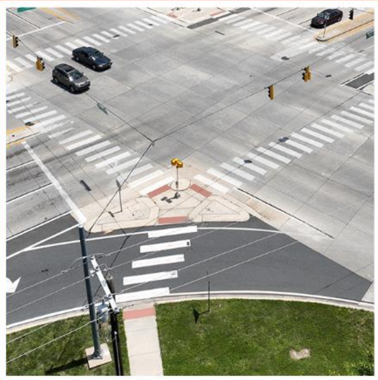
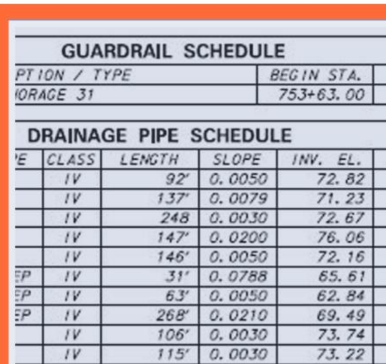


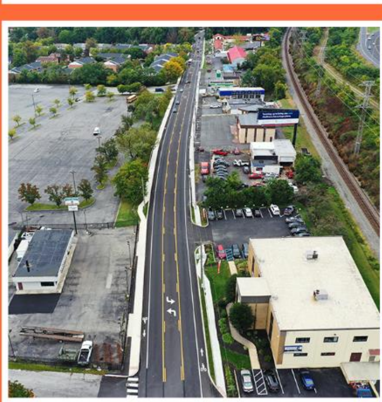

Delaware Department of Transportation

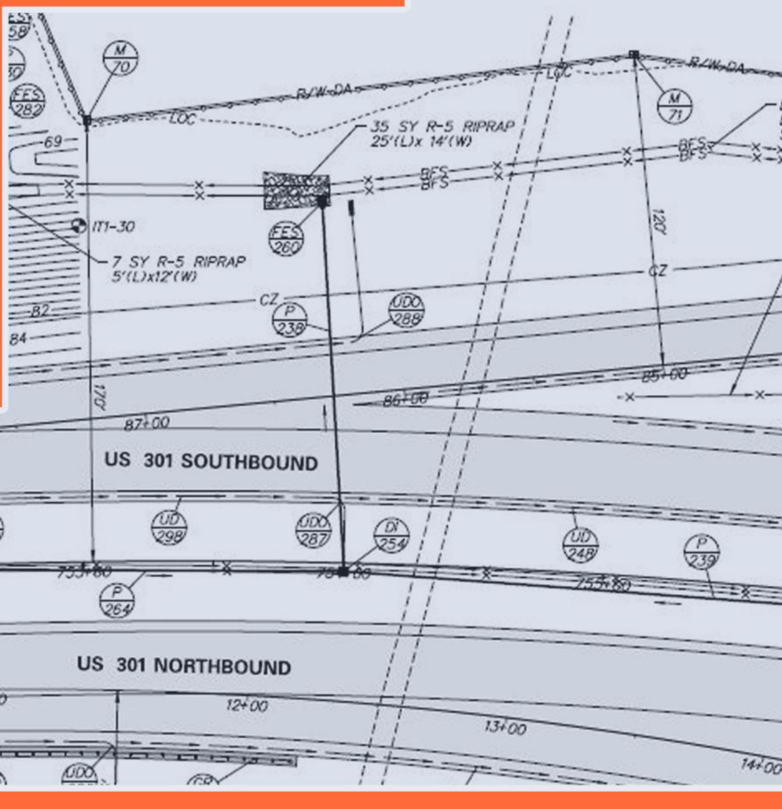
ROAD DESIGN MANUAL

2022 Edition





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ROAD DESIGN MANUAL
2022 EDITION

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PREFACE

The intent of this updated version of the Delaware Department of Transportation's (DelDOT) Road Design Manual (RDM) is to adopt the American Association of State Highway Transportation Officials 2018 7th edition of A Policy on Geometric Design of Highways and Streets (AASHTO Green Book), and other industry recognized resource documents, to provide the design controls, criteria, and elements to be used on all DelDOT transportation projects. Additionally, certain DelDOT specific design criteria and guidance are presented in this updated version of the RDM. This version of the RDM specifies whether a user should refer to other resource documents or utilize DelDOT specific design criteria and guidance for application on DelDOT transportation projects. This version also eliminates all references to DelDOT process related material and guidance that appeared previously, resulting in a much shorter version than the previous RDM.

The previous version of the RDM has been archived and is available on the DelDOT Road Design Manual Website. It is intended that the archived RDM, in conjunction with the DelDOT Project Development Manual, the DelDOT RDM Website, the DelDOT Design Resource Center, and DelDOT Design Guidance Memoranda be used as resources to provide guidance on many DelDOT design processes and practices. As industry design practices advance and new documents are published or updated and adopted as industry best practice, these documents will be evaluated for inclusion as applicable design controls, criteria, and elements for DelDOT transportation projects and the RDM will be revised accordingly.

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1 Road Design Manual Introduction

1.1 Purpose

The Delaware Department of Transportation (DelDOT) has developed the Road Design Manual (RDM) to provide guidance and assistance in the standard practice of design of roadway features in the state of Delaware. The RDM adopts industry recognized design criteria or prescribes Delaware specific criteria for design of roadway features. Additionally, the RDM provides a general discussion of the relationship between design controls and design criteria to provide context for various design elements.

1.2 State and Federal Laws and Regulations

Title 17 of Delaware Code grants to DelDOT the absolute care, management, and control of all public roads and highways in the State of Delaware, excluding a small number of roads in incorporated municipalities.

As a very low-lying state, roadway flooding is of significant concern when planning, designing, constructing, and maintaining our infrastructure. In accordance with Delaware's Climate Action Plan, the Department should consider the effects of sea level rise when designing projects. In addition, as weather patterns are changing, overall resiliency and sustainability considerations and options should be taken into consideration. Designers should take into consideration the purpose, need, scope, and impacts of each project to determine what, if any, measures may be taken as part of the project.

