APPENDIX A
PAVEMENT DRAINAGE

1.0 Introduction

The objective of an effective drainage design is to provide for safe passage of vehicles by reducing:

- damage to surrounding or adjacent property, resulting from water overflowing the roadway curbs and entering such property,
- risk and delay to traffic caused by excessive ponding in sags or excessive spread along the roadway,
- weakening of base and subgrade due to saturation from frequent ponding of long duration, and
- the potential for hydroplaning.

Pavement drainage design is greatly influenced by the roadway geometric design features and guidelines for effective removal of water from roadway surfaces are presented in the following sections.

2.0 Hydroplaning

To provide appropriate drainage of highway pavement requires the designer to evaluate the factors that influence the depth of water on pavement. These factors include length of flow path, surface texture, surface slope and rainfall intensity. If water is allowed to reach undesirable depths, the driver could experience what is known as vehicular hydroplaning.

Hydroplaning occurs when the drainage capacity of the tire tread pattern and the pavement surface is exceeded and the water begins to build up in front of the tire. As the water builds up, a water wedge is created and this wedge produces a hydrodynamic force which can lift the tire off the pavement surface. This is considered as full dynamic hydroplaning and, since water offers little shear resistance, the tire loses its tractive ability and the driver has a loss of control of the vehicle.

Designers do not have control over all of the factors involved in hydroplaning. However, many remedial measures can be included in development of a project to reduce hydroplaning potential. The following is provided as guidance for the designer as practical measures to consider:

Pavement Sheet Flow

- maximize cross slope (Section 4 - Appendix A)
- maximize pavement roughness
- limit draining of multi-lane highways to no more than three lanes in one direction.

Gutter Flow

- limit width of flow spread on highway (reference Appendix D)
- maximize interception of gutter flow above superelevation transitions.
- limit concentrations of sheet flow to no more than 0.1 cubic feet per second. Particular attention should be given to reversal points of superelevation where shoulder and gutter slopes may direct flow across the roadway and gore areas.

Sag Areas

- limit pond duration and depth
- minimize length of sag vertical curve (Section 3 – Appendix A)

Overtopping

- limit depth and duration of overtopping flow

In the event that suitable measures cannot be implemented to address an area of high potential for hydroplaning, or an identified existing problem area, consideration should be given to installing advance warning signs.

3.0 Longitudinal Slope

Longitudinal slope is a roadway feature considered during gutter, inlet, and pavement drainage calculations. The following general guidelines are presented:

1. A minimum longitudinal gradient is more important for a curbed pavement than for an uncurbed pavement since the water is constrained by the curb. However, flat gradients on uncurbed pavements can lead to a spread problem if vegetation or other debris is allowed to build up along the pavement edge.

2. Desirable gutter grades should not be less than 0.5 percent for curbed pavements with an absolute minimum of 0.3 percent. Minimum grades can be maintained in very flat terrain by use of a rolling profile, or by warping the cross slope to achieve rolling gutter profiles.

3. To provide adequate drainage in sag vertical curves, a minimum slope of 0.3 percent should be maintained within 50 feet of the low point of the curve. This is accomplished where the length of the curve in feet divided by the algebraic difference in grades in percent (K) is equal to or greater than 167. This is represented as:

$$K = \frac{L}{(G_2 - G_1)} \qquad \text{(Equation 1)}$$

Where:

K = vertical curve constant in feet per percent
L = horizontal length of curve in feet
G_i = grade of roadway in percent

Superelevation and/or widening transitions can create a gutter profile far different from the centerline profile. The designer must carefully examine the geometric profile early in the design of the gutter to eliminate the formation of sumps or “ponds” created by these transitions. These areas should be identified and eliminated.

4.0 Cross Slope

The design of pavement cross slope is often a compromise between the need for reasonably steep cross slopes for drainage and relatively flat cross slopes for driver comfort. It has been widely published that a cross slope of 2 percent has little effect on driver effort in steering or on friction demand for vehicle stability. It is not desirable to use a cross slope steeper than 2 percent on pavements with a central crown line. A steeper cross slope (2.5 percent) may be used to facilitate drainage in areas of intense rainfall.

On multi-lane highways where three (3) lanes or more are sloped in the same direction, it is desirable to counter the resulting increase in flow depth by increasing the cross slope of the outermost lanes. The two (2) lanes adjacent to the crown line should be pitched at 2 percent, and successive lane pairs, or portions thereof outward, should be increased to 2.5 percent.

