the definition of Vehicle Recovery Area.

Figure 7-5 Example of Endwall Treatment



7.6 Drainage and Gutter Guidelines

There are times when the need for a gutter section is solely due to drainage or erosion control requirements. For instance, use shoulder berms, gutters and curbing on the outside edge of fill shoulders as recommended by the hydraulics engineer to minimize the shoulder and slope erosion resulting from sheet flow off the pavement.

7.6.1 Addressing Erosion on Existing Facilities

Coordinate with the hydraulics engineer and the geotechnical engineer to define the proper solution based on individual site conditions. When erosion at the curb on existing installations causes undermining of the curb and erosion of fill slopes, try the following:

- On existing facilities with 2-foot or 4-foot paved shoulders, remove the curb and stabilize the shoulder and slope.
- On 10-foot paved shoulder facilities, extend the paved shoulder to abut the curb.

7.6.2 Proposed Construction

Coordinate with the Division and hydraulics engineers regarding gutter placement when developing the typical sections for the project. Address the shoulder treatment during the preliminary field inspection and discuss water quality issues that may arise at that time.

Refer to *NCDOT Design Resources* page on the Connect NCDOT website for the most current listing of the Field Inspection Questions document.

7.6.2.1 Shoulder Berm Gutter

Shoulder berm gutter is used in conjunction with guardrail, with the face of the rail directly above the flow line. Typically, diffuse flow is accomplished when surface water is allowed to flow across the shoulders and down the fill slope. However, simple grass cover cannot always prevent erosion of the embankment slopes and in those cases, it may be necessary to add shoulder berm gutter. The following conditions may warrant use of shoulder berm gutter:

- Presence of easily erodible soils or soils not conducive to vegetative growth along the shoulder and the embankment.
- Roadside development which might require stricter control of runoff.
- Potential for large runoff flow and velocity due to/or in combination with any of the following factors:
  - Pavement width (including paved shoulder) is 36 feet or greater flowing in one direction.
  - High embankments (over 20 feet) in combination with pavement width warrant.
  - Superelevated sections. Place shoulder berm gutter on the low side of superelevation.
  - Steep roadway grade in combination with pavement width warrant.

The hydraulics engineer will evaluate and indicate any other areas that may require shoulder berm gutter.

7.6.2.2 Expressway Gutter

Use expressway gutter when positive control of sheet flow is needed, and guardrail is not warranted. Expressway gutter is also used in cut sections where the right of way is not wide enough to accommodate the typical section. Expressway gutter used in combination with guardrail requires NCDOT Hydraulics and Roadway Units approval.

Refer to *NCDOT Roadway Standard Drawings* Std. No. 846.01.

7.6.2.3 Median Curbs

Coordinate early in the process with the hydraulics engineer since the recommended curb used will affect the typical section. The hydraulics engineer will make a recommendation based on the spread requirements for the facility. Several curb types are available depending on the type of facility and design speed.

Refer to *NCDOT Roadway Standard Drawings*, Std. No. 846.01.

- 1-foot 6-inch curb and gutter is used along the edge of a raised median divided section, which could be either grass or concrete. The 1-foot 6-inch curb is a mountable curb allowing emergency or service vehicles to navigate the median safely without the redirecting properties of a vertical or sloping curb such as 2-foot 6-inch curb and gutter.
- 2-foot 9-inch curb and gutter is often used on the low side of a fully superelevated section or along curves of greater lengths. In these cases, hydraulic spread begins to be an issue and the extended gutter width of 2 feet will provide adequate space to contain spread, keeping it further outside of the travel way. If determined by the hydraulics unit that 2-foot 9-inch curb and gutter should be used, obtain a special detail from NCDOT, as there is not currently a standard for it.

7.6.2.4 Curb and Gutter

A 2-foot 6-inch curb and gutter is a sloping curb used in urban and semi-urban environments to address issues such as access control, complex terrain, and limited right of way. The 2-foot 6-inch curb and gutter is used to collect surface runoff from paved streets, parking lots, or other impervious surfaces and convey it to a storm drain system. The 2-foot 6-inch curb and gutter is also used in interchanges at the edge of shoulder on the inside of the curve.

