Chapter 9 – HIGHWAY DESIGN

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CHAPTER 9

HIGHWAY DESIGN

9.1 GENERAL

This chapter provides policies, standards, standard practices, criteria, guidance and references for developing and documenting the highway design. This includes development of the final geometric design and the preparation of plans, specifications and estimates (PS&E) and related information to support highway construction and subsequent facility operations. The highway design policies and standards are applicable to new highway construction and reconstruction, as well as Resurfacing, Restoration and Rehabilitation (RRR) improvements. Section 1.1.1 provides policy definitions, standards, standard practices, criteria, and guidance. FLH Policy statements are shown in **bold type**. Statements regarding FLH Standard Practice are so indicated. Information on how to perform basic design procedures and fundamental steps for performing the design work are typically incorporated by references to other documents.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.1.1 ROLE OF THE DESIGNER

The role and responsibility of the highway designer is to gather and incorporate all of the interdisciplinary engineering and environmental input required to develop the highway design, and to provide a complete and acceptable PS&E assembly with all appropriate supporting documentation. The highway design and the PS&E package represents the final product of a collaborative, interdisciplinary and interagency design effort and depicts all the various decisions and commitments made during the planning, programming and project development processes.

The designer is responsible for participating in an interdisciplinary (e.g., cross-functional) team approach, led by the Project Manager, for evaluating design issues and developing design solutions for the project delivery. The designer is responsible for interpreting and applying guidance from each chapter in the *PDDM* as applicable to highway design development and PS&E compilation. The designer is also responsible for directly incorporating certain engineering data, plans, specifications and estimates produced by the other engineering disciplines into the PS&E and assuring that these products properly interrelate within the final PS&E assembly. The following briefly summarizes the designer's role and responsibility for development of the geometric design and PS&E, in relation to other disciplines described in the respective chapters of the *PDDM*.

- **Chapter 1 – Introduction.** Incorporate the philosophy, technical policies, and general approach to risk while developing the highway design and preparation of the PS&E.
- **Chapter 2 – Planning and Programming.** Designers should use information developed during the planning and programming phases including interagency agreements, planning and inventory data, program information and other general data developed on the scope, schedule and funding amount for the project being designed.

- **Chapter 3 – Environmental Stewardship.** Incorporate information regarding environmental requirements and public involvement. Environmental documents include the decisions and commitments made for mitigation of project impacts and concerns. Review all environmental documents for decisions, mitigation measures and commitments made during the conceptual studies and preliminary design phase that affect development and construction of the project or operation of the highway following construction. Coordinate any proposed deviation from the decisions, mitigation measures and commitments with the Environmental Section and affected resource agencies.
- **Chapter 4 – Conceptual Studies and Preliminary Design.** During the 30 percent design stage develop the recommended roadway location, design concepts and the basic design criteria for the facility. These engineering studies and preliminary designs are developed in conjunction with the environmental process using an interdisciplinary and interagency team approach, led by the Project Manager. Conceptual studies and preliminary design development include significant input from the highway owner agency, Federal land management agency, project stakeholders, the public and other interested parties, which is incorporated into the final design and PS&E.
- **Chapter 5 – Survey and Mapping.** The Survey and mapping unit provides information on the field survey, datum, coordinate system, property ties, right-of-way and utility locations and related data. The data collected is used to provide topographic maps, site maps, aerial imagery, right-of-way exhibits, land boundary and ownership information, utility maps and control information for developing the design.

  Closely coordinate the survey and mapping with the design and other engineering discipline activities to determine the type and limits of the survey and mapping required to complete the project delivery, and to share available information. Coordinate closely with the survey and mapping section to identify any additional information needs for developing the design and establishing controls for the construction process, and to use the available survey and mapping information most efficiently and effectively. When field reviews specifically for this coordination purpose are not possible, it is especially important for the designer and survey and mapping specialists to discuss the field information required. Use knowledge of the anticipated processes for design and construction, including new construction, reconstruction and RRR projects, to maximize the effectiveness of the survey and mapping activities performed to support the design and construction engineering.

  As needed, provide the appropriate information to the survey unit to stake the project design data in the field. This may include design data and notes to establish centerline, and to set slope stakes, clearing limits, reference points or hubs, grade stakes or hubs, right-of-way, and other control points necessary to complete the work. Keep the design files organized such that information provided for survey stakeout is current, correct and reflects the design criteria established for the project. It is the designer’s responsibility to verify and confirm all design data and notes provided for field use to prevent the possibility of staking incorrect data.

- **Chapter 6 – Geotechnical.** Incorporate the geotechnical information necessary to develop the highway design. The Geotechnical Unit provides subsurface data and recommendations for earthwork, slopes, materials, conditions, and geotechnical design. As applicable, the geotechnical investigations and report recommendations also include foundation designs for bridges, retaining walls and other structures, as well as information and recommendations regarding rock slopes and rock fall mitigation, geotechnical hazards, landslides and subsurface water.
- **Chapter 7 – Hydrology/Hydraulics.** Incorporate the hydrology/hydraulic data needed in developing the highway design. Develop culverts, ditches and other minor hydraulic features using the established standards and guidance described in the chapter. The Hydraulics Unit provides methodology and sources of runoff data, and recommendations for developing the roadside drainage design, provides data and recommendations to the Structural Design Unit for major drainage structures, and provides conceptual designs or design recommendations, and if necessary final designs, for major hydraulic structures and special water resource features for incorporation in the PS&E.
- **Chapter 8 – Safety and Traffic Operations.** Closely coordinate geometric design development, safety-related design features and PS&E compilation with the necessary information on roadway safety, roadside safety and traffic engineering data needed for highway design. The Safety and Traffic specialists provide guidance on evaluation of safety deficiencies, provision of safety features, and evaluation of traffic operations data.

  The crash history and safety performance should be analyzed for all projects. In addition, potentially hazardous features and locations should be identified to determine appropriate safety enhancements. A crash study analysis of the location, type, severity, contributing circumstances, environmental conditions and time periods may suggest possible safety deficiencies that need improvement or mitigation as part of the project. The chapter provides details on data collection, crash investigation and analysis. Also refer to Chapter 4 for additional information on incorporating the necessary traffic and crash data into highway design solutions.
- **Chapter 10 – Structural Design.** Coordinate the development of the geometric design and PS&E with the necessary information on structural design and bridges. The Structural Unit designs bridges, major retaining structures and special structural elements. The Structural Unit will provide complete structural plans, specifications and an estimate of cost for incorporation into the PS&E package.
- **Chapter 11 – Pavements.** Coordinate the development of the typical surfacing cross section and related highway design features with information and recommendations for the pavement or other type roadway surfacing. The Pavements Unit normally provides the roadway surfacing data and recommendations for pavement structure materials and thickness. Incorporate the recommendations for pavement materials and thickness provided by the Pavements Unit.
- **Chapter 12 – Right-of-Way and Utilities.** Coordinate closely with Right-of-Way and Utilities units to identify the proposed right-of-way acquisition needs and utility accommodation, adjustments or relocations, and to provide the design information and proposed impacts of construction activities to property and utilities. As applicable, the

Right-of-Way, Survey, Mapping, or the Design Unit may provide information on the existing right-of-way and utility deeds, plats, agreements and related data. The right-of-way and utility data provides the basis for development of proposed right-of-way and utility plans, descriptions, agreements and other documents for clearance of right-of-way and utilities for construction. Coordinate design efforts to minimize the needs for proposed right-of-way and utility adjustments.

- **Chapter 13 – Design Follow-up.** The designer is responsible for obtaining feedback and follow-up information from post construction reviews, evaluating the effectiveness of the constructed design, and incorporating the information as an input for improving the design and development of future FLH projects.

9.1.2 DESIGN REQUIREMENTS AND STANDARDS

Refer to Section 4.4 for determination of applicable design standards and selection of design criteria to be used for the development of the geometric design and PS&E. For all projects, document the applicable design standards and criteria using the Highway Design Standards Form and show in the PS&E on the title sheet and typical section plans sheets. The applicable design standards and criteria should be documented during the conceptual studies and preliminary design (prior to 30 percent design stage).

Design standards determination also applies to Resurfacing, Restoration and Rehabilitation (RRR) projects; however, the overall approach to the design process is treated differently, since it is generally not intended or feasible for all substandard design elements to be reconstructed to fully meet the current design standards on RRR programmed projects. The RRR design process accommodates existing conditions or existing elements to remain included as part of the project rather than be reconstructed to the current standards of design. This is done using a safety-conscious design approach including risk analysis, which often requires design exceptions. For RRR projects, the approach to safety-related elements is similar to reconstruction projects in that any substandard safety conditions or controlling criteria are identified, and addressed on an individual, case-by-case basis.

Within this chapter many of the geometric design requirements, FLH standard practices, and guidance refer primarily to the design of new construction or reconstruction projects, and may not be appropriate for RRR projects or other projects with a very limited scope of improvement. Refer to Section 9.4 for guidance specifically applicable to RRR projects.

9.1.3 EXCEPTIONS TO DESIGN STANDARDS

It is acknowledged that designers are challenged with balancing a multitude of needs and expectations in selecting design criteria and geometry for highway facilities. The exception to standards outlined in *FLHM 3-C-2* permits the FLH Division Engineer to approve exceptions to design standards that are proposed for incorporation into the project. In addition to the design exception process, FLH policy includes flexibility to consider and approve alternative design criteria for individual projects, when necessary and appropriate.

When exceptions to the standards are necessary, document these exceptions with the risk to the traveling public, or the client, or the maintaining agency, or combination thereof appropriately noted. Inform the client and the maintaining agency, if different, of the risk and the consequences; document the risk and consequences of its acceptance, and provide alternatives to waiving the engineering standards. If the risk is acceptable to the client and the maintaining agency (if different), document this acceptance.

When evaluating the need for a design exception the design standards are not devalued; rather, in-depth understanding of the standards including the underlying theories and basis for derivation of the standard values, and the margins of substantive safety and operational performance that the standards provide, is used to add value to a unique situation by applying flexibility.

For all projects, document the selection of applicable design criteria from approved standards, and when approved standards are not attained, document all exceptions. Refer to *FLHM 3-C-2*. There are 13 principle design elements that are considered controlling criteria, and 4 supplemental standards, that require formal approval and documentation each time they are not attained. The 13 principle controlling criteria are:

- Design speed,
- Lane width,
- Shoulder width,
- Bridge clear roadway width,
- Horizontal curvature,
- Vertical curvature,
- Gradient,
- Stopping sight distance,
- Normal travel lane cross slopes (crown),
- Superelevation,
- Structural capacity,
- Horizontal clearance to structures (tunnels and bridge underpasses), and
- Vertical clearance.

The 4 supplemental standards are:

- Clear zone,
- Barrier crashworthiness,
- Design flood, and
- Pavement design service life.

In addition to these 13 controlling criteria and 4 supplemental standards requiring formal approval, the designer should receive concurrence and document in some manner any other elements of the highway design relating to safety, operational performance or functionality that do not meet applicable FLH standards. Refer to Division Supplements for guidance on documenting other highway design elements not meeting applicable FLH standards. Deviations from FLH standards for critical elements of other technical functions described in other *PDDM* chapters should also be approved and documented, as applicable for the technical function. The client and highway owning/maintaining agency should be informed of and concur in deviations from FLH standards and standard practices, as well as the consequences and risks of such decisions.

Any existing substandard elements that will remain after completion of the project must be identified, evaluated and documented in the same way as new design features.

There are basically two different approaches for evaluating and documenting design standard exceptions:

- A project-wide, or corridor design exception; and
- A site-specific design exception.

A project-wide or corridor design exception may be advantageous for design consistency, maintaining driver expectancy, and to coordinate geometric design features within the corridor (albeit using lower design criteria), but may be disadvantageous if the necessity for the lower design criteria is not a prevailing condition throughout the corridor. A corridor design exception is best reserved for those elements (e.g., roadway width) that are not functions of the design speed. A design speed exception relates to either 1) the minimum design speed applicable to the functional classification and terrain, or 2) individual design elements that are based on design speed and addressed on an individual basis. The design speed is not necessarily constant within the corridor if there are distinct zones that are appropriate to change both design speed and posted speed. A design exception to apply a lower design speed than the posted speed should not be recommended, especially if it is feasible to design a majority of the corridor or zone to meet criteria for the posted speed. It will potentially result in the unnecessary reduction of all of the speed-related design criteria rather than just the one or two features that led to the need for the exception. Refer to Section 9.3.1.13 for additional guidance on design speed and posted speed.

A site-specific design exception acknowledges the necessity for using lower geometric design criteria for a specific feature while providing higher design criteria for the prevailing conditions along the corridor, and the exception will usually affect only a single element of the geometric design criteria (e.g., a horizontal curve radius, a vertical curve length) and other elements are not compromised.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information including applicable Highway Design Standards form for use within each FLH Division.

9.1.3.1 Need for Design Exception

Before an exception is recommended, there must be compelling and demonstrated reasons why the approved standard criteria should not be used.

Describe and explain the conditions that preclude conformance to the applicable design standard. A preliminary estimate of the additional construction cost to conform to the applicable standard may be required, as compared with the proposed design exception.

The need for a design exception should be identified, evaluated and decided as soon as possible in the design and decision-making process. The key milestone for identification and evaluation of design exceptions is at the completion of the preliminary design (30 percent) stage.

9.1.3.2 Design Exception Consequences and Risk Assessment

When considering project elements that may require design exceptions to the applicable standards, the resultant safety and operational risk aspects must be 1) understood by the designer, and 2) properly communicated to project stakeholders.

Identify and describe the estimated operational and safety effects and potential risks of the design exception, and its compatibility with adjacent sections of roadway within the project. Safety enhancement is an essential element of any project design, therefore, a design exception should not be recommended if it would decrease the relative safety performance of the roadway in the affected area. Functional classification of the road, the amount and character of the traffic, the type of project (i.e., new construction, reconstruction, RRR) and the crash history should be considered in the risk assessment. The cost of attaining full standards and the resultant impacts on scenic, historic or other environmental features, as well as whether other future improvements are programmed, should also be taken into consideration. As a minimum, the following issues should be considered in the risk assessment:

- What is the degree to which a standard is being reduced?
- Will the exception affect other standards or projects?
- Are additional features being included in the project (e.g., improved roadway geometry, signing, delineation, roadside safety) that would adequately mitigate the safety and operational effects of the deviation?