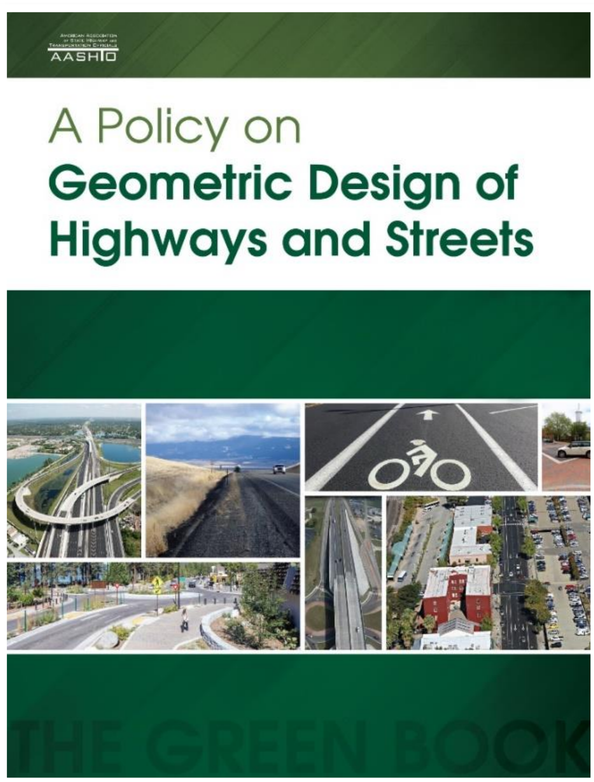
Title 23 Section 109 of the U.S. Code is the Federal Law that requires that the plans and specifications for proposed highway projects under Title 23 provide for a facility that will adequately serve the existing and planned future traffic of the highway in a manner that is conducive to safety, durability, and economy of maintenance; accounting for the constructed and natural environment of the area, the environmental, scenic aesthetic, historic, community, and preservation impacts of the activity; and access for other modes of transportation.

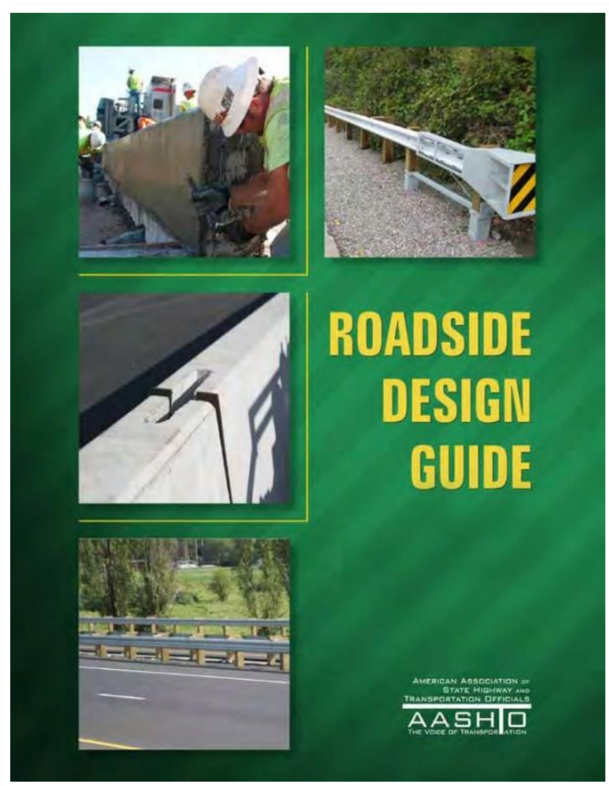
Title 23 Highways of the Code of Federal Regulations (23 CFR) and, more specifically, 23 CFR Part 625-Design Standards for Highways (23 CFR Part 625) grants the authority to the Federal Highway Administration (FHWA), in cooperation with State transportation departments, to develop criteria to implement design for the National Highway System (NHS). For specifics regarding FHWA's role in transportation projects in Delaware, reference is made to the most current *Stewardship and Oversight Agreement on Project Assumption and Program Oversight* between FHWA, Delaware Division and DelDOT.

1.3 Primary Source for Design Criteria and Design Elements

The American Association of State Highway and Transportation Officials (AASHTO) is the recognized authority on highway design policies and criteria. Except for certain DelDOT specific design criteria and guidance presented in subsequent chapters of this manual, the AASHTO Green Book is adopted and recognized as the source for design criteria and design elements used for all DelDOT transportation projects. All DelDOT specific design criteria and guidance appearing in subsequent chapters of this manual are presented in **bold text**.

Many sections of the RDM provide references to guidance material located in the AASHTO Green Book and the AASHTO Roadside Design Guide (AASHTO RDG). The references may only represent areas of the AASHTO Green Book and the AASHTO RDG where guidance material is introduced. Users should investigate all sections of the AASHTO Green Book and the AASHTO RDG to ensure guidance material is relevant for the type of project being designed.





1.4 Additional Reference Documents

In addition to the AASHTO Green Book, this manual relies on many other federal and state resource documents and manuals that expand upon the information in the AASHTO Green Book when determining design criteria and design elements for use on DelDOT transportation projects. All DelDOT authored documents referenced here are the latest edition. These reference documents appear in *italics* in subsequent chapters of this manual and include but are not limited to:

- AASHTO Roadside Design Guide 2011 4th Edition (AASHTO RDG)
- AASHTO Policy on Geometric Design Standards - Interstate System 2016 6th Edition
- AASHTO Highway Safety Manual 2010 1st Edition
- AASHTO Drainage Manual 2014 1st Edition
- AASHTO Guide for the Planning, Design and Operation of Pedestrian Facilities 2021 2nd Edition
- AASHTO Guide for the Development of Bicycle Facilities 2021 4th Edition
- Hydraulic Engineering Circular No. 22 - Urban Drainage Design Manual 2009 3rd Edition Rev 2013
- Hydraulic Engineering Circular No. 17 - Highways in the River Environment 2020 1st Edition
- Hydraulic Engineering Circular No. 25 - Highways in the Coastal Environment 2020 3rd Edition
- Transportation Research Board Highway Capacity Manual 2022 7th Edition
- Delaware Strategic Highway Safety Plan
- DelDOT Project Development Manual
- DelDOT Pedestrian Accessibility Standards for Facilities in the Public Right of Way 2021 Edition
- Delaware Manual on Uniform Traffic Control Devices (MUTCD)
- DelDOT Standard Construction Details
- DelDOT Standard Specifications
- DelDOT Development Coordination Manual
- DelDOT Traffic Design Manual
- Delaware Transit Corporation Bus Stop and Passenger Facilities Policy Revised 2018
- NCHRP Report 672, Roundabouts: An Informational Guide 2010 2nd Edition
- NCHRP Report 600, Human Factors Guidelines for Road Systems 2012 2nd Edition

1.5 Process Related Material and Guidance

Process related material used in the development of DelDOT transportation projects can be found in other sources including the *DelDOT Project Development Manual*, the DelDOT Road Design Manual Website, the DelDOT Design Resource Center, and in DelDOT Design Guidance Memoranda.

DelDOT's Project Development Manual describes processes to develop and design DelDOT transportation projects. Its focus is the documentation of DelDOT's plan development process and coordination between sections within DelDOT and with outside agencies and the public/stakeholders required to design and implement a transportation project. In addition, the Road Design Manual Website and the Design Resource Center contain project development guidelines, policies, and resources to be used during the preparation of design plans to ensure consistency in the plan development process.

2 Design Controls and Criteria

2.1 Introduction

Decisions on appropriate geometric design elements are influenced by the type of transportation improvement project and the project area. Each project type and area have its own unique characteristics. These characteristics need to be considered when determining a project's design controls and criteria which dictate the design elements used when designing a project. These design controls include functional classification, design speed, traffic volumes, design vehicles, design level of service, and project type.