Additional guidelines related to cross slope are:

1. Although not widely encouraged, inside lanes can be sloped toward the median if conditions warrant.

2. Median areas should not be drained across travel lanes.

3. The number and length of flat pavement sections in cross slope transition areas should be minimized. Consideration should be given to increasing cross slopes in sag vertical curves, crest vertical curves, and in sections of flat longitudinal grades.

4. Shoulders should be sloped to drain away from the pavement, except with raised, narrow medians and superelevations.

5.0 Curb and Gutter

Curbs are normally used at the outside edge of pavements for low-speed, highway facilities, and in some instances adjacent to shoulders on moderate to high-speed facilities. They serve the following purposes:

- contain the surface runoff within the roadway and away from adjacent properties,
- prevent erosion on fill slopes,
- provide pavement delineation, and
- enable the orderly development of property adjacent to the roadway.

The designer is referred to **Chapter 8** for additional information on ODOT curb types and dimensions.

A pavement gutter is defined as the section of pavement next to the curb which conveys water during a storm runoff event. Gutter cross-sections usually have a triangular shape with the curb forming the near vertical leg of the triangle. The gutter may have a straight cross slope or a composite cross slope where the gutter slope varies from the pavement cross slope. Shallow swale gutters typically have V-shaped or circular sections and are often used in paved median areas or roadways with inverted crowns. The designer is referred to **Chapter 8** for additional information on ODOT gutter types and dimensions.

A curb and gutter combination forms a triangular channel that can convey runoff equal to or less than the design flow without interruption of the traffic. When a design flow occurs, there is a spread or widening of the conveyed water surface. The water spreads to include not only the gutter width, but also parking lanes or shoulders, and portions of the traveled surface. The distance of the spread (T) is measured perpendicular to the curb face to the extent of the water on the roadway.

Limiting spread to gutters and shoulder widths on highways is essential to the service level and traffic safety. The designer is referred to Appendix B for additional discussion and guidelines.

Effective drainage of highway pavement is essential to the service level and traffic safety. To provide these conditions requires the evaluation of stormwater spread on pavement surfaces. Stormwater spread should be considered early in the design while the roadway geometry is being developed because changes to roadway or structure geometrics are less problematic early in the design phase. Spread is dependent on the selected recurrence interval and roadway geometry as presented in Appendices B, C, and D.

Where practical, runoff from cut slopes and other areas draining toward the roadway should be intercepted before it reaches the highway. By doing so, the deposition of sediment and other debris on the roadway as well as the amount of water which must be carried in the gutter section will be minimized. Where curbs are not needed for traffic control, shallow ditch sections at the edge of the roadway pavement or shoulder offer advantages over curbed sections by providing less of a hazard to traffic than a near-vertical curb and by providing hydraulic capacity that is not dependent on spread on the pavement. These ditch sections are particularly appropriate where curbs have historically been used to prevent water from eroding fill slopes.

6.0 Roadside and Median Channels

Roadside channels would typically be used with uncurbed roadway sections to collect and convey highway pavement runoff. They also would be used to intercept runoff from areas that drain toward the highway. Within urbanized areas, roadside channels would only be effectively used in cut sections, depressed sections, and locations with adequate right-of-way.

It is preferable to slope median areas and inside shoulders to a median channel to prevent drainage from the median area from running across the pavement. This is recommended for high-speed facilities, and for facilities with more than two lanes of traffic in each direction.

Roadside and median channels should be designed to convey the predicted peak flow. They should be located and shaped in a manner that does not present a traffic hazard. All channels should have a vegetative lining where permitted by the design velocities. When vegetative linings could not control erosion, the designer is referred to **Chapter 8** for additional discussion on stability of channel linings.

7.0 Bridge Decks

The main requirement of the drainage system on a bridge deck is that it removes rainfall-generated runoff from the bridge deck before it collects and spreads in the gutter to encroach onto the travel roadway to the limit of a design spread as described in Appendix D. In accomplishing this purpose, the drainage system must meet other design criteria, as presented below.

7.1 Differences with Pavement Components

While drainage of bridge decks is accomplished in the same manner as drainage of other curbed roadway sections, bridge decks are often less efficient, because cross slopes are flatter, parapets collect large amounts of debris, and small drainage inlets or scuppers have a higher potential for clogging by debris. Bridge inlets collect flow into relatively small ductile-iron or welded-steel chambers. By contrast, pavement systems have pre-cast, cast-in-place, or masonry structures that are much larger. Such weight and size is incompatible with bridge structures. Bridge drains are typically steel tubes that must withstand vibrations and deflections better than the storm drains associated with pavement drainage.