7.7 Hydroplaning

Hydroplaning occurs when a vehicle loses traction due to a layer of water that builds up between a vehicle's tires and the roadway, preventing constant contact between the tires and the road surface. This situation may lead to vehicle skidding.

There are mitigating strategies to reduce the potential for hydroplaning. These strategies need to be coordinated with the NCDOT Hydraulics Unit and involve an iterative and ongoing collaboration. Some strategies may also require coordination with the Division, and Pavement Design, and Materials and Tests Units.

The NCDOT Hydraulic Design Unit is currently developing hydroplaning guidance specific to North Carolina roadways. Portions of the guidance will be included in the Roadway Design Manual when they become available.

Refer to *NCDOT Guidelines for Drainage Studies* for information on the current hydroplaning assessment. Refer to GB Chapter 3 Section 3.3.2.1 and Chapter 4 Section 4.2.4 for additional detailed information.

7.8 Paved Ditches

When paved ditches are necessary, they will be included in the drainage recommendations made by the Hydraulics Unit. Discuss the need for paved ditches during the field inspection.

Refer to *NCDOT Roadway Standard Drawings* Std. No. 850.01 and section 7.9 below.

7.9 Rip Rap for Drainage Ditches

Rip rap for drainage ditches is normally proposed by the Hydraulics Unit where significant water flows are anticipated. Rip rap used to line ditches is typically either Class A, Class B or Class I. Class II rip rap is typically reserved for usage along stream channels.

7.9.1 Class A Rip Rap

Class A rip rap is usually recommended within the clear roadside recovery area and is measured by the ton. See Roadway Standard Drawings, Std. No. 876.03 for typical placement of Class A rip rap.

7.9.2 Class B, Class I and Class II Rip Rap

Class B, Class I and Class II rip rap are usually recommended outside the clear roadside recovery area. Class B rip rap will be measured by the ton. Measurement in the form of square yards by means of a special provision is permitted if requested by the Division. See Roadway Standard Drawings, Std. No. 876.04 for typical placement of Class B rip rap. See Roadway Standard Drawings, Std. No. 876.01 for typical placement of Class I and Class II rip rap.

7.10 Rip Rap at Pipe Outlets

Place rip rap at pipe outlets as recommended by the Hydraulics Unit. Rip rap will be measured by the ton. Measurement in the form of square yards by means of a special provision is permitted if requested by the Division.

Refer to *NCDOT Roadway Standard Drawings* Std. No. 876.02 for typical placement of rip rap at pipe outlets.

7.11 Geotextile Fabric for Drainage Ditches and Pipe Outlets

Use geotextile fabric in conjunction with rip rap Class B, Class I and Class II unless the Hydraulics Unit specifies otherwise.

Refer to *NCDOT Roadway Standard Drawings* Std. Nos. 876.01 and 876.04 for placement of geotextile fabric in drainage ditches.

Refer to *NCDOT Roadway Standard Drawings* Std. No. 876.02 for placement and quantities of geotextile fabric at outlet pipes.

Do not use geotextile fabric with Class A rip rap unless specifically directed by the Hydraulics Unit.

7.12 Special Ditches

The Hydraulics Unit recommends specially designed ditches to accommodate drainage. These ditches are shown on plans, cross sections, and special details. Show the location, description,

and estimated quantity of drainage ditch excavation for all these ditches on the plan sheets or in a summary table.

7.13 Berm Ditches

The Hydraulics Unit recommends berm ditches; however, it is the responsibility of the roadway designer to check each project and determine if berm ditches should be constructed. Recommend berm ditches where the cut slopes are 10 feet high or greater and 100 feet or more of natural ground at the top of the cut slopes (measured perpendicular to the roadway) drain towards the project. Verify adequate right of way and easements at berm ditch locations. Show berm ditches on plan, profile, and cross section sheets.

Refer to *NCDOT Roadway Standard Drawings* Std. No. 240.01 for berm ditch construction.

Refer to *NCDOT Roadway Standard Drawings* Std. No. 850.10 and 850.11 for berm drainage outlets.