2.2 Functional Classification

Reference: AASHTO Green Book Section 1.4

DelDOT has adopted a system of classifying and grouping highways, roads, and streets based on FHWA guidance found in the latest version of *Highway Functional Classification Concepts, Criteria and Procedures*. These recognized functional classifications include Interstate Highways, Freeways and Expressways, Principal and Minor Arterials, Major and Minor Collectors, and Local Roads. These functional classifications are further broken down into urban and rural classifications depending on the roadway's setting. A roadway may have different functional classifications along its entire length. Determining the appropriate functional classification is critical when defining a transportation project's design criteria.

2.3 Design Speed

Reference: AASHTO Green Book Section 2.3.6

Design speed has a greater influence on the design of a project than any other design control. To some degree, design speed impacts all elements of a project's geometric design criteria. It is important to note that design speed is a selection, and the selected design speed should be logical with respect to the characteristics of the terrain, adjacent land use, traffic volume, and functional classification of the roadway.

Selecting a design speed equal to the anticipated posted speed upon completion of the project has become an increasingly common practice in many agencies and is the method of design speed selection for DelDOT projects. In many cases evaluating operating speeds using speed studies is an important tool when selecting the most appropriate design speed.

2.4 Traffic Volumes

Reference: AASHTO Green Book Sections 2.3.2, 2.3.3, and 2.3.5

The existing and future expected motor vehicle traffic volume is a significant factor in establishing a project design. Some important traffic information for design purposes includes Annual Average Daily Traffic (AADT), Design Hourly Volume (DHV), Directional Distribution (D), and Truck Percentage.

For all projects involving new construction or major reconstruction, the design controls normally will be based on the traffic volumes estimated for 20 years after the expected completion of the project, expressed as AADT and DHV. For projects where the scope of work is limited to minor modifications to the existing roadway network, traffic volumes estimated for 10 years after the expected completion of the project should be used. Some asset management projects such as pavement rehabilitation projects will replace in-kind and/or make very minor modifications to improve traffic flow and/or safety within their limited scope of work, in which case traffic projections and analysis may not be required at all.

Existing and future expected pedestrian volumes and bicyclist traffic volumes must be considered as well. For projects on existing facilities, typically pedestrian and bicyclist volumes will be counted. However, there are no good quantitative procedures available to predict future pedestrian and bicyclist volumes. **For most projects, if there is any expected level of pedestrian or cyclist demand, the design should include facilities to accommodate that demand.** In particular, pedestrian desire lines should be considered related to sidewalks, shared use paths, and crosswalk locations. On some smaller projects with a limited scope of work it may not be possible to add these multi-modal facilities.

2.5 Design Vehicles

Reference: AASHTO Green Book Section 2.8.1

Where turning movements are involved, the geometric design requirements are affected significantly by the types of vehicles using the facility. Four general classes of vehicles are identified including passenger cars, buses, trucks, and recreational vehicles. The passenger car class includes cars of all sizes, sport utility vehicles, vans, and pick-up trucks. Buses include school buses, transit buses, and motor coaches. The truck class includes single unit trucks and truck and trailer combinations. Recreational vehicles include motor homes and cars or motor homes pulling camper trailers or boat trailers. Each design vehicle has physical and operational characteristics that affect the design controls including acceleration and deceleration capabilities, ability to climb steep grades, and sweep path dimensions of turning vehicles.

2.6 Level of Service

Reference: AASHTO Green Book Section 2.4.5

Level of Service (LOS) characterizes the operating conditions on a facility in terms of traffic performance measures such as delay, speed, and density. It establishes a grading system where letter grades from A through F are assigned to different types of highway facilities based on their traffic performance. The Transportation Research Board's (TRB) *Highway Capacity Manual* (HCM) presents a thorough discussion of the concept of LOS, specific methods to estimate traffic performance measures, and charts that establish LOS based on those traffic performance measures. In addition to the specific traffic performance measures that are directly related to LOS, there are other important traffic performance measures that can be measured and/or estimated such as travel time delay, queuing, and pedestrian/bicyclist level of stress. Furthermore, beyond the estimating methods presented in the HCM, there are other methods which may be used, such as traffic simulation models.

Level of Service is closely related to the concept of capacity. Capacity is the maximum traffic flow that can be accommodated on a highway facility during a given time period under prevailing roadway, traffic, and control conditions. Generally, the dividing line between LOS E and F coincides with a volume-to-capacity (v/c) ratio of 1.0. In other words, when the v/c ratio is less than 1.0, the LOS is E or better, and when the v/c ratio is greater than 1.0, the LOS is F.

While the HCM provides methods to determine LOS for motor vehicles, bicyclists, and pedestrians, for transportation projects in Delaware the LOS (and/or other traffic performance measures) related to motor vehicle traffic is nearly always the controlling factor related to a project design. Including multi-modal facilities within a transportation project is critical, but the design of the multi-modal aspects of a project do not rely on multi-modal LOS.

DelDOT projects should generally strive to attain a LOS E or better based on design year traffic projections and analyses during the design hours. This may vary based on the context of the project, or other factors such as being included within a Transportation Improvement District (TID) which has a previously defined service level. The design hours are often peak traffic hours related to morning and afternoon commuting periods, but could also include weekend shopping peaks, summer recreational peaks, school peaks, or others depending on the context of the project.

2.7 Project Type

Reference: AASHTO Green Book Section 1.7

There are many types of projects requiring varying levels of design effort and selection of design controls and criteria. Occasionally projects involve new alignments and new construction or major reconstruction that require significant changes in grades and geometry. New construction and major reconstruction projects should be in conformance with appropriate design criteria and design exceptions should be rare.

Many projects are planned and designed to maintain the existing highway system and many projects are funded to address immediate and/or specific needs such as improvement of the riding surface, or improving traffic operations/safety, or adding a shared use path to address multi-modal needs. These projects may include but are not limited to-patching, pavement overlays, traffic control device improvements, drainage improvements, auxiliary lane modifications, channelization, and improved safety infrastructure (e.g., guardrail, roadway lighting, high friction surface treatment). These projects may also include the addition of facilities to better serve bicycles, pedestrians, and transit. For these project types, the proposed scope of work, available funding, and project needs must be evaluated when establishing the design criteria and design elements. For these types of projects when applicable design criteria from this manual is not appropriate, design exception documentation is required.

3 Design Elements

3.1 Introduction

Reference: AASHTO Green Book Sections 1.8 and 2.9

Designers are called upon to make numerous decisions as to the geometrics and physical characteristics of transportation improvement projects. Without some basic framework of design elements, the judgements of individual designers may vary considerably. The purpose of design criteria is to assure that transportation improvement projects are consistently designed with due consideration of safety, operations, and fiscal responsibility consistent with the environmental and social context of the area and expectations of users of the facility. Designers should prioritize safety considerations as the design of a project progresses by referencing the *AASHTO Highway Safety Manual* which provides guidance for incorporating quantitative safety analysis in the design of transportation projects.