The interdisciplinary project team should describe the context of the design exception and provide input for consideration. The designer should consider the context and the basis of the design standard, describe the safety effects or risks of the design exception, and provide a professional recommendation about alternatives to consider.

Refer to the sections on geometric design controls for considerations and guidance on risk assessment and mitigation of specific geometric design elements. The Interactive Highway Safety Design Model (IHSDM) should be used to help identify potential safety consequences and risks of geometric design elements.

Refer to Section 1.1.3 and Section 4.4.6 for general guidance on risk assessment. Refer to various sections elsewhere in this chapter for guidance on evaluation of the geometric design and operational effects, risk assessment and mitigation related to specific geometric design elements and features.

9.1.3.3 Mitigating Design Exceptions

Describe the mitigating measures proposed to maximize operation and safety of the facility in the affected area. Refer to the sections on geometric design controls for specific considerations and guidance on mitigation. If the mitigation for a design exception cannot be resolved at the preliminary design stage, it should be resolved at the intermediate design (50 percent) stage. For more information see FHWA-SA-07-011, *Mitigation Strategies for Design Exceptions*.

9.1.3.4 Documenting Design Exceptions

Documentation for all design exceptions should follow the guidelines in this manual, FHWA procedure from the *Federal-Aid program Guide (FAPG) Subchapter G-Engineering and Traffic Operations, Part 625-Design Standards for Highways, Non-Regulatory Supplement for Part 625, No. 8. Design Exceptions*, and relevant FHWA Policy and Engineering Directives.

Refer to the format in the Division Supplements for documenting design exceptions on a project.

Tort liability is a major concern of the government. The designer must ensure that the design process is in compliance with all applicable standards, and that decisions regarding design exceptions are properly documented. Documentation of the design exception should include the applicable controlling criteria and standard for which a design exception is requested, the background information, need, consequences, risks, and mitigation described in the preceding sections.

The documentation supporting the design exception decision should be prepared at the earliest possible point in the design process, and must become a part of the PS&E package presented to the owner agency. Any design exceptions should be identified, evaluated and documented during development of the conceptual studies and preliminary design (30 percent stage of project development). However, it may not be possible to finally resolve and document the approval of design exceptions until later in the final design process.

Refer to Chapter 4 of the AASHTO publication *A Guide for Achieving Flexibility in Highway Design* for additional information about concerns regarding tort liability and documenting design exceptions.

9.1.3.5 Monitoring Design Exceptions

Design exceptions should be collected and periodically reviewed in order that the managers in the Division offices remain fully informed on the nature and extent of design exceptions being approved for given categories of projects.

The safety and operational performance of the roadways that are constructed with design exceptions should be monitored, using performance management systems, to assist in future analysis and decision-making. Refer to Section 2.4 for information on system-wide planning and performance management.

9.1.4 VARIANCES TO FLH STANDARD PRACTICE AND GUIDANCE

Variations from the highway design standard practice and guidance will be necessary for special or unusual conditions, or to provide the proper balance among diverse user needs, environmental concerns, and fiscal restraints. Consequently, the provision of standard practice and guidance in this Chapter is not intended to preclude the exercise of discretion and engineering judgment in response to site-specific conditions, or achievement of appropriate flexibility in the highway design. Rather, such discretion and judgment is encouraged where it is appropriate and there is a clear need and a rational basis for deviation. However, it is equally important to promote consistency in the application of the standard practice and guidance, to regularly match the highway design with the needs, conditions and context of the facility and its users.

To fulfill these objectives, obtain endorsement and document the rationale for variances from FLH highway design standard practice in the project design file. The extent of documentation may depend on the specific nature of the variation and its potential effect (if any) on safety performance, traffic operations, or serviceability. The terms "consider" and "should" denote suggested guidance only and do not designate a standard practice or a design requirement; but convey an expectation for the highway designer to evaluate the situation before proceeding. Differences from the suggested guidance do not require documentation; however considerations for selecting special or unusual design parameters should be noted in the project design file. Procedures for documenting variations from highway design standard practice may be described in applicable Division Supplements.

9.1.5 DESIGN PHILOSOPHY AND CONTEXT SENSITIVE SOLUTIONS

The Federal land management agencies, and FLH, have long recognized the need to modify traditional approaches to the planning, design and construction of roads on such sensitive and protected lands. This has resulted in a philosophy for design of roads to exercise sensitivity and care in application of the established design requirements and standards described in Section 9.1.2. The FLH design philosophy is evident in the following design policy references:

The Foreword to the *Green Book* states:

> *"Highway engineers, as designers, strive to meet the needs of highway users while maintaining the integrity of the environment. Unique combinations of design controls and constraints that are often conflicting call for unique design solutions."*

The *Park Road Standards* state:

> *"The fundamental purpose of national parks–-bringing humankind and the environment into closer harmony–-dictates that the quality of the park experience must be our primary concern. Full enjoyment of a national park visit depends on its being a safe and leisurely experience. The distinctive character of park roads*

> *plays a basic role in setting this essential unhurried pace. Consequently, park roads are designed with extreme care and sensitivity with respect to the terrain and environment through which they pass–-they are laid lightly onto the land."*

The highway design must carefully balance the user's safety needs, desires, expectations, comfort, and convenience within the context of many constraints and considerations including terrain, land use, roadside and community effects, environmental effects, aesthetics and cost. To balance the user's needs with the values of the Federal land management agencies, while exercising stewardship and oversight, a specialized design philosophy has evolved. The FLH design approach is to actively engage the project stakeholders in applying the design policies, standards, criteria, best practices, guidance and engineering judgment to achieve an outstanding solution. Designers must represent the design policies and understand their engineering basis; and also must understand and respond to the values, concerns and constraints of each situation with flexibility and creative solutions. In applying flexibility the goal is not to lower, but to raise the performance level of the facility by optimizing the design criteria to exactly fit each situation using expert tools, information and communication.

The FLH and the Federal land management agencies share a legacy of working together on the planning, design and construction of roads. As a result, long-standing relationships and collaborative processes have evolved for successfully delivering the work, which actively engage the Federal land management agencies, State and local road-owning agencies, resource agencies and the public. These processes are essentially similar to the process described for achieving Context Sensitive Solutions (CSS). NCHRP Report 480, *A Guide to Best Practices for Achieving Context Sensitive Solutions*, provides guidance that is also closely aligned with the design approach used by FLH. CSS represents a collaborative, interdisciplinary approach to roadway planning, design and construction, which involves all partners, stakeholders and the public to ensure that transportation projects are in harmony with communities and that projects preserve environmental, scenic, aesthetic and historic resources. The effective application of CSS techniques can achieve these goals while maintaining safety and mobility.

Evaluating diverse needs and contextual issues, to balance and optimize the level of enhancement, may require collection and analysis of more data and project-specific information than for a non-CSS type approach. Fully understanding the context, and the true needs of the users, requires comprehensive data and personal interaction. Facilitating the collaborative interdisciplinary approach, effectively engaging stakeholders and the public with enhanced communication and decision-making tools and processes, risk assessment, and management endorsement requires planning and technical information. Ensuring that safe and technically sound solutions result from this exercise of flexibility in design requires expert thinking and analysis. To closely fit the design within the physical site constraints requires accurate survey and mapping, and iterative design to reach the optimum solution. The facility may need to deliver excellent operational performance to equally meet transportation demands and contextual enhancement goals. In addition to design, the construction techniques, materials, drainage and safety appurtenances may need to provide superior performance to accomplish the goals of CSS. The final cost of the resultant solution may not be any more than a non-CSS approach, but the level of data collection, analysis, engineering and construction may require higher thinking, performance and quality than may be the norm elsewhere in the highway industry.

Within FLH design policy, the products of the design philosophy will vary between projects that are executed by different interdisciplinary teams and designers, despite that precisely the same design standards are used. The differing emphasis for diverse goals, the unique context of each location, the technical knowledge of the designer and the amount of input from stakeholders in shaping the design, will result in unique solutions.

The remaining sections of this chapter describe the requirements and factors that influence the highway design and PS&E process, and guidance that should be considered by designers. These include the geometric design, types of projects and their approach, other highway design elements, the PS&E development and design documentation, including Division Supplements.

Also refer to Section 4.4.5 for guidance on applying flexibility in the design and Section 4.6.1 for guidance on achieving Context Sensitive Solutions.

9.2 GUIDANCE AND REFERENCES

The publications listed in this section provided much of the fundamental source information used in the development of this chapter. While this list is not all-inclusive, the publications listed will provide the designer with additional information to supplement this manual.

Abbreviations and definitions are described in Section 1.4.

9.2.1 STANDARDS OF PRACTICE

1.	Green Book	*A Policy on Geometric Design of Highways and Streets*, AASHTO, current edition (specific references in this chapter are to the 2011 edition).
2.	Park Road Standards	*Park Road Standards*, US Department of the Interior, National Park Service, 1984.
3.	FP-XX	*Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects*, FHWA, current edition.
4.	MUTCD	*Manual on Uniform Traffic Control Devices*, FHWA, current edition.
5.	RDG	*Roadside Design Guide*, AASHTO, current edition.
6.	VLVLR	*Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤400)*, AASHTO, 2004
7.	DS-Interstate	*A Policy on Design Standards-Interstate System*, AASHTO, current edition.
8.	FLHM 3-C-2	Federal Lands Highway Manual Policy Guide, Chapter 3, Section C, Subsection 2, *Exception to Minimum Engineering Standards - Risk Factors*
9.	ADAAG	*Americans with Disabilities Act Accessibility Guidelines*, Architectural and Transportation Barriers Compliance Board, current edition
10.	PROWAC	*Guidelines for Accessible Public Rights-of-Way*, current edition
11.	23 CFR 650 Subpart B	*Erosion and Sediment Control on Highway Construction Projects*, 1994
12.	E380-93	*Standard Practice for Use of the International System of Units (SI), The Modernized Metric System*, ASTM, 1993.

13.	FAR	*Federal Acquisition Regulations*
14.	Specification Writer's Guide	*Specification Writer's Guide for Federal Lands Highway*, FHWA-CFL/TD-08-001, 2008.

9.2.2 GUIDANCE

1.	AASHTO Flexibility Guide	*A Guide for Achieving Flexibility in Highway Design*, AASHTO, 2004,
2.	IHSDM	*Interactive Highway Safety Design Model* (IHSDM), FHWA, current edition.
3.	NCHRP Report 480	*A Guide to Best Practices for Achieving Context Sensitive Solutions*, TRB, 2004.
4.	AASHTO SR	*Highway Safety Design and Operations Guide*, AASHTO, 1997.
5.	T 5040.28	Technical Advisory 5040.28, *Developing Geometric Design Criteria and Processes for Non-Freeway RRR Projects*, FHWA, October 17, 1988.
6.	Special Report 214	TRB Special Report No. 214, *Designing Safer Roads*, Transportation Research Board, 1987.
7.	HCM	*Highway Capacity Manual*, Transportation Research Board, current edition.
8.	FHWA-RD-00-67	*Roundabouts: An Informational Guide*, FHWA-RD-00-67, 2000.
9.	NCHRP Report 502	*Geometric Design Consistency on High-Speed Rural Two-Lane Roadways*, TRB, 2003.
10.	NCHRP Report 504	NCHRP Report 504, *Design Speed, Operating Speed, and Posted Speed Practices*, TRB, 2003
11.	FHWA-RD-99-207	*Prediction of the Expected Safety Performance of Rural Two-Lane Highways*, FHWA-RD-99-207, FHWA, 2000.
12.	FHWA-RD-94-034	*Horizontal Alignment Design Consistency for Rural Two-Lane Highways*, FHWA-RD-94-034, FHWA, 1995.
13.	FHWA-RD-01-103	*Highway Design Handbook for Older Drivers and Pedestrians*, FHWA-RD-01-103, 2001

14.	AASHTO GPF	*Guide for the Planning, Design and Operation of Pedestrian Facilities*, AASHTO, 2004.
15.	AASHTO GBF	*Guide for Development of Bicycle Facilities*, AASHTO, 2012.
16.	Access Management Manual	*Access Management Manual*, Transportation Research Board, 2002.
17.	ITE Driveway Guidelines	*Guidelines for Driveway Location and Design*, Institute of Traffic Engineers (ITE), 1987.
18.	Practical Highway Esthetics	*Practical Highway Esthetics*, ASCE, 1977.
19.	Trail Design Manual	*Trail Design Manual, "Trails for the Twenty-First Century," Planning, Design, and Management Manual for Multi-use Trails*, Rails to Trails Conservancy, 1993.
20.	FHWA-FLP-91-001	*Design Risk Analysis* (Volume I and II), FHWA-FLP-91-001, FHWA, 1991.
21.	FHWA-SA-07-001	*Good Practices: Incorporating Safety into Resurfacing and Restoration Projects*, FHWA-SA-07-001, December 2006
22.	FHWA-SA-07-010	*Railroad-Highway Grade Crossing Handbook*, FHWA-SA-07-010, Revised 2nd edition, March 2008.
23.	FHWA-SA-07-011	*Mitigation Strategies for Design Exceptions*, FHWA-SA-07-011, July 2007
24.	NCHRP Report 279	*Intersection Channelization Design Guide*, 1985.
25.	FHWA-HRT-05-139	*Evaluation of Safety, Design, and Operation of Shared-Use Paths*, FHWA, 2006
26.	AASHTO GL-6	*Roadway Lighting Design Guide*, AASHTO, 2005.
27.	NCHRP Synthesis 430	*Cost-Effective and Sustainable Road Slope Stabilization and Erosion Control*, TRB, 2012.
28.	FHWA-FLP-94-005	*Best Management Practices for Erosion and Sediment Control*, FHWA, 1995.
29.	AASHTO MDM	Model Drainage Manual, AASHTO, Chapter 16, *"Erosion and Sediment Control."*

30.	AASHTO HDG	Highway Drainage Guidelines, AASHTO Volume III, *"Erosion and Sediment Control in Highway Construction."*
31.	FAPG 23 CFR 630B	*Guidelines for Preparation of Plans, Specifications, and Estimates*, FHWA Non- Regulatory Supplement for 23 CFR, Part 630, Subpart B, 1991
32.	AASHTO HLED	*A Guide for Transportation Landscape and Environmental Design*, AASHTO, 1991

33. FLH Specifications Procedures

34. FLH Safety Philosophy

35. FLH Context Sensitive Solutions Philosophy

9.3 GEOMETRIC DESIGN

Before beginning detailed design activities see Chapter 4 for standards and guidance on conceptual studies, project scoping, background data, and development of the preliminary design.