7.2 Deck, Gutters, and Grades

Bridge deck drainage should be evaluated early in project development and designed to take into consideration:

- Avoid zero gradients, sag vertical curves and superelevation transitions with flat pavement sections on bridges.
- The minimum longitudinal slope for a bridge deck should be 0.5 percent or the designer should design gutter grades with high points that create acceptable longitudinal slopes between inlets.
- Spread on bridge decks should be evaluated to determine if deck inlets are required. Bridge deck inlets would not be required when adequate cross slope, longitudinal slope, and shoulder width is available to meet spread guidelines noted in Appendix D.

7.3 Structural Considerations

The two main structural considerations in drainage system design on bridge decks are:

1. inlet sizing and placement must be compatible with the structural reinforcement and components of a bridge; and

2. the drainage system should be designed to deter flow (and associated corrosives) from contacting vulnerable structural members or eroding embankments.

Structural and hydraulic designers should work together to design a system that has the necessary hydraulic capacity and is compatible with structural elements. To avoid corrosion and erosion, the design must:

- Include proper placement of outfalls,
- prevention of flow from splashing or being blown back onto support members
- provide protection from erosive velocities
- Prevent water from running down a crack at the paving notch joint, between pavement and bridge, and undermining an abutment or wingwall.

7.4 Maintenance Considerations

Maintenance requirements must be considered in the system design because the drainage system will not function properly if it becomes clogged with debris. In particular, the design should avoid the following common maintenance problems:

- Clogging on inlets or outlet pipes because of flat grades, points where debris is trapped, poor location, or lack of self-cleansing velocities at low-flow conditions.
- Lack of room for maintenance on the bridge deck and access beneath the bridge.
- Unsafe working areas for maintenance personnel that could result in infrequent maintenance.
- No provisions for cleanouts of the outlet pipe system or poorly placed cleanouts.

7.5 Inlet Locations

Gutter flow from roadways should be intercepted before it reaches a bridge because of the difficulties in providing and maintaining adequate deck drainage systems. If bridge deck inlets are required, they should be spaced according to procedures described in Appendix D.

Scuppers are another method of deck drainage. Scuppers have a low initial cost and are relatively easy to maintain. However, the use of scuppers should be evaluated for site-specific concerns. Scuppers should not be located over:

- embankments
- slope pavement
- slope protection
- aquatic habitat
- driving lanes or
- railroad tracks.

Runoff collected and transported to the end of the bridge should generally be collected by inlets and down drains although sod flumes may be used for extremely minor flows in some areas. Inlets located on the downslope bridge end should be sized assuming inlets on the bridge are clogged.

Note: Bridge runoff should also be handled in compliance with applicable storm water quality regulations.

8.0 Median/Median Barriers

Medians are commonly used to separate opposing lanes of traffic on divided highways. It is preferable to slope median areas and inside shoulders to a center depression to prevent drainage from the median area from running across the traveled pavement. Where median barriers are used and, particularly on horizontal curves with associated super-elevations, it is necessary to provide inlets and connecting storm drains to collect the water which accumulates against the barrier. Slotted drains adjacent to the median barrier and in some cases scuppers in the barrier can also be used for this purpose.

9.0 Impact Attenuators

The location of impact attenuator systems should be reviewed to determine the need for drainage structures in these areas. With impact attenuator systems such as G.R.E.A.T. or C.A.T. systems, it is necessary to have a clear or unobstructed opening as traffic approaches the point of impact to allow a vehicle to impact the system head on. If the impact attenuator is placed in an area where superelevation or other grade separation occurs, grate inlets and/or slotted drains may need to be placed to prevent water from running through the clear opening and crossing the highway lanes or ramp lanes. Curb, curb-type structures or swales cannot be used to direct water across this clear opening as vehicle vaulting could occur when the impact attenuator system is utilized.

10.0 Pavement Texture

The pavement texture is an important consideration for roadway surface drainage. Although the hydraulic designer will have little control over the selection of the pavement type or its texture, it is important to know that pavement texture does have an impact on the buildup of water depth on the pavement during rain storms. A good macrotexture provides a channel for water to escape from the tire-pavement interface and thus reduces the potential for hydroplaning.

A high level of macrotexture may be achieved by tinning new portland cement concrete pavements while it is still in the plastic state. Re-texturing of an existing portland cement concrete surface can be accomplished through pavement grooving and cold milling. Both longitudinal and transverse grooving is very effective in achieving macrotexture in concrete pavement. Transverse grooving aids in surface runoff resulting in less wet pavement time. Combinations of longitudinal and transverse grooving provide the most adequate drainage for high speed conditions.