Designers should be aware that there is flexibility in the design criteria and design elements set forth by AASHTO and others that allows choices to be made as the design progresses and complex community and environmental issues arise. Since there are many decisions made during the design process affecting the design criteria, documentation of these decisions is a critical part of the design. **Designers shall document the project's design controls and criteria on DelDOT specific design checklists located on the DelDOT Road Design Manual Website.**

3.2 Departure from Design Criteria

New construction or major reconstruction projects should meet all applicable design criteria. The need for exceptions to the design criteria should be identified early in the project development process in order that approvals or denials will not delay the completion of the design. **DelDOT's Design Control Checklist and Design Criteria Form should be used to document decisions on design controls and criteria and as a basis for developing and documenting requests for design exceptions.** Deviations from the FHWA's controlling criteria for design, listed on DelDOT's Design Criteria Form, require a design exception. FHWA's ten controlling criteria are design speed, travel lane width, travel lane cross slope, outside shoulder width, minimum horizontal curve radius, superelevation rate, stopping sight distance, maximum grade, vertical clearance, and design loading structural capacity.

Design exceptions for design speed should be extremely rare as this criterion establishes most of the design criteria to be met. Design criteria that cannot be met within a selected design speed should be supported by seeking a design exception for those specific design criteria.

3.3 Design Elements Based on Design Speed

Determining the appropriate design speed is the first step in establishing several design elements that are directly related to the design of a transportation facility. Design speed is discussed in Section 2.3 and at length in the AASHTO Green Book. Some design features, such as curvature, superelevation, and sight distance are directly related to, and vary appreciably with, design speed. Other features, such as width of lanes, shoulders, and lateral clearances, are not directly related to design speed but do affect vehicle speeds.

3.3.1 Horizontal Alignment, Curvature, and Superelevation

Reference: AASHTO Green Book Sections 3.3.2, 3.3.3, 3.3.5, and 3.3.8

Horizontal alignment of a roadway is defined graphically using a series of straight-line tangents with transition sections into and out of horizontal curves. **When developing horizontal alignments, designers should use simple curves only and avoid the use of spiral curves**.

Establishing the proper relationship between design speed and curvature, as well as their joint relationship with the proper superelevation on the curve, is an important decision. Although these relationships are derived from laws of physics (speed, centrifugal force, and side friction factor), the actual values for use in design depend on practical limits and factors determined empirically over a range of variables. For example, the maximum permissible rate of superelevation is based on a practical consideration that a high operating speed can be accommodated on a relatively sharp curve if the superelevation is steep enough. However, roadways must serve vehicles traveling at a wide range of speeds. Slow moving vehicles or stopped vehicles could be adversely affected with excessively steep superelevation, particularly in ice and snow conditions. AASHTO suggests maximum superelevation rates in the range of 4 to 12 percent. **Delaware's roadways are subject to the effects of ice and snow during the winter; therefore, DelDOT has adopted a maximum superelevation rate of six (6) percent.**

Figure 1: Horizontal alignment, curvature, and superelevation along Delaware roadways.

3.3.2 Sight Distance

Reference: AASHTO Green Book Section 3.2.1

Sight distance is the length of roadway ahead of the vehicle that is visible to the driver. Horizontal curvature, vertical curvature, roadside obstructions, or any combination of these elements can restrict sight distance.

3.3.2.1 Stopping Sight Distance

Reference: AASHTO Green Book Sections 3.2.2, 3.2.3, and 3.3.12

Stopping sight distance is the total distance required to bring a vehicle to a complete stop and is affected by the time for a driver to react and the braking distance. The available stopping sight distance must be sufficient to enable a vehicle traveling at the design speed to come to a stop before reaching an object on the roadway. Factors that influence the required stopping sight distance include the speed of the vehicle, the drivers eye height, the height of the object on the road, the driver's reaction time, and the surface condition of the road.

3.3.2.2 Passing Sight Distance

Reference: AASHTO Green Book Section 3.2.4

Consideration of passing sight distance is limited to two-lane, two-way roadways on which vehicles frequently overtake slower moving vehicles and the passing operation must be accomplished within a lane used by opposing traffic. Passing sight distance for design is determined by the length needed to accomplish the passing maneuver.

3.3.3 Vertical Alignment and Grades

Reference: AASHTO Green Book Sections 3.4.1 and 3.4.2

The topography of the land has a significant influence on the alignment of roadways. Topography affects horizontal alignment and has an even more pronounced effect on vertical alignment. Variations in topography are generally separated into three different classifications according to terrain: level, rolling, and mountainous. The terrain in Delaware is typically level or rolling. The terrain on which a roadway is located has a direct impact on the grades associated with the vertical alignment of the roadway.

Maximum allowable grades are based on the functional classification of the roadway and the design vehicle anticipated to utilize the roadway and should only be used when necessary. Maximum grades permitted are based on various combinations of functional classification, design vehicle, and terrain. Minimum allowable grades are based on the slope required to properly drain the pavement surface of the roadway. **Due to very flat terrain in many areas in Delaware, minimum allowable grades of 0.3% may be used when developing vertical alignments.**

Flooding of transportation facilities is of increasing concern due to sea level rise related to climate change and land subsidence in some low lying, coastal areas. For projects within an area mapped by DNREC as vulnerable to sea level rise inundation, designers should consider future projected sea levels and FEMA flood levels when making decisions related to roadway and bridge elevations.

3.4 Elements Based on Traffic Volumes and Design Vehicle

Design elements not directly related to design speed are influenced primarily by functional classification, traffic volumes, and the appropriate design vehicle.

Figure 2: Elements Based on Traffic Volumes and Design Vehicle

3.4.1 Number of Lanes

The number of travel lanes required for any roadway is directly related to the facility's traffic volume and desired level of service; however, there is no simple fixed criteria for these relationships. The *Highway Capacity Manual (HCM)* provides analysis methods for determining the number of travel lanes required to obtain a design flow rate, and the analysis method varies based on the type of facility. For some projects, providing additional lanes to meet LOS criteria may not be consistent with other project goals, such as multi-modal safety. An iterative process considering the number of lanes, LOS, multi-modal safety, and possibly other project goals may be required. Additional information is included in Section 2.6.

3.4.2 Travel Lane Widths

Reference: AASHTO Green Book Section 4.3

The traveled way designated for vehicles normally consists of two or more travel lanes. Providing adequate lane widths maintains and/or enhances driver safety, driver comfort, level of service, and capacity.

For new construction and reconstruction projects, 12-foot travel lanes should be used on roadways with design speeds of 55 mph, or greater and 11-foot travel lanes should be used on roadways with design speeds from 35 mph to 50 mph. Ten-foot travel lanes should be used on roadways with design speeds below 35 mph with consideration for 11-foot lanes that are adjacent to bike lanes. Ten-foot travel lanes should also be avoided along transit routes and roadways with heavy truck traffic.