The over-arching considerations for geometric design are:

- Design the highway geometry with regard to the function, use, context and the environment in which the facility operates, and
- Provide consistency in the quality, appearance and operational performance of the roadway.

The following sections describe specific considerations and elements for geometric design.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.3.1 GEOMETRIC DESIGN CONTROLS

Identify design constraints early and optimize the vertical and horizontal geometry for compatibility. The geometric design controls should normally be established during the project scoping, see Section 4.3. Determination of geometric design controls should take into account the FLH Safety Philosophy and the FLH Context Sensitive Solutions Philosophy. Balance the user's needs with provisions for automobiles, trucks, motorcycles, pedestrians, bicyclists, and transit. In making these determinations, consider that routinely selecting only the minimum recommended values may not result in the optimum design for all users from a safety, operational or cost-effectiveness perspective. Also consider that other controls such as environmental requirements, structural design requirements, and supplemental standards for safety elements, design flood and pavement design may affect certain geometric design elements and their cost and scope. Refer to the respective Chapters for such controls and requirements. The following sections address the various geometric design controls.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.3.1.1 Roadway Context

Consider the roadway context as a critical factor in determining geometric design elements such as alignment and cross section, and in selecting design features such as curb type and traffic barrier, and in selecting construction materials and aesthetic treatments. Identify roadway design controls that are sensitive to, and respectful of, the surrounding context to facilitate the project success. It is essential that all transportation facilities be designed as part of the total environment. Traditionally, the highway design process has focused first on a project's transportation elements and design controls, particularly those associated with motor vehicle travel. A context-sensitive approach for identification of design controls begins with analysis of the contextual elements, such as environmental and community resources, of the area through which the roadway passes. After there is a thorough understanding of the area surrounding the road, the road's users, the affected non-users, constraints, and enhancement opportunities, then the transportation controls of the roadway, its function within the regional transportation system, and the appropriate level of speed, mobility and access may be considered. Three primary concepts should be considered in establishing the roadway's contextual design controls:

- The character and level of sensitivity of the surrounding natural and built environment,
- The roadway function in terms of providing regional mobility versus local access, and
- The level of access management, i.e., separation versus connectivity, between the roadway and the adjacent land use.

Also refer to Section 9.5.10 for consideration of design elements for environmental protection and enhancements.

9.3.1.2 Functional Classification

The AASHTO *Green Book* establishes a relationship between functional classification and design criteria (refer to *Green Book* Section 1.3). Also refer to FHWA functional classification guidelines. The functional classification of a particular highway establishes a range of design speeds, and together with the selected design speed further defines a range of parameters associated with horizontal and vertical alignment, lane width, shoulder type and width, median area type and width, and other major design features.

The functional classification of the project will normally be determined during the planning and programming phase, and it is verified with consideration of additional data as part of the conceptual engineering studies. Determine the functional classification from a statewide perspective not simply a "forest," "county" or tribal reservation point of view. For NPS projects refer to Section 9.3.1.2.5. Some Forest Highways and IRR roads may fulfill a relatively high function within their respective area; however, the functional classification should be from the point of view of all roads within the State. Many State DOTs maintain maps indicating the functional classification of all roads in that State.

Grade separations and interchange ramps may be associated with highways having any functional classification or design speed. Refer to *Green Book* Chapter 10 for design of grade separations and interchanges.

9.3.1.2.1 Local Roads

Local roads primarily provide access to adjacent land with little through movement. Very few FLH projects are located on routes with local road functional classification. Some Refuge Road projects, IRR projects and ERFO projects are located on local roads.

Green Book Section 5.5 references the VLVLR for design of certain very low-volume local roads (ADT ≤ 400). The VLVLR may be used in lieu of the *Green Book* for designing FLH projects on local roads that fit the criteria. The VLVLR is applicable for local roads that are 1) primarily used by familiar drivers, and 2) design average daily traffic volume of 400 or less. Verify with the

Branch Chief responsible for Highway Design that the VLVLR is appropriate for the specific project.

The VLVLR Exhibits 3, 4, 5, 6, and 7 are based on side friction factors provided in the 2001 edition of the *Green Book*. The values for maximum side friction factor, f_{max}, in these exhibits should be revised using the values provided in the current edition of the *Green Book*. The corresponding values for minimum radius, R_{min}, in these exhibits should be revised using Equation (2) of the VLVLR. FLH standard practice for using the VLVLR is to apply the revised limiting values of f_{max} and R_{min} with Exhibits 3 and 4 for horizontal curve design of the designated roadways. *Green Book* Tables 3-7 and 3-13 may be substituted for the VLVLR Exhibits 3 and 4, respectively to obtain these values. In especially constrained situations, as described in the VLVLR, the revised limiting values of f_{max}, and R_{min} and the reductions in design speed shown in Exhibits 5, 6, and 7 may be used for horizontal curve design of the designated roadways, if endorsed and documented as a variance from FLH highway design standard practice.

9.3.1.2.2 Collectors

Collectors provide a medium level of service at moderate speed for intermediate distances by collecting traffic from local roads and connecting them with arterials. Many FLH Forest Highway and Public Lands projects are located on routes with collector classification.

9.3.1.2.3 Arterials

Arterial roads provide a high level of service at high speeds for relatively long distances, with little interruption and with some degree of access control. Some FLH program projects, and a number of FLH special projects, are located on routes with arterial classification.

9.3.1.2.4 Freeways

Freeways are a type of arterial road that provide full access control, accommodate the highest speeds with no traffic interruption. A few FLH special projects are located on routes with freeway classification.

9.3.1.2.5 National Park Service Roads

The National Park Service, in its 1984 *Park Road Standards*, has established its own system of functional classification. The assignment of a functional classification to a park road is not based on traffic volumes or design speed, but on the intended use or function of the particular route.

The fundamental considerations in park road design are distinct from most other State and local highway systems. The design controls and criteria, design elements, and roadway features may share some theoretical similarities with corresponding AASHTO design criteria, however the purpose of park roads and associated design values are different. Where the source of design criteria is noted as compiled from the 1984 AASHTO *Green Book* (e.g. vehicle dimensions, turning paths, grades, vertical curves, radius, sight distance tables and figures), instead use the corresponding values from the current edition of the *Green Book*. If design criteria and standards for certain elements are not addressed by the *Park Road Standards*, use appropriate values recommended by the *Green Book*.

9.3.1.2.6 Special Routes

When applicable, consider the requirements for special routes designated to serve specific purposes as described below:

- **National Highway System (NHS).** The NHS is separate and distinct from the functional classification system.
- **Strategic Highway Corridor Network (STRAHNET).** The STRAHNET includes highways which are important to support an emergency military defense deployment. The minimum vertical clearance on these routes is 16 ft [4.9 m].
- **Bicycle Routes.** Bicycle routes are designated and signed as preferred routes through high bicycle travel demand corridors. Roadway widths and surfacing are important to assure their usability as discussed in Section 9.3.17.

9.3.1.3 Terrain

The type of terrain has an influence on design speed, maximum grade, and the alignment. Section 3.4.1 of the AASHTO *Green Book* separates terrain into three classifications:

- Level,
- Rolling, or
- Mountainous.

Terrain classifications pertain to the general character of a specific route corridor. For example, routes in mountain valleys and in mountain passes that have all the characteristics of level or rolling terrain should be classified as such. The terrain classification determines the maximum allowable grades in relation to design speed.

9.3.1.3.1 Level Terrain

Level terrain is generally sloping at 1V:20H or less. Sight distances, as provided by horizontal and vertical geometry, are generally long or can be made so without construction difficulty, major expense, or undue adverse effects. Trucks and passenger cars can operate at similar, consistent speeds.

9.3.1.3.2 Rolling Terrain

Rolling terrain is generally sloping between 1V:20H and 1V:3H. Natural slopes repeatedly rise above and fall below the road grade, and occasional steep excavation and embankment slopes restrict or control the horizontal and vertical alignment. The terrain generates steeper grades than in flat terrain, causing trucks to often operate at speeds below those of passenger cars.

9.3.1.3.3 Mountainous Terrain

Mountainous terrain is frequently sloping over 1V:3H. Changes in terrain elevation with respect to the roadway cross section and profile are abrupt. Benched side-hill excavation and limited locations for embankments are typical restrictions that control the horizontal and vertical alignment. The terrain generates steep grades causing some trucks to operate at substantially slower speeds than passenger cars.

The AASHTO *Green Book* recognizes the unique difficulty and expense of road construction in mountainous terrain, and for some geometric design elements, it suggests reduced values in the criteria than for other terrain.

9.3.1.4 Location

Refer to *Green Book* Section 1.3.1 for guidance on determining the applicable location, for determining design criteria. A highway located within the corporate limits of a city does not necessarily determine if it should have an urban cross-section. Consider the development density and land use adjacent to the highway corridor. Presence of several of the following typically indicates urban character:

- Sidewalks or frequent pedestrian travel
- Bicycle usage
- Curbing
- Closed drainage systems
- Cross street frequency 8 or more per mile [5 or more per km]
- Driveway frequency 25 or more per mile [15 or more per km]
- Minor commercial driveway frequency 10 or more per mile [6 or more per km]
- Multiple major commercial driveways per mile [km]
- Numerous right of way constraints

For design of certain cross-section elements, urban roadways may be further categorized as lower-speed urban (40 mph [60 km/h] or less posted or regulatory speed), transitional (45 mph [70 km/h]), and high-speed urban (50 mph [80 km/h] or more).

9.3.1.5 Traffic Volume

Daily, peak hour, and patterns of motor vehicle traffic are key design controls for the roadway facility. Daily traffic estimates are also used in making design decisions related to the total user benefit of a proposed improvement. For example the benefit of highway safety roadside improvements is directly related to the crash exposure (expressed in ADT) on the road. Refer to *Green Book* Section 2.3.2 for guidance on determination of traffic volume.

9.3.1.5.1 Traffic Volume Measures

Refer to Section 4.3.2.3 for a description of traffic volume measures in establishing design controls. Automatic traffic recorder/vehicle classification counts are generally needed for determining the design criteria and for analyzing capacity and delay conditions. Turning movement counts are generally needed for the design of critical or high volume vehicle turning movements at intersections.

9.3.1.5.2 Volume Classifications

For determining design criteria, the *Green Book* classifies traffic volume as < 250, < 400, < 1500, < 2000 or > 2000 average daily traffic (ADT).

9.3.1.5.3 Design Hourly Volumes

Consider the design hourly volume (DHV), or daily peak-hour traffic, in the design of travel lanes and shoulder width, intersection layout, and consideration for level of service to be provided. Refer to the paragraph on "Peak-Hour Traffic" in *Green Book* Section 2.3.2 for guidance on determining the DHV for the project.

9.3.1.5.4 Future Traffic Projections

Projects that are developed should serve a useful function for some time into the future. Projects that involve significant capital investment are generally assumed to have a long functional lifetime, while projects of lesser investment are generally assumed to have a shorter functional lifetime. This requires anticipation of the future transportation demands and resultant safety and operational conditions, at a future period commensurate with the level of capital investment, with and without the project to assess its effectiveness at meeting the transportation needs.

Traffic projections are typically forecast for a period 20 years ahead of the anticipated completion of the construction project. Some metropolitan planning organizations have developed traffic projections on various routes for a specific planning horizon year, based on region-wide traffic modeling systems. To determine the future traffic projection, consider the recent and projected traffic growth rates for other highways in the vicinity, the statewide and national traffic growth rates for similar type of highways, the recent and anticipated population growth rate of the area including areas of trip origin and destination, visitation growth rate, land use planning data, and other available information. Also consider the effects of improvement of the route on trip generation and travel routing, especially if proposed improvements include significant reduction of travel time or significant change in the type of surfacing. Base future traffic projections using a growth rate factor applied to the current traffic volume, including adjustment if applicable for induced traffic growth.

Forecasts of future activity levels should include estimates of pedestrian and bicycle activity. Exercise care when forecasting pedestrian and bicycle volumes to consider latent demand above presently observed pedestrian and bicycle volumes because the facilities do not yet exist in the project area, are substandard, or do not provide complete connectivity to destinations.

9.3.1.6 Level of Service and Mobility

When applicable, determine the level of service (LOS) criteria as a design control to characterize the quality of movement through a transportation network, such as for urban or rural arterials, or urban collector functional classifications. Guidelines applicable for selection of the design LOS are provided in *Green Book* Table 2-5. A variety of analytical methodologies and computer software packages are available to estimate LOS for facility users. The desired level of service should be determined through input of the affected community and the facility stakeholders; therefore ensure that the project participants have a thorough understanding of the resulting level of service from the design so that the expectations can be met, or objectives modified. Generally, for the design year LOS C or better is desired and LOS D is the recommended minimum.

Refer to Section 8.6.2 for guidance on determining appropriate level of service. Refer to *Green Book* Section 2.4 for information on capacity characteristics, levels of service and design flow rates. Also refer to the *Highway Capacity Manual* and the FHWA Traffic Analysis Tools. When applicable in urban areas, determine the level of service for pedestrians, bicyclists, or transit; see NCHRP Report 616, *Multimodal Level of Service Analysis for Urban Streets*.

9.3.1.7 Level of Access and Management

Determine the level of access control and management to maintain safe and efficient roadway operations for all users. Consider the management of driveway locations, approach roads, median treatments, turn lanes, curbs, barriers, and other access management features. The degree of access management is influenced by both the function of the roadway and the roadway context. Consider more stringent access control on arterials than on collectors and local roads, reflecting the mobility and land access functions of these roadways. Consider the existing access points along the roadway and the possibility for changes in access that are consistent with the project's objectives, and need for future access to developing areas. For example, it may be possible to relocate, redesign, or consolidate some driveways along an existing roadway to improve sight distances and safety.

The *Access Management Manual*, TRB, 2003 provides guidance on the application of access management techniques for both existing and new roadways. Also refer to *Green Book* Section 2.5.

9.3.1.8 Cross Section and Multi-modal Accommodation

Determine the design controls that will influence the overall roadway width, and components of the cross section that will accommodate the various users. Approach the formulation of needed cross section components beginning from the right-of-way or construction limits edge to edge then inward, rather than the more traditional approach of beginning from the centerline outward. Through this approach, the accommodation of pedestrians and bicyclists should be positively encouraged and safely enhanced, and contextual elements considered from the outset.

Determine the level of multi-modal accommodation within the cross section for pedestrians, bicyclists and motor vehicles, i.e., whether separate accommodation of travel for all type users must be provided (e.g., sidewalk, bike lane, shoulder, travel lane) or whether some form of shared use may be acceptable within the roadway. If a public transit system exists or is anticipated, determine the level of separate accommodation needed. Consider the operating speed of motor vehicles, and the relative volumes of pedestrians, or bicyclists, or both, the vehicular needs for usable shoulders, roadside or on street parking, and environmental or right-of-way constraints in establishing the level of multi-modal separation or shared-use cross section relationships.

Consider the overall roadside including the criteria for slopes, clear zones, ditch sections, curbs, barrier systems, auxiliary lanes and medians as these elements typically contribute greater influence and impact on the overall cross section than the range of travel lane and shoulder widths considered. Also consider the needs for snow storage, maintenance, placement of utilities (poles and buried conduit), roadside signage, fencing, and other appurtenances for inclusion as cross section design controls.

Determine the various factors that control the range of travel lanes and shoulders that should be considered, (i.e., to meet the highway function, traffic volume, speed and mix of motor vehicles and drivers that are anticipated to use the facility). These factors are discussed in the previous and following sections.

Once the level of multi-modal accommodation, roadside design criteria, and roadway cross section design controls are determined, the dimensions for each cross-sectional element can be identified and assembled. Consider a variety of alternative arrangements that can be combined for the various cross section elements, which optimizes the mobility and safety for all users, within the environmental and right-of-way constraints.

9.3.1.9 Design Vehicle

The design vehicle is the controlling vehicle constraint for design of the project. This can be represented as a standard passenger car, motor home, single-unit truck, bus or semi-trailer. *Green Book* Section 2.1 describes representative design vehicles parameters. Selection of an appropriate design vehicle should be made with knowledge of the existing and anticipated type-of-use, the tradeoffs involved with design and spatial impact, and with input from stakeholders and the public. The largest class of vehicle that uses the facility on a regular basis should be selected as the design vehicle. It should represent a cost-effective choice for the project and be appropriate for its context. The use of the facility by the design vehicle should be a measurable (i.e. over 0.5 percent) and reasonably predictable percentage of the average daily traffic.

9.3.1.9.1 Selection of Design Vehicle

In comparison to some major State highways, FLH Program projects are typically designed with a need to accommodate relatively high-use by recreational vehicles (motor home or passenger car with trailer) or intercity tour buses, and relatively low-use by large semi-trailer trucks.

The AASHTO classification parameters represent all vehicles within a particular classification and therefore the dimensions are larger than most vehicles of that class. Considerations for selection of a design vehicle are summarized in the following:

1. **Passenger Car (P) and Trailers (P/T)**. A passenger car may be selected as the design vehicle when the main traffic generator is parking lot or series of parking lots. A combination of passenger car and boat trailer or camper trailer should be considered when the parking facilities include such recreational uses.
2. **Motor Home (MH) and Boat Trailer (MH/B)**. A motor home may be selected when the main traffic generator is a recreational facility. A combination of MH and boat trailer should be considered when the recreational facility includes such use.
3. **Single Unit Truck (SU)**. A single unit truck may be used for intersection design of major residential streets, and is generally recommended for local roads, collectors and park or forest roads that serve visitor concession facilities. Generally for FLH projects the SU-30 [SU-9] is used rather than the SU-40 [SU-12]
4. **Buses**.
    a. An intercity bus (BUS-45 [BUS-14]) may be used for collector roads and minor arterials, and park roads, serving intercity bus routes, tourism destinations, visitor lodging and interpretive facilities, etc.
    b. A city transit bus (CITY-BUS) may be used for intersections of urban highways and city streets that are designated city bus routes, and otherwise have relatively few large trucks using them.
    c. The large (S-BUS-40 [S-BUS-12]), or conventional (S-BUS-36 [S-BUS-11]), school bus may be used for intersections of highways with low-volume county highways or very low-volume local roads and for residential subdivision major street intersections.
5. **Semi-trailers (WB)**.
    a. The intermediate semi-trailer WB-40 [WB-12] may be used for local or collector roads and minor arterials that serve some level of commercial truck traffic.
    b. The interstate semi-trailer WB-62 [WB-19] or WB-67 [WB-20] should be used for intersections of arterial roads and for other intersections on highways and industrialized streets or industrialized local roads that carry either high volumes of traffic or that provides local access for large trucks.
    c. For Forest Highways and other Forest access roads consider the wheelbase requirements of logging trucks, which are typically less than WB-40 [WB-12] semi-trailers.

9.3.1.9.2 Encroachments and Oversized Vehicles

Using the largest vehicle expected to use the facility on a less frequent basis, as design vehicle can result in a conflict of design objectives (e.g. designing for the larger vehicle results in larger corner radii which increases pedestrian crossing distances and paved areas). Design the facility for use by the largest legal vehicle, or the largest oversized vehicle anticipated, with an allowable encroachment. The allowable encroachment should not extend beyond the paved shoulders or encroach on sidewalks, but may include the opposing travel direction if sufficient sight distance is available for the maneuver and it is permitted by the state's vehicle code. In order to provide a balanced design, encroachments are generally acceptable for:

- Shoulders at intersections,
- Intersections along low-speed urban streets,
- Intersections along low-volume rural roads,
- Single left turns that use two receiving travel lanes in the same direction, and
- Double left or double right turn lanes that cannot accommodate side-by-side operation of the design vehicles, however designs should accommodate a passenger car alongside the design vehicle.

The WB-67 [WB-20] is commonly the largest legal vehicle in many states, and the WB-40 [WB-12] is the most common vehicle to transport commercial products in rural areas. In some areas the maximum oversized vehicle may be a modular home unit on a WB-67 [WB-20] trailer. The dimensions of this trailer may be assumed to be a maximum of 16 ft [4.9 m] high including the trailer, 16 ft [4.9 m] wide, and 56 ft to 80 ft [17 m to 24 m] long. When oversized vehicles encroach beyond the traveled way, consider:

- Wider shoulders,
- Full-depth surfaced shoulders,
- Sloping curb in lieu of vertical curb,
- Stabilized areas behind curbing,
- Relocation of signs, poles, appurtenances,
- Removable signs and appurtenances, and
- Removal of trees and shrubs.

As an alternative to a site-specific evaluation and design for the largest oversize vehicle, consider an alternate routing to bypass the particular site.

Commercially available computer software (e.g., AutoTurn) may be used for verifying vehicle tracking paths at intersections, in parking lots, sharp curves, etc., and for developing templates for special design vehicles.

9.3.1.10 User Characteristics

A fundamental expectation in roadway design is that all users will be accommodated safely. Virtually all roadways serve a variety of users including pedestrians, bicyclists, motor vehicle drivers and their passengers. Determine the composition of users anticipated for the facility, and account their needs. Consider the needs of pedestrians and bicyclists as an initial design control, not as an afterthought later in the design development. When human and vehicular factors are properly accommodated, the safety and effectiveness of the highway is greatly enhanced.

Driver performance and human factors are integral to the determination of highway design criteria. *Green Book* Section 2.2 provides guidance on consideration of user characteristics.

For application of design criteria and design of countermeasures, consider the presence, characteristics and special needs (i.e., information, time, visibility) of the following types of users:

- Pedestrians,
- Bicyclists, and
- Motor vehicle drivers (e.g., inexperienced, aging, unfamiliar, familiar).

Consider a wide variety of pedestrian users and abilities, including children, older adults, and people with various disabilities in the design. Design the facility to accommodate a wide range of pedestrians' physical, cognitive, and sensory abilities, including aids such as wheelchairs and power chairs. Accommodate pedestrian crossing needs at all intersections where sidewalks or pathways exist. Refer to Section 9.3.16 for pedestrian considerations and facilities. Refer to the *Highway Capacity Manual* for definitions of pedestrian level of service based on spatial and delay measurements.

Provide designs that will accommodate and encourage bicycle use. Typically design for bicyclists with moderate skills, which will encompass the needs of most riders. In the vicinity of schools, recreational areas and neighborhood streets consider special accommodation of young, inexperienced bicyclists. An operating space of 4 ft [1.2 m] should be used as the minimum width for one-way bicycle travel. Where motor vehicle traffic volumes, truck and bus volumes, or speeds are high, a more comfortable operating space of 5 to 6 ft [1.5 to 1.8 m] is desirable. Also, adjacent to on-street parking, 5 to 6 ft [1.5 to 1.8 m] is desirable to provide space for the opening of car doors into the travel lane or shoulder. Refer to Section 9.3.17 for bicycle considerations and facilities.

Also refer to Section 9.3.4.1 for discussion of the relationship of human factors and driver performance to the geometric design.

9.3.1.11 Maximum and Minimum Superelevation Rate

FLH standard practice includes the following:

- Establish a maximum superelevation value, e_{max} of 4, 6, or 8 percent, depending on the considerations described below, and

- The minimum superelevation rate, also referred as reverse crown, is equal to the normal crown rate for the type of pavement or surfacing.

Design criteria for e_{max} may be established by individual FLH Division practice, with values selected for the specific project. Establish the e_{max} for the project, with consideration for:

- Climatic conditions during travel seasons (frequency and amount of rain, snow, ice),
- Functional classification,
- Rural or urban location,
- Design speed,
- Frequency of slower-moving vehicles (e.g. trucks, traffic congestion, farm equipment),
- Environment (terrain conditions, elevation, adjacent land use),
- Constructability, and

- Road maintenance.

Higher e_{max} should be used for higher design speeds or friction demands. An e_{max} of 8 percent is typically recommended for higher design speeds, equal to or greater than 50 mph [80 km/h]. In rural areas the e_{max} should typically be either 6 or 8 percent. In urban areas the e_{max} should typically be either 4 or 6 percent, due to the constraints imposed by adjacent development (e.g., intersecting curbs, sidewalks, driveways and streets). In low-speed urban areas, less than 50 mph [80 km/h], the typical e_{max} rates of 4 or 6 percent may be undesired or impractical, and in such cases AASHTO Method 2 may be used for design of curves to minimize superelevation. In such cases the roadway may remain normal crown in curves so long as the resultant side friction demand is less than the allowable side friction factor, *f,* for design (see *Green Book* Figure 3-6).

An e_{max} of 6 percent is typically recommended where snow or icy conditions routinely occur during winter. An e_{max} of 4 percent may be appropriate for locations where the predominant traffic use operates in snow-packed or icy conditions (e.g., primarily serves winter recreation and ski areas). In selecting e_{max} consider combinations of longitudinal grade and cross slope such that the vector components of the curve design superelevation rate, *e* and the longitudinal grade, G should not exceed 10 percent where snow or icy conditions routinely occur during winter, which is expressed by the following:

$$(e\%)^2 + (G\%)^2 \leq 100$$

Green Book Section 3.3.3 provides guidance on selection of e_{max}. See *Green Book* Table 3-19 for maximum limiting superelevation rates for design speeds.

9.3.1.12 Speed Characteristics

Speed is a key design control for the alignment, lane and shoulder width, and the width of the roadside recovery clear zones for errant vehicles. Speed characteristics should meet the user's expectations, and also be consistent with the community's goals and objectives for the facility. Consider the various measures and characteristics of speed for design control, as described in the following sections. Refer to *Green Book* Section 2.3.6 for additional guidance.

9.3.1.12.1 Operating Speed

Operating speed is the speed at which drivers are observed operating their vehicles in typically good weather and surface conditions during off-peak free-flow conditions (not following). Operating speed is measured at discrete points along a roadway. Use the 85^{th} percentile of the distribution of observed speeds to characterize the operating speed associated with a particular location or geometric feature. The operating speed is affected by the roadway features such as curves, grades, topography, width, access to adjacent properties, presence of pedestrians and bicyclists, parking, traffic control devices, lighting, etc.

The 50^{th} percentile (mean) speed is also used for certain operational analyses. The average speed is the summation of the instantaneous or spot-measured speeds, at a specific location, of the free-flowing vehicles divided by the number of vehicles observed.

The pace speed is the highest speed within a specific range of speeds that represents more vehicles than in any other like range of speed. The range of speeds typically used is 10 mph [16 km/h].

A target speed (recommended speed) is the desired operating speed along a roadway, under optimal conditions. The purpose of a target speed is to define an operating environment that provides cues to the driver to conform to the intended speed. An appropriate target speed should be determined early in the project development process and should consider:

- The roadway context (i.e. character of the surrounding area, function of the roadway, and level of access management);
- The roadway geometry including alignment, sight distance, superelevation;
- Other physical conditions such as narrow lanes, roadside development, steep grades;
- The volume and mix of traffic, expectations of facility users, and expected safety performance;
- The anticipated driver characteristics, workload, and level of familiarity with the route; and
- The current range of operating speeds along the route.

The target speed is operating speed rather than desired average running speed. Consider that predicted 85th percentile operating speeds may be significantly higher in many locations along the route than average running speed, and that the actual operating speeds upon completion of the project will differ from what is intended or desired. The target speed should be considered as a factor in the selection of an appropriate design speed as discussed in Section 9.3.1.13.