3.4.3 Shoulder Widths

Reference: AASHTO Green Book Section 4.4

The shoulder is the portion of the roadway contiguous with the traveled way that accommodates stopped vehicles, emergency use, bicycles, and pedestrians. The shoulder also provides lateral support to the subbase, base, and surface courses of the travel way. The total shoulder width is the distance from the edge of travel lane to the intersection of the shoulder slope with the front slope, or the face of curb.

For all DelDOT interstate highways, freeways, and expressways the width of paved shoulder should be 10 feet. For all other roadways 8-foot-wide paved outside shoulders should be considered for roads with frequent driveway access points. If there is no separate shared use path, outside paved shoulders are desired to be 5 feet wide, and at a minimum should be 4 feet wide. If there is a separate shared use path, outside paved shoulders should be a minimum of 2 feet wide.

3.5 Cross Sectional Elements

Reference: AASHTO Green Book Section 4.1

The term cross section is used to define the configuration of a proposed roadway at right angles to the centerline. In addition to travel lane and shoulder width, there are other elements that make up a roadway's cross section. Typical sections show the width, thickness, and description of materials that make up the pavement section, as well as the geometrics of the final graded travel lanes, shoulders, sidewalks, roadside ditches, side slopes, and clear zones. The cross-section elements of a facility are the most visible features to the driver and have the greatest physical effect on the construction of a roadway.

3.5.1 Clear Zone and Lateral Offset

Reference: AASHTO Green Book Section 4.6; AASHTO RDG Chapters 3 and 10

The clear zone is defined by the *AASHTO Roadside Design Guide* as the unobstructed, traversable area provided beyond the edge of the through traveled way for the recovery of errant vehicles. The clear zone includes shoulders, bike lanes, and auxiliary lanes, except those that function like through lanes such as bypass lanes. Vehicles leaving the roadway should have a reasonable opportunity to recover control and return to the roadway without overturning or colliding with fixed roadside obstacles such as trees, utility poles, headwalls, or other large non-breakaway objects. The determination of the clear zone is a function of speed, volume, horizontal curvature, and embankment slope. The *AASHTO Roadside Design Guide* shall be used for determining appropriate clear zone widths and for all elements associated with designing an appropriate roadside environment.

The lateral offset concept is used to identify acceptable locations for fixed objects in urban environments characterized by sidewalks, closed drainage, signs, utility poles, fire hydrants, and frequent traffic stops. Where curb is used, the lateral offset is measured from the face of the curb to an object. Reference shall be made to the *AASHTO Roadside Design Guide* for more information on this concept and its applications.

3.5.2 Cross Slopes

Reference: AASHTO Green Book Section 4.2

It is important to enable surface water to drain from travel lanes and shoulders as quickly as possible. Accumulations of water (ponding) can cause hazards by reducing surface friction and vehicle stability. Sufficient cross slope is needed for adequate drainage, but slopes that are too great adversely affect vehicle operation. In addition, good drainage minimizes moisture penetration into the pavement thus increasing stability and service life of the pavement. Sloping the shoulders steeper than the travel lanes assures rapid surface drainage, reduces the chance of ponding, and minimizes subgrade penetration of moisture through the pavement.

3.5.3 Curbs

Reference: AASHTO Green Book Section 4.7

Curbs generally serve the following purposes: drainage control, roadway edge delineation, right-of-way reduction, delineation of pedestrian walkways or shared use paths, and delineation of access points. Curb configurations include both vertical and sloping curbs. Vertical curbs are those having a vertical or nearly vertical face six inches or higher. They are intended to discourage motorists from deliberately leaving the roadway. Sloping curbs are those having a sloping traffic face six inches or less in height and can be readily traversed by motor vehicles when necessary. **For DelDOT projects, the use of vertical curb is limited to design speeds of 45mph and below.** Curbs four inches or lower with a nearly vertical face and sloping curbs may be considered for use on facilities with design speeds above 45 mph when necessary due to drainage considerations, restricted right of way, or where needed for access control. When used under these circumstances, they should be located at the outside edge of the shoulder. ***DelDOT's Standard Construction Details*** **shall be referenced for the types of curbs used on projects in Delaware.**

3.5.4 Side Slopes

Reference: AASHTO Green Book Sections 4.8.4 and 4.9.1; AASHTO RDG Chapters 3 and 5

Side slopes are important in maintaining the stability of the roadway and have a direct relationship to the required width of the clear zone. Side slopes shall be evaluated and designed in accordance with the *AASHTO Roadside Design Guide*.

3.5.5 Roadside Ditches

Reference: AASHTO Green Book Section 4.8.3; AASHTO RDG Chapter 3

The two principal functions of roadside ditches are to drain water from the pavement subgrade and to collect surface water from the roadway surface and/or adjacent roadside areas and remove it. Ditch designs can play a major role in managing stormwater runoff, removal of sediment, controlling erosion, and reducing the impact of roadway pollutants on watercourses. Ditch cross sections should be traversable within the clear zone and designed in accordance with the criteria presented in the *AASHTO Roadside Design Guide*.

3.5.6 Medians

Reference: AASHTO Green Book Section 4.11

Medians can enhance safety and are provided on divided multi-lane highways to provide separation of opposing travel lanes, a recovery area for errant vehicles, and an area for emergency stops. Medians can also provide space for left turn lanes, emergency crossovers, snow removal storage, space for collecting surface drainage, pedestrian refuge, installation of traffic control devices, and adding future lanes. Median widths are always measured between the inside edges of opposing travel lanes and operate best when they are highly visible during the day and night. Reference shall be made to both the *AASHTO Green Book* and *AASHTO Roadside Design Guide* for design criteria and design elements regarding medians.

3.5.7 Barriers

Reference: AASHTO Green Book Section 4.10; AASHTO RDG Chapters 4, 5, and 6

The purpose of roadside barriers is to reduce fatalities and injuries by preventing a vehicle from leaving the traveled way and striking a fixed object or terrain feature that is less forgiving than striking the barrier itself. The need for barriers is directly related to the selected cross-sectional elements as well as the clear zone and lateral offset concept discussed previously. The need for barrier and its design shall be in accordance with the *AASHTO Roadside Design Guide*.

Roadside barriers are used to shield obstacles located along either side of the traveled way. W-beam steel guardrail and concrete safety barriers are the most used roadside shielding devices. Geometric design criteria and typical installations are in the *DelDOT Standard Construction Details.*

The basic function of median barriers is to prevent errant vehicles from crossing the median and entering opposing travel lanes. Median barriers should be installed on all high-volume, high speed divided highways where engineering studies establish a need or in accordance with the *AASHTO Roadside Design Guide*. The most common types of median barriers are dual faced W-beam steel guardrail, concrete safety barrier, and high-tension cable barrier. Concrete safety barrier is preferred in narrow medians where regular maintenance is difficult, or where deflection of the barrier would affect opposing traffic. Median barriers may also be used to funnel pedestrians to designated crossing locations. **DelDOT has adopted guidelines that recommend median barrier more frequently than the *AASHTO Roadside Design Guide*. Designers should reference the applicable Design Guidance Memorandum regarding the need for and type of median barrier.**

Vehicles impacting the unprotected end of a roadside barrier can result in serious consequences. The vehicles may be stopped abruptly, barrier elements could penetrate the passenger compartment, or the vehicle may become unstable or potentially roll over. A wide variety of devices are used as end treatments and are designed to mitigate vehicle impact with ends of roadside barriers. Proper grading in advance of and in close proximity to end treatments is a critical element in the safe design and installation of end treatments. Additionally, proper curb placement at barriers and barrier end treatments is critical for barriers to function properly. The *AASHTO Roadside Design Guide, DelDOT Standard Construction Details*, and the *DelDOT Standard Specifications* shall all be referenced when considering and designing proper end treatments.

4 Intersections

4.1 Introduction

Reference: AASHTO Green Book Sections 9.1, 9.2, 9.3, and 9.4

The intersection of two or more roads presents an opportunity for conflict among vehicles and other users of the transportation facility. For freeways the potential for conflict is significantly reduced by using interchanges or grade separated intersections which are typically not feasible for most intersections along arterials and collectors. The principal objectives in the design of at-grade intersections are to minimize the potential for and severity of conflict points and to provide adequate safety, mobility, and capacity for the intersecting movements of all road users.

Intersection designs range from simple residential driveways to a complicated convergence of several high-volume multi-lane roadways. Intersection designs implement various types of traffic control which can include two-way stop controlled, roundabouts, signalized, and all-way stop controlled. They all have the same fundamental design elements including level of service, alignment, profile, roadway cross section, intersection radii, and sight distance. In addition, other elements are introduced in intersection designs such as turning lanes, auxiliary lanes, traffic islands, medians, channelization, and bicycle/pedestrian accommodations.

Figure 3: Intersections, Turning Movements, and Channelization

4.2 Turning Movements

Reference: AASHTO Green Book Section 9.6.1

All intersections involve some degree of vehicular turning movements and there are various factors that influence the geometric design of turning lanes. The design controls for turning roadways are the traffic volume and types of vehicles making the turning movements. One movement of concern in intersection design is right turning traffic. The three typical types of designs for right turning movements in intersections are a minimum edge of traveled-way design, a design with a corner triangular channelizing island, and a free flow design using a simple radius or compound radii.

Designers should be aware that large right turn radii often required for larger design vehicles lead to high speed right turning traffic. These large radii are not desirable at locations with an appreciable number of pedestrians and bicycles as they result in longer crossing distances and safety concerns for pedestrians and bicycles associated with the high speed right turning traffic. If a small right turning radius is selected to reduce turning vehicle speeds, a mountable outside apron may be required to accommodate larger design vehicles, though potential conflicts with bicycle/pedestrian facilities should be evaluated.

4.3 Channelization

Reference: AASHTO Green Book Sections 9.6.2 and 9.6.3

Channelization is the separation of traffic movements into defined paths of travel by traffic islands, curb, and/or pavement markings to facilitate the safe and orderly movement of vehicles, bicycles, and pedestrians. Proper channelization increases capacity, improves safety, and aids in user navigation. Over channelization should be avoided because it could create confusion and operational problems within the intersection.

Channelization of at-grade intersections is generally warranted for several factors including to narrow the area of potential conflict between users, provide clearer indication for the proper path in which movements are to be made, provide areas for pedestrian refuge, and provide areas for traffic control devices. Design of a channelized intersection usually involves the following controls – the type of design vehicle, the cross sections on the crossroads, drainage, the projected traffic volumes, bicycle and pedestrian facilities, the speed of vehicles, and the type and location of traffic control devices. In addition, physical controls such as right-of-way and terrain influence the extent of channelization that is economically feasible.

4.4 Intersection Sight Distance

Reference: AASHTO Green Book Section 9.5

Sight distance is the length of roadway ahead of the vehicle that is visible to the driver. The driver of a vehicle approaching an at-grade intersection should have an unobstructed view of the whole intersection, termed approach sight distance. The minimum sight distance considered safe under various assumptions of physical conditions and driver behavior is directly related to vehicle speeds and the resultant distances traversed during perception time, reaction time, and braking. In addition to approach sight distance, sight distance is also provided to allow stopped vehicles sufficient view of the intersecting roadway to decide when to enter or cross the intersecting roadway, termed departure sight distance. All sight distances must be checked on all intersection designs based on the procedures set forth in the *AASHTO Green Book* and the *Delaware MUTCD*.

4.5 Auxiliary Lanes

Reference: AASHTO Green Book Section 9.7

Auxiliary turning lanes may be introduced at intersections under a variety of conditions including rural or urban locations and free flowing, signalized, or stop controlled facilities. Using auxiliary lanes to handle turning movements at high traffic volume intersections can reduce congestion, improve safety, and provide better traffic control. Auxiliary lanes are also used on multi-lane divided roadways and high volume-two lane roadways under open road conditions. They improve safety and traffic flow when introducing median openings, intersections at minor cross-roads, or U-turn locations.

Auxiliary lanes include left and right-turn lanes, right-turn and median acceleration lanes, and auxiliary through lanes. **To facilitate the movement of traffic at signalized intersections efficiently, all mainline approaches should have at a minimum one dedicated left turn lane in addition to the through lane(s). Additionally, all side street approaches at signalized intersections should at a minimum have a two-lane approach with either a shared left turn through lane configuration or a shared right turn through lane configuration as determined by traffic and turning movement analysis.**

At some high-volume intersections, the use of auxiliary through lanes may be considered. Auxiliary through lanes function as additional through lanes on the approaches to the intersection that more efficiently move traffic through the intersection. The use of auxiliary through lanes requires properly designed tapers for both the lane addition in advance of the intersection and the lane drop exiting the intersection.

The length of auxiliary lanes depends on local conditions, traffic volumes, design speed, selected level of service, and operating speed. **Ideally, turn lanes should be long enough to accommodate 95 percent of the expected queue for the design volume in the design year.** Auxiliary lanes should be 11 feet wide to minimize encroachment of turning vehicles upon the adjacent travel way. A minimum 10-foot-wide auxiliary lane may be acceptable in locations where space is limited, truck volumes are low, and operating speeds are below 35 mph.

On freeways, acceleration and deceleration lanes should be provided in accordance with AASHTO Green Book criteria. **In addition, parallel rather than tapered designs should be used.** On all other roads, acceleration lanes are not desirable where the requisite acceleration lane length cannot be achieved or where entering drivers can wait for an opportunity to merge without disrupting through traffic, such as at signalized intersections. Acceleration lanes should also be avoided at intersections with pedestrian crossings, poor geometry, and differences in grade that affect the driver's ability to properly navigate the acceleration lane. Entrances to properties should not be provided within the acceleration or deceleration lane and taper. The use of acceleration lanes should generally be restricted to rural, free flow, or controlled access situations where the requisite acceleration lane length can be provided.