9.3.1.12.2 Running Speed

Refer to the section on “Running Speed” in *Green Book* Section 2.3.6 for guidance on determination of the running speed for a section of the project.

Average running speed is typically used to characterize conditions on a roadway for analytical (planning, route selection, air quality) purposes rather than for the design of roadway geometry.

9.3.1.12.3 Posted Speed

The posted speed is the signed and legally enforceable speed limit established by the entity with responsibility for the highway. The regulatory speed is the speed limit applicable to the highway in the absence of a posted speed limit, and is typically established by state or local statute, local ordinances or other regulations. The *MUTCD* typically references the posted speed, or the measured 85th percentile operating speed if greater, for design of traffic control devices. Numerous studies have indicated that drivers will not significantly alter what they consider to be a safe operating speed, regardless of the posted speed limit, unless there is continuous enforcement.

9.3.1.12.4 Design Speed

Refer to the section on "Design Speed" in *Green Book* Section 2.3.6. PDDM Section 9.3.1.13 describes considerations for selection of the design speed.

Design traffic control devices (e.g., warning signs, no-passing zones) based on either the overall measured 85th percentile operating speed, or the posted or regulatory speed limit, rather than the design speed.

9.3.1.13 Selecting an Appropriate Design Speed

It is FHWA policy that the design speed should equal or exceed the posted or regulatory speed limit of the completed facility.

Where an established geometric design standard for the posted or regulatory speed cannot be met, and lesser values are proposed, the condition must be treated as a formal design exception as outlined in Section 9.1.3.

To encourage a "self-explaining, self-enforcing" roadway (see Section 9.3.1.14) it is FLH standard practice to select a design speed that:

- Is logical and recognizable to the driver (i.e. the reason for the speed is evident);
- Reinforces the driver's expectations and behavior with respect to the purpose and function of the highway, its location, topography, adjacent land use and intended speed;
- Is appropriate for the topography, adjacent land use, and type of highway; and
- Is consistent with other geometric and roadside design features (e.g., lane and shoulder widths, cross section elements).

The selection of an appropriate design speed involves consideration of many additional factors including the functional classification, expected volume and composition of traffic, usage, operating speeds, access, topography, contextual characteristics, and impacts. The section on "Design Speed" in *Green Book* Section 2.3.6 explains the philosophy of design speed and its relationship to operating speed and running speed. A discussion of design speed is covered in pages 12-13 of the *Park Road Standards*. Recent research on design speed, operating speed and posted speed practices is provided in *NCHRP Report 504* and *Transportation Research Record (TRR) 1796*, 2002.

Typically, a higher functional classification prescribes a higher range of design speeds. Refer to *Green Book* Table 6-1 for recommended design speeds for rural collector roads. For rural arterial roads the *Green Book* recommends design speeds in the range of 40 to 75 mph [60 to 120 km/h]. Also refer to Table 1 of the *Park Road Standards* for typical design speeds.

When either 1) the minimum design speed applicable to the functional classification and terrain, or 2) individual design elements that are based on design speed and addressed on an individual basis, cannot be achieved, address the situation as a formal design exception. The design exception can cover a single location on the project, multiple locations, or the entire project corridor. A lower design speed for an isolated segment of a project should not be proposed as a design exception, due to the importance of relating all geometric features of the highway. A reduction in the design speed in one area may be unlikely to affect overall operating speeds. It may potentially result in the unnecessary reduction of all of the speed-related design criteria in the area rather than just the one or two features that led to the need for the exception. The acceptable alternative approach to such a design speed exception is to evaluate each geometric feature individually, addressing the design exceptions for each feature, and applicable mitigation, within the context of the appropriate design speed.

The design speed is not necessarily constant within the corridor if there are distinct, recognizable zones (e.g. terrain, land use) that are appropriate to change both design speed and posted speed.

Consider the inter-relationship between speed and roadway geometry in design. The selection of design speed influences the geometrics of the roadway. Consequently, the geometrics of the roadway are important determinants of the operating speeds that result on the constructed facility. Current best practice for the selection of a design speed is through an iterative process:

- Develop a preliminary design,
- Estimate the overall 85th percentile operating speeds along the alignment,
- Check for large differences between the 85th percentile speeds on successive curves, and
- Revise the proposed alignment to reduce these differences to acceptable levels.

Where revision of the proposed alignment is not feasible, then effective mitigation to address the speed differences should be provided.

9.3.1.13.1 Coordination of Design Speed, Operating Speed, and Posted Speed

Occasionally projects (e.g. RRR projects) retain geometric elements, such as tight curves, superelevation, or restricted sight distances that, overall, are applicable for a speed lower than the posted speed for the corridor. This may be due to terrain, adjacent land use, or environmental or historic constraints. In these cases, the designer should recommend a posted speed consistent with the overall geometric features. In most instances, the owner agency has the authority to establish the posted speed for the facility. When necessary, the establishment of speed limits, and guidance in setting posted speeds that are consistent with the design of the highway, should be recommended to the owner-agency. However, when system-wide regulatory speed limits prevail they mandate the posted speed.

In order to provide overall design consistency, and to minimize the use of design exceptions, all possible effort should be made to coordinate the proposed design with current standards for the regulatory or posted speed limit through one of the following methods:

- By obtaining agreement with the owning/maintaining agency to establish a posted speed limit that is most consistent with the proposed design, or

- By reconstruction of deficient features to meet the regulatory or posted speed design standards, or
- By a combination of these approaches.

Current best practice for speed management is to establish the posted speed limit with strong consideration for the overall measured 85th percentile operating speed. Higher posted speeds impose greater challenges and constraints on the design. Difficult or constrained conditions may lead to consideration of a lower design speed for an element or portion of the highway. Designs based on artificially low speeds can result in inappropriate geometric features that violate driver expectations and degrade the safety of the highway. Posting a speed limit and setting the design speed significantly lower than the overall 85th percentile operating speed may not adequately address substantive safety needs. It has been found that reducing the posted speed limit (e.g., matching with too low of a design speed) will likely have little or no effect on the overall 85th percentile operating speed without adequate enforcement. Inconsistencies and safety risks inherent in the geometric design cannot be corrected or masked simply by lowering the posted speed limit, even though the number of formal design exceptions, legal liabilities and need for mitigation of safety risks may be perceived as reduced. Instead, emphasize consistency of design so as not to surprise the driver with unexpected features. Where the measured 85th percentile operating speed is significantly higher overall than the posted speed limit (e.g., 10 mph [16 km/h] or more), it is recommended to use a design speed that is higher than the posted speed limit.

9.3.1.13.2 Considerations of Speed

Design speed selection should seek to balance the benefits of high speed for mobility, efficiency and long-distance regional travel with environmental, community, right-of-way, and construction-cost constraints. The longer the trip, the greater the driver's desire to use higher speeds, therefore knowledge of users' travel distance from trip origin to destination is important. Except for local streets, park roads and other recreational roads where higher speeds are not needed or desired, every effort should be made in the design to minimize the time of travel and to use as high a design speed as practical. On rural highways, a greater percentage of vehicles are usually able to travel at the limiting speed that is governed by the geometric design, so the selection and relationship of the geometric design elements affecting speed are especially important to optimize. On rural arterials, the driver expectation is to safely operate at higher speeds than for collector and local roads.

Occasionally a project's existing geometric elements, including horizontal and vertical curvature, sight distance, lane and shoulder width, are generally suitable for speeds significantly higher overall (more than 10 mph [16 km/h]) than the posted speed for the corridor. This may be due to gentle terrain, or the prevalence of design values that are several times greater than the minimum for the posted speed. In these cases, the designer should evaluate the inferred design speed, which is the maximum speed for which all critical design-speed related criteria are met for a particular length of the highway. The inferred design speed for a horizontal curve radius-superelevation design is the maximum speed for which the limiting-speed side friction value, f_{max}, is not exceeded for the design superelevation rate. The inferred design speed for a vertical curve is the maximum speed for which the limiting-speed stopping sight distance is not exceeded. An inferred design speed that is significantly higher than the posted speed may result in operating speeds that are substantially higher than anticipated. In these cases the design speed for the project should be selected with strong consideration of the inferred design speed, as well as the posted speed and operating speed. Where applicable, consider speed reduction techniques for transitions to lower-speed environments.

9.3.1.13.3 Considerations of Calming and Low-speed Environment

In selecting a design speed consider appropriate elements to maintain the safety of pedestrians, bicyclists, and anticipated mix of slower traffic (e.g. local farm vehicles, local residential and commercial vehicles), and include transitional elements at locations necessitating lower operating speeds. Traffic calming measures may be considered, primarily in residential neighborhoods, to address demonstrated safety problems caused by excessive vehicle speeds and conflicts with pedestrians, bicyclists, and school children.

Where conflicts exist between higher-speed and lower-speed users, pedestrians, bicyclists, wildlife, recreational uses, residential activity, business activity and complex traffic situations, it may be beneficial to provide lower design speed criteria, features and traffic calming measures for reduced speeds, as appropriate. Speed can be reduced by inducing curvature into the alignment, with greater accumulated curvature deflection of the alignment having greater affect. A curvilinear alignment consisting of a series of low-speed curves, with a gradual change in radius between the successive curves, will reinforce the desired low-speed operation. Sudden unexpected changes in the alignment, profile, cross section or roadside elements are not recommended; however, gradual changes over a transition section that is apparent to the driver can be effective to introduce a low-speed operating environment.

Traffic calming measures include features added to the roadway to create horizontal or vertical deflections, narrowing the real or apparent roadway width and more constrained cross section, signing, noise, humps or vibration to increase the driver's awareness of speed, and devices increasing the driver's attentiveness to the presence of pedestrians. A description of traffic calming techniques is available at Traffic Calming from FHWA and from Traffic Calming for Communities from ITE. Additional guidance on traffic calming is provided in Section 8.5.5 and TrafficCalming.org.

9.3.1.13.4 Managing Variations in Operating Speed

Many vehicles operate at speeds higher than the design speed on long tangents and flatter curves. These vehicles have to slow to the design speed in order to safely and comfortably negotiate the sharpest curves. In areas of sharp curves, the radius and the superelevation of adjacent curves should be designed to limit the difference in operating speed between the curves to a maximum of 15 mph [20 km/h], and preferably, to less than 5 mph [10 km/h]. If the maximum differential is exceeded, the plans must include advance curve and advisory speed signs for the lower speed curves. Additional delineation of the lower speed curvature should be considered on a case-by-case basis (e.g., delineators, raised pavement markers, chevrons).

The IHSDM and its associated references provide methodology to determine the predicted operating speeds for a particular design and horizontal alignment. Application of the IHSDM is described in Section 8.4.5.1

Alternatively, the variation in operating speed may be roughly predicted by determining the inferred design speed of the geometry at various locations based on a comparison with the horizontal and vertical design criteria prescribed by the *Green Book* for the various design speeds, and by a correlation of the inferred design speed with observed operating speeds. The speed correlations are described in *NCHRP Report 504*.

Except for a controlled intersection, design of the roadway geometry for less than 20 mph [30 km/h] is not recommended. For design speeds of 60 mph [100 km/h] or greater, strive to provide a design having highly consistent geometry that facilitates vehicle operation at a uniform speed. Exhibit 9.3-A describes recommended maximum variations in operating speed for design consistency.

Exhibit 9.3-A MAXIMUM VARIATIONS IN OPERATING SPEED BETWEEN SUCCESSIVE CURVES, AND BETWEEN LONG TANGENTS AND CURVES, FOR DESIGN CONSISTENCY

Condition Status	US Customary			Metric		
	Design Speed (mph)			Design Speed (km/h)		
	< 35	35 to 55	> 55	< 60	60 to 90	> 90
Unacceptable	15	20	15	25	30	25
Undesired	10	15	10	15	20	15
Typical	5	< 10	5	10	< 10	5
Desired	5	5	0	5	5	0

For recommended maximum variations of operating speeds between the main roadway and interchange ramps, refer to *Green Book* Section 10.9.6. For weaving sections see *Green Book* Section 2.4, 10.9.3 (subsection entitled “Cloverleafs”), and 10.9.5.

Also refer to Section 9.3.4.2 for additional guidance on the concepts of design consistency.

For high-speed roads, a reduction in operating speeds in the area of a major intersection may be beneficial. For high-speed roadway segments approaching a major intersection, consider the need for a speed reduction treatment within a transition area of sufficient length for comfortable deceleration in advance of the intersection. Refer to NCHRP Report 613, *Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections*.

9.3.1.14 Self-explaining, Self-enforcing Road Concepts

Incorporate self-explaining, self-enforcing road concepts into the design, as appropriate. The concept of the self-explaining, self-enforcing road is that the road (both the roadway and the roadside) is specifically and completely designed for a particular, commonly recognizable, purpose or function. This concept, or philosophy, relies on the physical roadway design attributes to passively "enforce" or reinforce intended operating speeds and other driver behaviors, rather than relying primarily on signs, directives and active enforcement. Conflicting road attributes (e.g., a high-speed cross section combined with a low-speed alignment) are removed, and agreeing design attributes are substituted, which maintain safety and desired operations. This philosophy is considered a speed management and behavioral design approach in which the objective is not necessarily to restrict speed, but to plan and design a roadway where the appropriate speed and operational safety naturally result, and a "self-explaining" look and feel is achieved for the particular type of highway facility.

Implement this concept by including in the design various roadway design features and treatments, including aesthetic enhancements, which are commonly associated with a recognizable "standardized" road category, to communicate to the driver the sense of its function type and the facility context. Special treatments should be provided at the transition zones between differing road functions or speed categories, to serve as "gateways" that overtly emphasize and accentuate those attributes that define the new road function and its intended speed. Design the new road function (and its intended speed) to be readily recognized and understood by the driver. Design a recognizable speed-reduction treatment to transition between a high-speed rural countryside and a low-speed suburban community. Also, design a recognizable speed-reduction treatment to transition between a high-speed arterial highway and a low-speed interpretive park road. The criteria and guidelines described in Section 9.3.1.13.4 may be applicable to these transitions. In addition to emphasizing the transition zones, fully provide the design and safety features appropriate for the differing road function or speed categories. For additional description of the concepts and philosophy of a self-explaining, self-enforcing road design, see *Geometric Design Practices for European Roads* (FHWA, June 2001).

9.3.2 AESTHETIC CONSIDERATIONS

FLH standard practice is to:

- Emphasize curvilinear alignment, generally defined as having an equal or greater proportion of the alignment in curves than on tangents, and
- Apply the general considerations, general design controls, and alignment coordination found in *Green Book* Section 3.5.

Also strive to accomplish the following:

- Provide curvilinear alignment through scenic terrain.
- Avoid short, abrupt horizontal and vertical curves, especially if the central angle or change in grade is small and a substantial length of both tangents is visible.
- Designate sufficient right-of-way area on the inside of curves, and at the ends of long tangents, to facilitate adequate control of vegetation or setback of potential future development that could impair sight distance, and tangential views, especially in scenic terrain.

Broken-back vertical curves are visually unpleasing and undesired, and should be substituted with a single overall vertical curve when practical.

From an aesthetic standpoint, the geometric design for bridges should blend in with curvilinear alignment. Design superelevation to avoid or minimize unsightly kinks, humps or dips in bridge railing or curbs. Coordinate the vertical alignment closely with the bridge location. Consider that bridges placed on conspicuous sag vertical curves can have an unfavorable appearance.

Coordinate the clearing, slope design, and vegetation management in vista areas to provide a visual buffer, frame views, define spaces or to provide visual context for the roadway. Consider aesthetic treatment of curbs, culvert headwalls, retaining walls, traffic barriers, and structures to blend and de-emphasize new features and enhance prominent vistas. Consider the location and type of signing, posts, fencing and other appurtenances to minimize blockage of views.

The ultimate test for an aesthetically pleasing facility is whether it complements the area through which it passes and enhances the user's appreciation of its context. The designer should strive to achieve this goal.

9.3.3 HORIZONTAL AND VERTICAL ALIGNMENT RELATIONSHIPS

Apply the general controls and guidelines for coordination of line and grade described in *Green Book* Section 3.5.2, and also refer to *Green Book* Figure 3-46 for recommended alignment and profile relationships in roadway design.

Horizontal and vertical alignments should not be designed independently. Horizontal and vertical alignments are mutually related and their interrelationship can have a significant effect on the operational and safety characteristics of the roadway. What applies to one is generally applicable to the other. The highway designer should visualize the completed facility in a three-dimensional mode to ensure that the horizontal and vertical alignments complement each other and enhance the beneficial features of both. Excellence in a coordinated design will maximize the sight distance and safety of the highway, encourage uniform speed and make a positive contribution to the visual character of the road.

9.3.4 COMBINATIONS OF DESIGN ELEMENTS AND FEATURES

Consider design criteria and elements in combination with all the various elements and features that interplay at any given location, and in sequence, along the highway, rather than each in isolation. Specific considerations are described in the following sections.

9.3.4.1 Human Factors and Driver Performance

In developing the highway design, consider human factors with the intent to minimize driver error. Refer to *Green Book* Section 2.2 for information on the driving task, guidance tasks, roadway information handling, and driver error. Also refer to the *Highway Design Handbook for Older Drivers and Pedestrians*, FHWA-RD-01-103, which provide recommendations for improving the highway design beneficial to all users.

9.3.4.2 Design Consistency

Provide geometric design elements and operational features consistent with driver expectancy and the driving tasks required. Provide a highway design that minimizes:

- Changes in predicted 85th percentile operating speed,
- Changes in predicted roadway safety,
- Improper lane positioning,
- Complexity of traffic control devices, and
- Driver workload.

Consistency with respect to these measures can help minimize the potential for driver error.

At locations where the highway characteristics change, provide adequate visibility or notice of the changed condition, and provide the safest environment possible.

Design consistency also relates to using consistent design speeds for the design of the various individual geometric elements present along the corridor and consistent application of criteria for various design elements. If design speed for a horizontal alignment is increased (e.g., to match the posted speed limit), all design criteria must meet the standards for the increased speed.

Alignment consistency refers to the design of successive geometric design elements to minimize large variations in operating speed, using curvilinear alignment design to avoid long tangent lengths and designing sequences of horizontal and vertical alignment elements which follow one another within acceptable ranges for variation in operating speed. Designs that generally conform to the terrain contours (i.e., "laying lightly" on the landscape) will generally result in a curvilinear alignment; however, variability in the alignment consistency can be expected to increase as the severity of the terrain, or other alignment controls, increases.

It is especially important to consider successive curve radii in transitions from long tangents or flat curves to those of minimal radius, since actual operating speeds typically exceed design speeds on tangents and flat curves (radius greater than 1,500 ft [450 m]). In evaluating alignment consistency the designer may assume 85th percentile operating speeds of 60 mph [100 km/h] approaching curves following tangents or flat curves with radius greater than 1,500 ft [450 m], for distances traveled in 30 seconds or more at the design speed, on rural two-lane highways. See Section 9.3.1.13.4 for guidance on managing variations in operating speed between successive curves.

Refer to NCHRP Report 502, *Geometric Design Consistency on High-Speed Rural Two-lane Roadways* for additional information on design consistency.

9.3.4.3 Combinations of Design Elements with Intersections and Bridges

Combinations of alignment and cross section design elements, together with such features as intersections and bridge structures, must be carefully considered during design. The complex traffic operations at intersections are sometimes difficult to predict, and may be exacerbated by unforeseen traffic peaks and future operational conditions. The design of bridge structures may far outlast the life of the original roadway alignment or cross section, and may in the future experience greater traffic volumes and speeds than originally envisioned for the roadway. Avoid using minimum design criteria at these types of locations, especially the combination of minimal design criteria for multiple design elements (e.g., horizontal and vertical alignment, lane and shoulder width, sight distance).

Where possible, locate bridge structures entirely on tangents, curves, or superelevation transitions, but not on combinations of these. This may require minor adjustments in horizontal alignment to avoid or minimize these types of combinations. Wherever possible, avoid the introduction of new cross section elements (widening, additional lanes or shoulders) on the bridge, but introduce the cross section element ahead of the bridge and carry the element across the bridge structure.

9.3.4.4 Additive Design Risk Assessment

Safety and operational risks increase substantially as combinations of critical design elements are added. Combinations of minimal horizontal curve geometry, minimal vertical curve geometry, minimal roadway width and cross section elements, steep grades, limited sight distance, presence of intersections and driveways, structures and barriers each add a greater level of risk to the situation. While using minimum design criteria for a single design element may not pose a great risk, the combination of minimum design criteria, or below-minimum design criteria, or both, for several design elements at the same location may result in unacceptably high levels of safety or operational risk. When using minimum design criteria is proposed, the combinations of other roadway and design elements and features should also be considered.

Consider the combinations of volume, speed and type of traffic that is exposed to the risk, in evaluating the site-specific conditions (e.g., nighttime versus daytime traffic volume and speed) to factor into design risk decisions.

9.3.5 HORIZONTAL ALIGNMENT

Refer to *Green Book* Section 3.3.13 for general guidelines applicable to the design of all horizontal alignment.

The horizontal alignment design should provide for safe and continuous operation at a uniform design speed for substantial lengths of highway. Use an iterative geometric design process consisting of sufficient analysis to determine the predicted operating speeds on tangents and curves, and a feedback loop to adjust the horizontal alignment design. The design speed, minimum radius, superelevation, and transitions are the primary criteria in horizontal alignment design. These design elements are related by the laws of mechanics and also involve side friction factors, centripetal force, gravity, etc. that are discussed in detail in the following subsections.

In addition to the above general criteria, apply the following considerations in all horizontal alignment design:

- Safety,
- Functional classification,
- Topography,
- Compatibility between existing and proposed conditions (contextual controls)
- Tangent to curve transitions
- Vertical alignment,
- Compatibility with the roadway cross section,
- Design vehicle characteristics,
- Driver characteristics, driver expectancy and workload,
- Lines of sight,
- Drainage considerations,
- Construction cost,
- Environmental protection,
- Cultural development, and
- Aesthetics.

These factors, when properly balanced, should produce an alignment that is safe, economical and in harmony with the natural contour of the land and the environment.

9.3.5.1 Horizontal Curves

Horizontal alignment design focuses on the design of horizontal curves, as they are the primary controlling feature. The following sections address the elements for design.

9.3.5.1.1 Speed

Speed prediction is an essential element that should be considered in the development of the geometric design and especially for design of horizontal alignment and curves. Refer to Section 9.3.1.12 for a description of speed characteristics relating to highway design.

9.3.5.1.2 Side Friction Factor

FLH standard practice is to use the *Green Book* values of side friction factor for curve design. Refer to *Green Book* Figure 3-6 and Table 3-7 for side friction factors assumed for design.

For unpaved roads, the designer may establish an appropriate value for side friction factor that is less than the values provided in the *Green Book*. VLVLR Exhibit 17 lists ranges of traction coefficients used by the Forest Service in design of unpaved or snow-packed roads

(ADT ≤ 400), and recommends using a side friction factor that is 0.2 less than the listed traction coefficients as a basis for establishing minimum radius.

9.3.5.1.3 Superelevation

FLH standard practice is to use AASHTO Method 5 for determination of design superelevation rates for the various curve radii of a horizontal alignment. Refer to *Green Book* Figure 3-8 for a description of the Method 5 procedure for superelevation distribution.

Superelevation may be minimized in low-speed urban areas, 45 mph [70 km/h] or less, by using AASHTO Method 2 for design of curves. In such cases the roadway cross slopes may remain normal crown in curves so long as the resultant side friction demand is less than the allowable side friction factor, *f,* for design (*Green Book* Figure 3-6). Refer to *Green Book* Table 3-13 for minimum radii and superelevation in low-speed urban areas, in cases where the typical superelevation rates using AASHTO Method 5 are either undesired or impractical. See *Green Book* Section 3.3.6 for additional guidance in such cases.

Very flat horizontal curves need no superelevation because the side friction needed to sustain the lateral acceleration developed by vehicles, even at high speeds, is minimal. The minimum curve radii for a section with normal crown (NC) are designated in the *Green Book* superelevation tables (Tables 3-8 to 3-12). See *Green Book* Section 3.3.5 for more information.

9.3.5.1.4 Curve Radius

Refer to *Green Book* Section 3.3.5 for guidance on selection of the minimum curve radius. Select a curve radius that fits the terrain and other controls, and that meets, and preferably exceeds, the minimum criteria for the design speed. Strongly consider adjacent curves to minimize excessive variations in operating speed and to promote design consistency. Refer to Section 9.3.1.13.4 for guidance in managing variations in operating speed.

9.3.5.1.5 Reversals in Alignment

Avoid abrupt reversals in alignment by providing enough room between curves for superelevation runoff or for spirals. See Section 9.3.5.2 for information on horizontal curve and superelevation transitions. Design the tangent distance between reversing curves to either be sufficiently long to establish a normal crown (tangential) driving mode, or a lesser length to provide a flowing reversal of the superelevation with a continuous transition between the reversing curves.

For simple, reversing curves with intervening normal crown template, design the tangent distance to preferably exceed 6 to 7 seconds duration, at the design speed. For a continuous, merged transition between the reversing curves, preferably design the tangent length to be approximately 3 to 4 seconds duration. For simple curves, tangent lengths of 5 seconds duration at the design speed may cause conflicts with the desired superelevation transitions.

9.3.5.1.6 Broken Back Curves

Broken-back curves (i.e., adjacent curves in the same direction with short intervening tangents) violate drivers' expectations. When broken-back curves are visible for some distance ahead, they present an unpleasing appearance, even with tangents as long as 1,300 ft [400 m]. It is desirable to introduce a slight reverse curve between them to eliminate the broken-back effect. Broken back curves with intervening tangent lengths of 200 ft to 400 ft [60 m to 120 m] are especially undesirable. However, broken-back curves may be necessary in difficult terrain or due to sever alignment controls. In some cases, a single long curve or compound curves may be preferred to replace the broken-back curve.

9.3.5.1.7 Compound Curves

Avoid compound curves if practical because drivers do not expect, or readily discern, changes in the rate of curvature within a curve and will tend to drift outside of their travel lane. However, compound curves may be necessary in difficult terrain or due to severe alignment controls, to eliminate excessive cuts or fills, encroachments into rivers or creation of broken-back curves. A single curve, in cases of minimal additional impact, is always preferable to a compound curve.

Because neither compound nor broken-back curves are desirable, involve senior design experience and judgment to determine which to use in an unavoidable situation.

When designing for compounding curves, the radius of the flatter curve should not be more than one-and-a-half times that of the sharper curve. If this is impractical, design a partial spiral or a curve of intermediate radius between the main curves. The rate of change in radius of a partial connecting spiral should be approximately equal to the average for the normal spirals used on the curves. Intermediate connecting curves should have a length not less than the runoff length for the flatter main curve as obtained from the superelevation runoff tables as shown in the *Green Book*.

The arc length of compound curves should be designed to provide at least 3 seconds, and preferably 5 seconds, of driving time on each main curve, excluding transitions.

9.3.5.1.8 Small Deflection Angles

Small alignment angle deflections (less than 5 degrees) should have relatively long curves to avoid the appearance of a kink. The minimum curve length should provide at least 3 seconds, and preferably 4 seconds, of driving time on the curve.

Avoid very small angle deflections (less than 1 degree) if practical by substituting a single tangent. Angle deflections of 15 minutes and less may become undetected and thus can create computational problems with design or surveying software data, and should not be used in the design. When very small deflections of between 15 and 40 minutes are required (e.g., to connect with a previously established tangent construction), they do not necessarily require using a curve, but it is preferable to locate changes in grade with vertical curves at these angle points to mitigate the visible effect to the road user.

Ensure tangency at all connections of tangents with curves or spiral curve transitions, and at compound curves. In no case provide an angle point at these locations.

9.3.5.1.9 Curvature on Through-Fills

Use only very flat curvature on long, high through-fills, unless guardrail, or other measures (e.g., delineators, guardrail retro-reflectors), or both, are used to delineate the edge of the roadway.