Figure 4: Auxiliary lanes along US13 corridor.

4.6 Grade Separated Intersections and Interchanges

Reference: AASHTO Green Book Chapter 10

The safest, most efficient manner of accommodating traffic for all road users on intersecting roads occurs when the intersecting roads are separated at grade separated intersections or interchanges. The selection of the appropriate type of grade separation or interchange and its design is influenced by many factors including highway functional classification, composition of traffic, design speed, and access control. In addition to these controls, economics, terrain, and right of way are important in designing facilities with adequate capacity to accommodate traffic on the intersecting roads.

A ramp includes all types, arrangements, and sizes of roadways that connect two or more intersecting roads at a grade separated intersection or interchange. Typically, the horizontal and vertical alignment of ramps is based on design speeds lower than the intersecting roadways. Ramp acceleration and deceleration lengths are based on the design speed of the intersecting roadway, the merge speed of vehicles on the ramp, and the grade of the ramp as it enters the intersecting roadway. The ramp width is governed by the curvature of the ramp, and the volume and type of traffic. It is important to note that the ramp roadway width includes the traveled-way width plus the requisite shoulder width. Additionally, entrances should not be provided within the limits of the ramp.

Figure 5: Grade Separated Interchanges and Intersections

4.7 Median Openings

Reference: AASHTO Green Book Sections 9.8 and 9.9

Median opening designs range from designing for simple U-turn movements to more complex unsignalized and signalized rural and urban intersections that may include traffic from minor crossroads and streets, major roadways, and commercial entrances. The design of median openings is based on traffic volumes, operating speeds, predominant types of turning vehicles, and median width. Crossing and turning traffic must operate in conjunction with the through traffic on a divided highway which makes it necessary to know the volume and composition of all movements occurring simultaneously.

4.8 Traffic Control Devices

Reference: AASHTO Green Book Section 9.11.2

Traffic control devices, such as signs, markings, and signals, are essential to establish and maintain safe and effective traffic operations at intersections. The extent of such traffic control may range from a stop sign at a simple road approach, to a complex system of synchronized traffic signals on a high-volume urban arterial. Consideration should be given to the need for traffic control devices during the geometric design of intersections, particularly those that carry considerable traffic volume with many turning movements. The needed types of traffic control devices may influence the shapes of turning roadways and traffic islands. Designers need to consider effective placement of signs and signals as well as locations of cross walks where pedestrians are present and accommodations for bicyclists when applicable. Designers shall refer to the *Delaware MUTCD* for a comprehensive discussion and direction in the use of traffic control devices and their application to intersection design.

4.9 Roundabouts

Reference: AASHTO Green Book Section 9.10

A roundabout is a form of circular intersection in which traffic travels counterclockwise around a central island and in which entering traffic must yield to circulating traffic. The most used roundabouts are single lane roundabouts, multi-lane roundabouts, and mini roundabouts. Roundabouts in all three categories should be designed with pedestrian and bicycle facilities. They should also be designed for low entering speeds for entering vehicles and provide accommodations for the appropriate design vehicle. Designers shall refer to *NCHRP Report 672, Roundabouts: An Informational Guide, 2nd Edition* for a comprehensive discussion on the concepts and design of roundabouts.

Roundabouts are the preferred safety alternative for a wide range of intersections. Although they may not be appropriate in all circumstances, they should be considered as an alternative for all proposed new intersections, particularly those with major road volumes less than 90 percent of the total entering volume. Roundabouts should also be considered for all existing intersections that have been identified as needing major safety or operational improvements.

Roundabouts in rural areas should be designed with appropriate truck aprons and other features (such as properly located signs) to accommodate large agricultural vehicles and equipment.

Figure 6: Roundabout Design on rural Delaware roadways.

5 Multi-Modal Facilities

5.1 Multi-Modal Facilities

Reference: AASHTO Green Book Section 1.6

As part of improving the transportation network, DelDOT initiates and designs projects to enhance multi-modal transportation. These projects include the addition of sidewalks, shared use paths, bicycle facilities, transit facilities, and park-and-ride lots. These projects enhance multi-modalism while also decreasing vehicular traffic and automobile emissions. Consistent with DelDOT's Complete Streets Policy, all new roadway projects, reconstruction projects, and projects that widen the pavement shall consider all modes of transportation and accommodate accordingly. System maintenance projects should strive to improve pedestrian, bicycle, and transit facilities within their limits and project scope if feasible.

Figure 7: Multi-Modal Facilities - Vehicles, Bikes, and Pedestrians.

5.1.1 Pedestrian Facilities

Reference: AASHTO Green Book Section 1.6.1.3

The transportation system should provide a safe network of facilities to accommodate pedestrians. Pedestrian facilities are a key connection point in the design of multi-modal systems. Pedestrian facilities benefit both pedestrians and motorists by creating separation between pedestrian and vehicular paths. Accordingly, pedestrian facilities are an integral part of DelDOT's transportation infrastructure program. Pedestrian facilities provide safe and reasonable access to public transportation, other adjacent land uses, and communities. Pedestrian facilities located along divided highways with significant traffic and pedestrian volumes may require the installation of a median barrier to direct pedestrians to designated crossing areas.

All pedestrian facilities should be designed and planned in accordance with the latest version of the *DelDOT Pedestrian Accessibility Standards for Facilities in the Right of Way* and the *AASHTO Guide for Planning, Design, and Operation of Pedestrian Facilities*. The designer should make connections to logical pedestrian termini of sidewalks and shared use paths, even if that requires a reasonable expansion of the project limits, though expansion of a project's limits needs to consider environmental, right of way, and budget impacts.

5.1.2 Bicycle Facilities

Reference: AASHTO Green Book Section 1.6.1.2

There are a wide range of facility improvements that can enhance bicycle transportation. In general, additional travel lane or shoulder width can increase the suitability of roadways for bicycling. Designation of bicycle lanes with appropriate signs and pavement markings can help increase the predictability of both bicycle and motor vehicle movements. Additional separation of bicycle traffic from motor vehicle traffic on shared use paths is generally desirable on most roads in residential areas to provide low stress bicycle facilities where bicyclists of varied skill levels may be present. It is important to note that pedestrians also use shared use paths and accordingly, shared use paths need to be designed in accordance with the latest version of the *DelDOT Pedestrian Accessibility Standards for Facilities in the Public Right of Way*. All bicycle facilities should be designed in accordance with the *AASHTO Guide for the Development of Bicycle Facilities* in conjunction with the *Delaware MUTCD*.

5.1.3 Bus Facilities

Reference: AASHTO Green Book Section 1.6.1.4

Bus transit facilities and bus stops should be identified and, where appropriate, included in transportation projects. Bus stops are generally located at or near major trip generators, destinations, or at regular intervals based on population density. Bus stops are located where passengers can board and alight safely and where buses can safely enter and exit the traffic flow. For specifics, designers shall refer to the latest version of the *Delaware Transit Corporation: Bus Stop and Passenger Facilities Policy*.