9.3.5.2 Horizontal Curve and Superelevation Transitions

The design of horizontal curve transitions includes the transition of the roadway cross slope as well as the possible incorporation of a spiral or compound transition curve in the alignment geometry. Refer to *Green Book* Section 3.3.8 for general guidance on horizontal curve and superelevation transitions.

The following sections provide guidance on specific design considerations for superelevation transitions.

9.3.5.2.1 Attainment of Superelevation on Tangent and Curve

The following FLH superelevation transition standards apply:

- Provide at least the minimum superelevation runoff length (L_r) determined by *Green Book* Equation 3-23,
- For determining the maximum superelevation runoff length, provide a relative gradient that is at least 70 percent of the maximum relative gradient values in *Green Book* Table 3-15, and
- Proportion the superelevation runoff on the tangent and curve within the allowable ranges, as described below.

FLH standard practice is to design the tangent runout distance (L_t) based on the same relative gradient as the superelevation runoff, as shown in Exhibit 9.3-B:

$$L_t = e_{ncr} \times L_r / e_d$$

where:

e_{ncr} = normal crown rate (%)

e_d = design superelevation rate

L_r = Superelevation runoff length

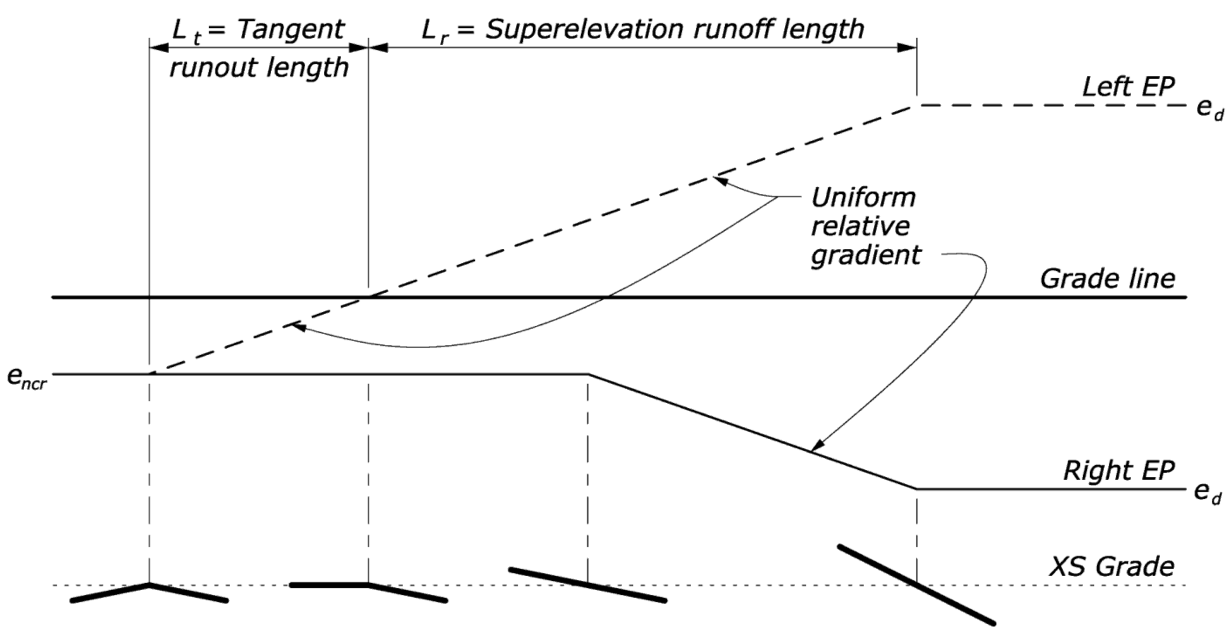
FLH standard practice is follow the *Green Book* recommended values for location of the superelevation runoff, with inclusion of the additional criteria described herein. *Green Book* Table 3-18 provides recommendations for allocation of the superelevation runoff between the tangent and curve to minimize vehicle lateral shifts, based on theoretical considerations.

To resolve the transition conflicts caused by a short tangent distance between curves, FLH standard practice includes the following:

- Up to 50 percent of the runoff length may be located on the curve and 50 percent on the tangent, if it is impractical to provide sufficient tangent length to accommodate the standard allocation of superelevation runoff; however,
- At least 60 percent of the superelevation runoff length on the tangent is the minimum desired, and 80 percent on the tangent is the maximum desired, for two-lane roadways; and
- For certain situations such as a short curve length, or if necessary to accommodate reversing curves with merged transitions, up to 90 percent of the superelevation runoff length may be located on the tangent.

Where there is insufficient tangent length to accommodate the minimum superelevation runoff length or allocation criteria between curves, redesign the curves to provide the minimum runoff length, or address the situation as a formal design exception. If the portion of superelevation runoff located on the tangent is not within the range of 50 to 90 percent, a formal design exception is required for the superelevation transition.

Exhibit 9.3-B SUPERELEVATION ATTAINMENT BETWEEN TANGENT AND CURVE



9.3.5.2.2 Reverse Curve Transitions

FLH standard practice for reverse curve transitions includes the following:

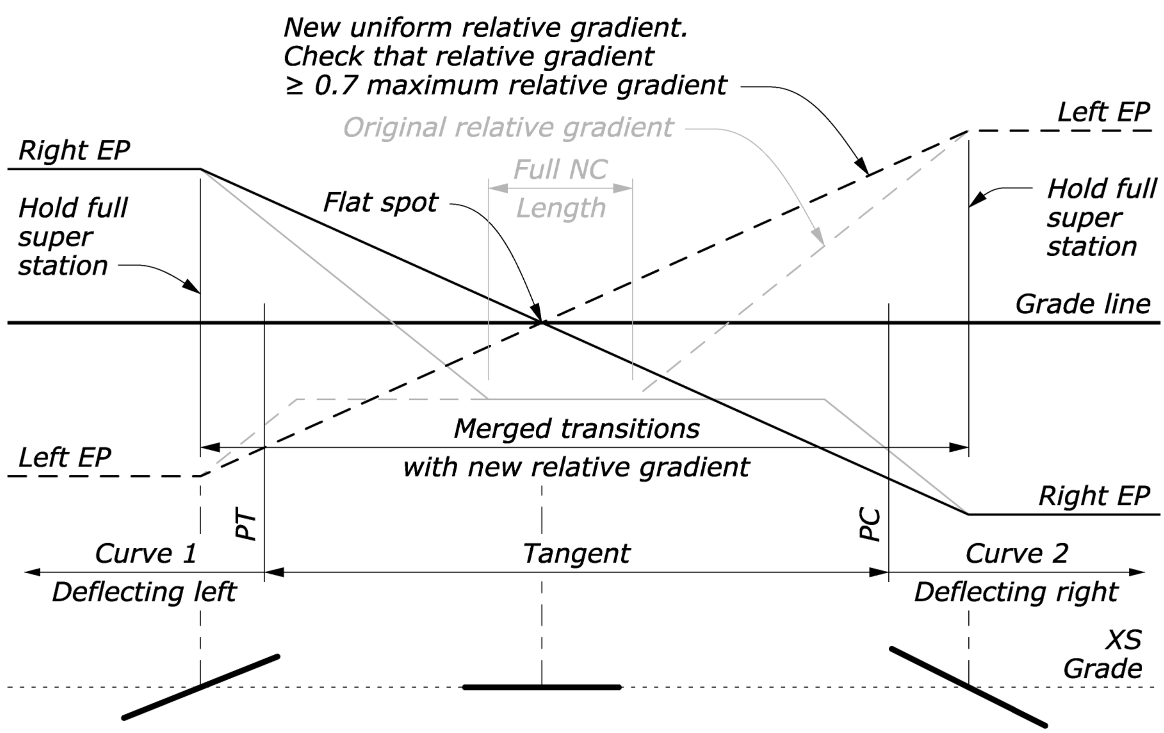
- The minimum length of normal crown section between reverse curves is 100 ft [30 m],
- The desired length of normal crown section is at least 200 ft [60 m], or 3 seconds travel time at the design speed whichever is greater, and
- In no case let tangent runouts overlap.

Provide superelevation runoff between the minimum and maximum lengths, and proportion the superelevation runoff on the tangent and curve within the allowable range, as described in Section 9.3.5.2.1. Otherwise, treat the situation as a formal design exception.

If the initially designed length of normal crown section is less than 1½ times the normal cross section interval, and less than 75 ft [30 m], FLH standard practice to resolve the situation includes the following, (as shown in Exhibit 9.3-C):

- Combine (merge) the two transitions as a supercritical case; and
- If the resultant relative gradient is within the maximum and minimum values, use the same uniform relative gradient for each transition, with the zero percent positioning determined by the original designed (unadjusted) full super (FS) stations; or
- If the relative gradient is not within maximum and minimum values, locate the zero percent position at a distance ratio based on the superelevation rate (*e*) of each curve, and use the average of the two original designed relative gradients, that it is within the maximum and minimum values.

Exhibit 9.3-C TREATMENT OF REVERSE CURVES: SUPERCRITICAL CASE

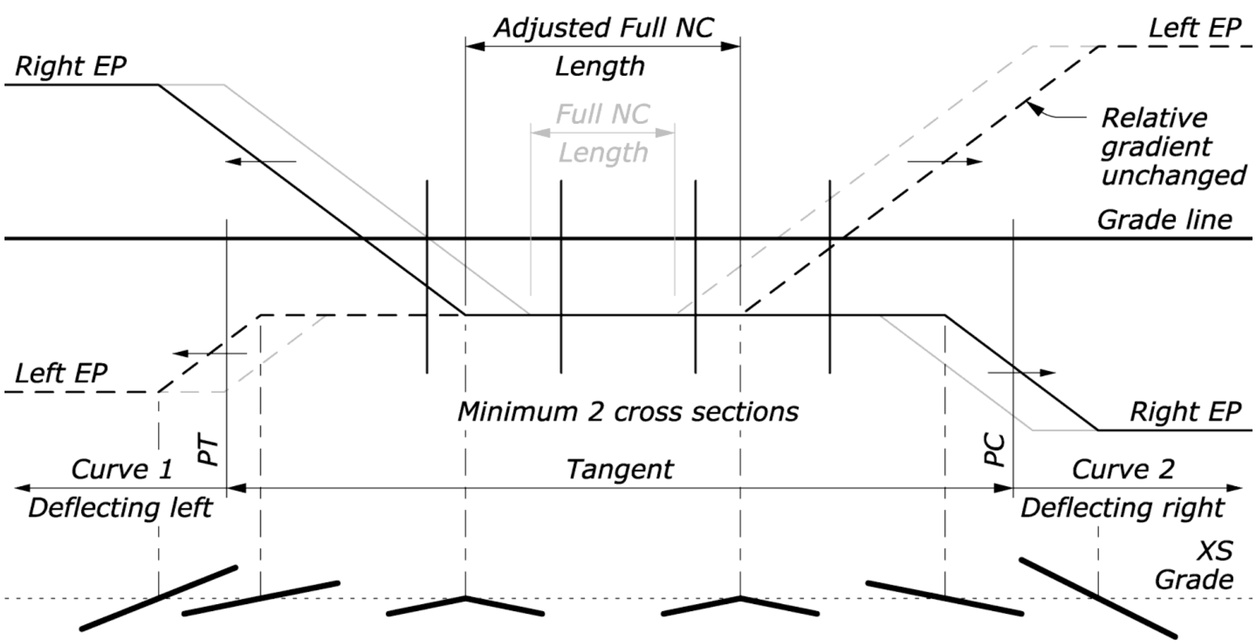


If the initially designed length of normal crown section is between 1½ and 2 times the normal cross section interval, or between 75 ft and 100 ft [30 m and 40 m] either adjust the full super stations to provide the necessary length of normal crown section, or provide an intervening section of minimum super rate (reverse crown).

To resolve a superelevation transition conflict (critical case) and provide the minimum normal crown section of at least 100 ft [30 m], the necessary length of normal crown section may be provided by adjusting the locations of the superelevation runoff relative to the ends of each curve (PT and PC) as shown in Exhibit 9.3-D, or by increasing the relative gradient (i.e., reducing the superelevation runoff length), or by a combination of both of these solutions. FLH standard practice in this case is to hold the original designed relative gradients and adjust the FS stations, if necessary, to provide the minimum length of normal crown section, within the following parameters:

- The portion of the superelevation runoff lengths located on each curve may be increased, providing that the portion of the superelevation runoff located on the curve does not exceed 50 percent.
- The original designed superelevation runoff length may be decreased, providing that the minimum superelevation runoff length (L_r) determined by *Green Book* Equation 3-23 is provided.