Figure 8: Delaware Transit Corporation Bus Stop with Shelter.

6 Miscellaneous

6.1 Landscaping and Reforestation Act

The Landscaping and Reforestation Act states that "forested land in the State, together with landscape features such as trees, shrubs, and ground covers...not only improve the aesthetic value of our State but carry with them valuable benefits to the health and welfare of our citizens and our environment." The Act also states: "It is likewise declared that the Department of Transportation is a leader in replacing forestlands that are required to be cleared for such projects and in providing travelers throughout the State with scenic vistas along its roadways while maintaining safe design and construction standards."

The requirements of the Act are invoked whenever the Department of Transportation performs a construction project. A "construction project" is defined as any activity undertaken, authorized, or required by the Department of Transportation through which any expressway, arterial, or collector road is constructed on a new alignment, or widened by adding one or more through travel lanes. Designers shall refer to the Design Resource Center for guidance and specific requirements when projects require implementation of the Landscaping and Reforestation Act.

6.2 Roadway Drainage

Reference: AASHTO Green Book Section 4.8.2

Adequate drainage is essential in the design of roadways since it affects the roadways serviceability and usable life, including the integrity of the pavement. Safety concerns such as ponding on the roadway are also addressed with adequate roadway drainage. Adequate drainage involves providing drainage systems that collect, transport, and remove runoff from the roadway.

Drainage systems can be classified as either open drainage systems or closed drainage systems. Open drainage systems typically convey stormwater to an outfall in roadside or median ditches. These systems are preferable based on the minimal cost and minimal maintenance required. However, in certain situations, especially for urban highways, it may not be practical to construct an open drainage system to collect pavement runoff and convey it to an outfall point. In these cases, a closed drainage system is utilized to convey stormwater to an outfall point. Closed drainage systems typically include curbs or curb and gutter combinations along the edge of pavement for containing the runoff and channelizing the flow into inlets through which the pavement runoff is removed. *Hydraulic Engineering Circular No. 22 – Urban Drainage Design Manual* and the *AASHTO Drainage Manual* should be referenced when designing drainage systems on roadway projects in Delaware**.** **Design criteria unique to drainage design in Delaware are summarized in Tables 6-1 through 6-5.**

DelDOT projects are also subject to the Delaware Sediment and Stormwater Management regulations. Stormwater management facilities must be accommodated and can affect the application of design elements such as foreslope and backslope grading.

Table 6-1: Design Criteria — Frequency

Functional Classification	Return Period in Years			
	Type of Drainage Installation [1]			
	Pipe Culverts	Storm Drains	Roadside Ditches	Median Drains
Interstate, Freeways and Expressways	50	10 [1]	50	50
Other Arterials	50	10 [1]	25	25 [1]
Collectors	50 [2]	10 [1]	25 [3]	10
Local Roads and Streets including Subdivision Streets	25	10 [4]	10	10 [4]

1 Use a 50-yr frequency at sag points, such as at underpasses or depressed roadways, where ponded water can be removed only through the storm drain system.

2 Use a 25-yr frequency for rural collectors.

3 Use a 10-yr frequency for rural collectors.

4 Use a 25-yr frequency at underpasses or depressed roadways where ponded water can be removed only through the storm drain system.

Table 6-2: Design Criteria — Allowable Spread on the Pavement Cross Section

Functional Classification	Allowable Water Spread
Interstate, Freeways, Expressways	Full Shoulder Width
Other Arterials Arterials with full shoulder or parking lane Arterials with less than full shoulder or parking lane	Full Shoulder or Parking Lane ½ of Adjacent Driving Lane
Collectors Design speed < 45 mph Design speed ≥ 45 mph	½ of Driving Lane Full Shoulder Width
Local Roads and Streets including Subdivision Streets	½ of Driving Lane
Sag Points (All facilities)	Full Shoulder Width

Table 6-3: Design Criteria – Ditches

Ditches	
Ditch flow line below edge of shoulder	≥ 2.5 ft preferred
Ditch water surface elevation below edge of shoulder/freeboard	0.5 ft minimum; 1 ft preferred
Minimum ditch grade	0.003 ft/ft; 0.005 ft/ft preferred
Ditch bottom width transition	25 ft for every foot change in ditch bottom width
Side slope transition	100 ft for every 1 horizontal increment change preferred

Table 6-4: Design Criteria – Pipes

Pipes	
Minimum size – cross road pipe/culvert (excluding entrance pipes and closed storm drain systems)	18 in
Minimum size – storm drain	15 in
Downstream pipe size	Must be same size or larger than upstream pipe segment
Minimum full flow velocity	3.0 ft/s
Maximum continuous distance between storm drain structures (without clean-out access)	300 ft
Personnel grate for pipe inlet	All pipes 12 in and larger with an open inlet that is not a straight run to the outlet without full daylight visible when looking through the pipe to the other end

Table 6-5: Design Criteria - Storm Drain System

Storm Drain Systems	
Hydraulic grade line (HGL)	≥ 1 ft below top elevation of all manhole covers or top of any inlet grate
Required manhole or inlet location	Intersection of two or more storm drains Pipe size change Pipe alignment change sag points in curbed sections
Discharge pipe invert elevation	≥ 0.2 ft below lowest incoming pipe elevation (preferred)
Outfall pipe of storm drain system	Discharge invert higher than the outfall elevation
Inlet clogging factor of safety in a sump condition	1.5 with curb and 2.0 without curb 1.0 for curb opening inlet 1.0 in drainage swale
Inlet clogging factor of safety on continuous grade	1.0

6.3 Pavement Subbase Drainage

Keeping the pavement subbase and underlying soil dry is a significant design consideration. Excessive moisture combined with increasing traffic will inevitably lead to premature pavement distress. Water can enter the pavement structure from many directions including poorly sealed or deteriorated joints, surface cracks, or high-water tables. If water is trapped within the pavement structure, pavement performance will be affected through loss of support due to erosion of any granular material and loss of material strength. Prevention and timely removal of water intrusion within the pavement structure are important steps to consider in extending the life of pavement sections on DelDOT projects. Designs should include proper pavement cross slopes, freely draining soils, and proper ditching where possible.

6.3.1 Underdrains

Underdrains are defined as a system of perforated pipes placed within the pavement section designed to collect and remove water from the pavement subbase. Underdrains are typically a wise investment when designing pavement sections as removal of water from the pavement subbase has a direct impact on extending the life of pavements. In low, poor draining areas with poorly draining soils, the use of underdrains has been very effective in the removal of water from pavement subbases.

On most higher volume roads, designers should include underdrains in the pavement section for new construction and reconstruction projects. However, sound engineering judgment should be used when deciding to implement underdrains on projects. For example, underdrains may often be omitted on projects constructed on higher fill sections with well-draining soils. Designers shall refer to the *DelDOT Standard Construction Details* and the *DelDOT Standard Specifications* for additional guidance on installation of underdrains.