Exhibit 9.3-D TREATMENT OF REVERSE CURVES: CRITICAL CASE

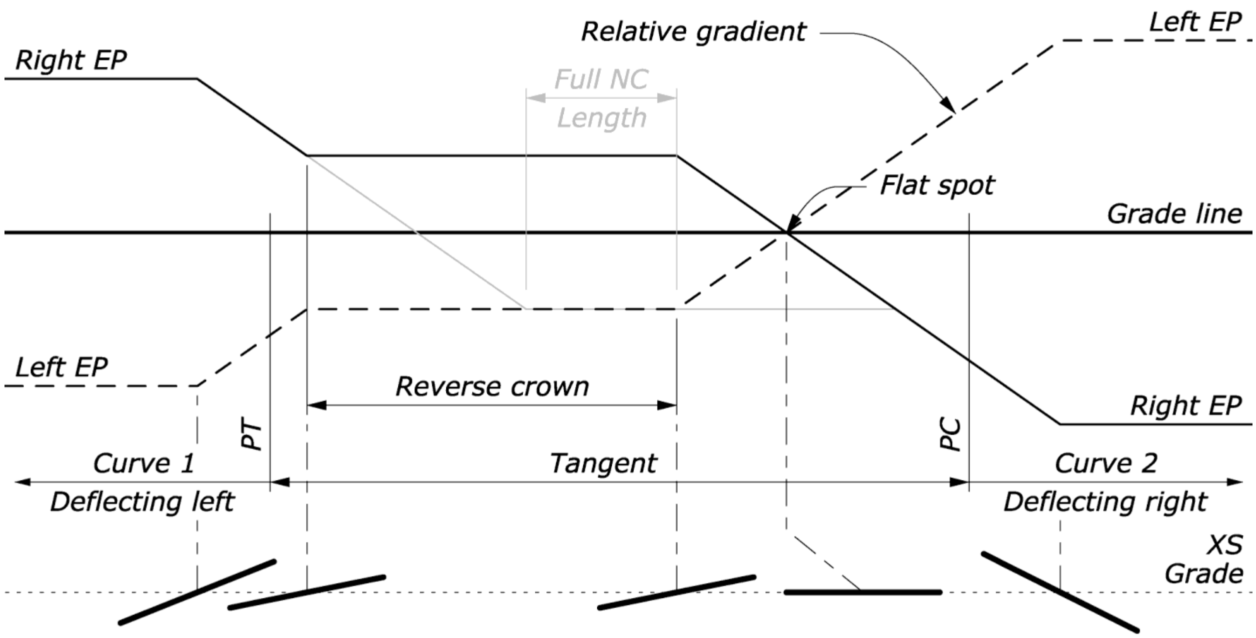


For intermediate tangent lengths between reversing curves, when the initially designed tangent length is insufficient to develop a minimum normal crown section of at least 100 ft [30 m], and desirably 200 ft [60 m] or 3 seconds of travel time at the design speed, yet is too long to merge the transitions comfortably between the curves with either the desired relative gradient, or desired allocation of superelevation runoff on the curve, or both, a section of minimum super rate (reverse crown) may be provided within the transition. FLH standard practice in this case includes the following as shown in Exhibit 9.3-E:

- The transition from full super to minimum super (reverse crown) passing through zero percent may be associated with either curve, depending on the geometric or pavement drainage considerations,
- Provide a minimum length of reverse crown section of at least 50 ft [20 m], or 1 second of travel time at the design speed whichever is greater, and

- Design the resultant superelevation transitions to provide the same relative gradient for each curve transition, within the maximum relative gradient recommended in *Green Book* Table 3-15, with approximately one-third of the theoretical superelevation runoff for each transition located on the curve and two-thirds on the tangent.

Exhibit 9.3-E TREATMENT OF REVERSE CURVES: USE OF REVERSE CROWN



9.3.5.2.3 Compound Curve Transitions

FLH standard practice is that the relative gradient of the superelevation transition must not exceed the maximum relative gradient values in *Green Book* Table 3-15, and should not be less than 70 percent of these values.

There are two primary considerations for designing superelevation transitions for compound curves:

1. Transition length
2. Position with respect to the PCC (allocation percentage on each curve)

FLH standard practice includes the following:

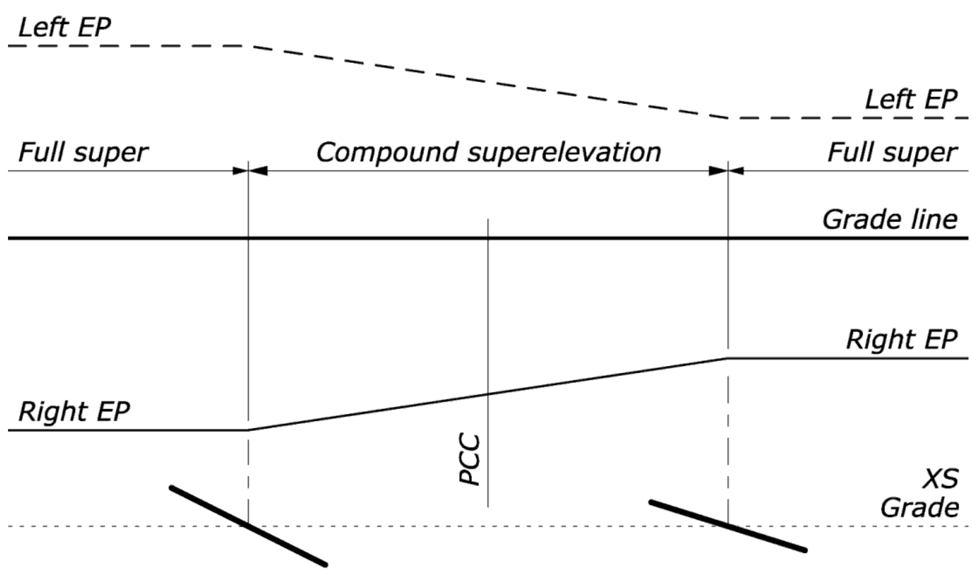
- Determine the relative gradient(s) appropriate for each curve, based on the design of a theoretical tangent transition for each curve;
- Determine the compound curve transition length, L_{cc}, based on *Green Book* Equation 3-23 by substituting L_{cc} for L_r, and substituting the difference in the design superelevation rates of both curves for e_d, and the average theoretical relative gradient of both curves for Δ;
- Determine the distribution percentages based on a ratio of the design superelevation rate (e_d) of each curve, divided by their sum:

$$\frac{e_d\,(curve1)}{e_d\,(curve1)+e_d\,(curve2)} \text{ and, } \frac{e_d\,(curve2)}{e_d\,(curve1)+e_d\,(curve2)};$$

- Allocate the lesser percentage of the compound curve transition length on the sharper curve, and the greater percentage length on the flatter curve, to establish the position of the full super stations with respect to the PCC.

Refer to Exhibit 9.3-F.

Exhibit 9.3-F COMPOUND CURVE TRANSITION



9.3.5.2.4 Broken Back Curve Transitions

FLH standard practice is that the minimum length of normal crown section between broken back curves is 200 ft [60 m], or 3 seconds of travel time at the design speed whichever is greater.

Broken back curve transitions may be categorized as one of three treatments:

1. Short intervening tangent treated as a compound curve
2. Intermediate intervening tangent with a minimum super rate (reverse crown) section
3. Long intervening tangent with a normal crown section

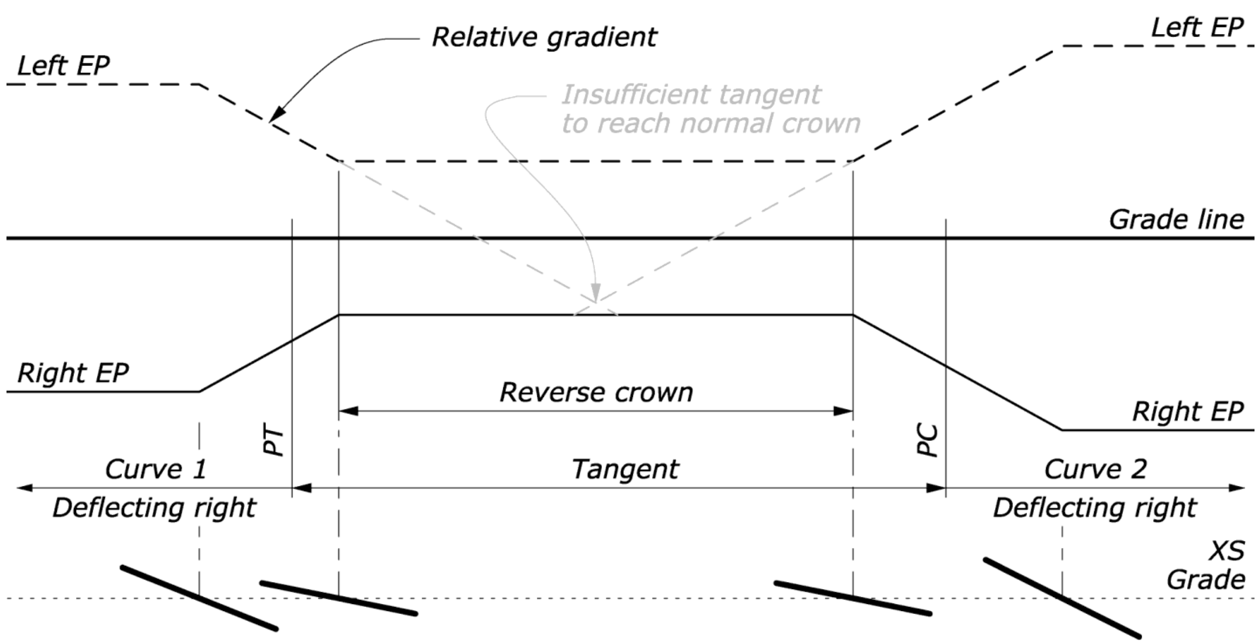
For short intervening tangent length treated as a compound curve, refer to Section 9.3.5.2.3. Avoid treatment as a compound curve if the intervening tangent length is greater than 200 ft [60 m], or more than 3 seconds of travel time at the design speed whichever is greater.

For intermediate tangent lengths, conflicts occur when the initial design of broken back curves have slightly overlapping superelevation transitions that cause the transition to be treated as a compound curve, instead of a preferred transition using a minimum super rate (reverse crown) template treatment. For a minimum super rate transition, there is no minimum length of reverse crown section (can be a singular location), although a desired length is 50 ft [20 m], or 1 second of travel time at the design speed whichever is greater. Recommended guidance to resolve such conflicts includes the following:

- If the initially designed lengths of reverse crown transitions overlap more than 50 ft [20 m], the situation should be treated as a compound curve, or
- If the initially designed lengths of reverse crown transitions overlap less than 50 ft [20 m], the situation may be treated either 1) as a compound curve, or 2) a minimal, or the desired, length of reverse crown may be provided by adjusting the location of the super transitions (full super to minimum super) relative to the ends of each curve (PT and PC). In this latter case the portion of the superelevation transition lengths that are located on each curve may be increased, providing that the portion of the theoretical superelevation runoff lengths located on each curve does not exceed 50 percent.

Exhibit 9.3-G describes an example of a transition between curves in a broken-back situation with minimum super rate (reverse crown) treatment.

Exhibit 9.3-G SUPERELEVATION TRANSITION ON SHORT TANGENTS



For longer intervening tangent lengths, conflicts occur when broken back curves initially have superelevation transitions that are in close proximity, such that the length of the normal crown section is less than the desired minimum of 200 ft [60 m], or 3 seconds of travel time at the design speed whichever is greater. Recommended guidance to resolve such conflicts includes the following:

- If the initially designed length of normal crown is less than 75 percent of the minimum, the treatment should either be a transition using the minimum superelevation rate (reverse crown) described above as treatment 2, or transition as a compound curve; or
- If the initially designed length of normal crown is more than 75 percent of the minimum of 200 ft [60 m] or 3 seconds of travel time at the design speed whichever is greater, the necessary length of normal crown section should be provided by adjusting the location of

the superelevation runoff relative to the ends of each curve (PT and PC), or by reducing the superelevation runoff length, or both, such that at least the minimum length of runoff as determined by *Green Book* Equation 3-23 is provided. In this situation the portion of the superelevation runoff lengths that are located on each curve may be increased, providing this portion does not exceed 50 percent.

9.3.5.2.5 Short Curve Transitions

Avoid designing short curve lengths, such as described in Section 9.3.5.1.8 if practical. A superelevation transition conflict can occur if the length of curve is too short to accommodate the combined standard proportions of the superelevation runoff lengths located on the curve, creating an overlap. Recommended guidance for resolving such conflicts includes the following:

- Preferably, increase the curve length by redesigning it with a sufficiently larger radius, with corresponding lower superelevation rate and resultant runoff length, to resolve the conflict; or
- Alternatively, reduce the percentage of superelevation runoff length located on the curve, but not less than 10 percent (preferably not less than 20 percent). If the above treatments are impractical, the design superelevation rate (*e*) of the curve may be truncated to a sufficiently lower value, with corresponding shorter runoff lengths that properly fit within the curve.

9.3.5.2.6 Vehicle Tracking

Often the driver's steered path is inconsistent with the alignment geometry such that the actual vehicle path does not follow a true circle, and drivers 'overshoot' the curve (track a path sharper than radius), and the tracked path is a spiral. Therefore, curve transitions should be designed to minimize and mitigate erratic vehicle tracking entering, during and exiting the curve. FLH standard practice is to:

- Provide traveled way widening in curves, and
- Use consistent methodology for the superelevation transition design from curve to curve, so that the driver can expect similar transition effects on their driving task.

Refer to Section 9.3.9.1 for additional guidance on vehicle tracking and traveled way widening on curves.

9.3.5.2.7 Spiral Transitions

Spiral transitions should be used whenever practical for smoother transitions and to enhance safety, particularly if using near-minimum standards for roadway widths or design speeds. For projects on a State DOT or local agency system, verify that using spiral transitions and the transition design criteria is consistent with the State DOT or local agency design policy.

When spiral transitions are used, FLH standard practice includes the following:

- The minimum length of spiral curve transitions is the length required for superelevation runoff, based on maximum relative gradient, and typical minimum superelevation runoff lengths are provided in *Green Book* Table 3-17;
- The superelevation runoff is applied uniformly over the full length of the spiral; and
- Design spiral transition curves to meet the additional criteria described in this section.

Ensure that the appropriate spiral length and transition treatment is used, and that the method for selecting spiral length is applied consistently throughout the project.

A discussion of transition spirals is provided in *Green Book* Section 3.3.8 subsection entitled "Spiral Curve Transitions".

Exhibit 9.3-H MAXIMUM RADIUS FOR BENEFIT OF A SPIRAL CURVE TRANSITION

US Customary		Metric	
Design speed (mph)	**Maximum radius (ft)**	**Design speed (km/h)**	**Maximum radius (m)**
15	211	20	45
20	375	30	100
25	585	40	177
30	842	50	276
35	1150	60	397
40	1500	70	541
45	1900	80	706
50	2340	90	893
55	2830	100	1110
60	3370	110	1340
65	3960	120	1590
70	4590	130	1870
75	5270		
80	5990		

Note: Spirals may be used on flatter curves if beneficial for aesthetic purposes. This table is not intended to define radii that either necessitate or prohibit the use of a spiral.

Green Book Table 3-20 provides recommendations on the maximum radius for spiral curve transition use, corresponding to the radius at which the safety and operational benefits of spiral curve transitions may become negligible. Based on consideration for aesthetics, anticipated operating speeds, and the unique conditions of FLH projects, the recommended maximum radius for use of a spiral transition curves for FLH projects are greater than the values provided in the *Green Book*. The maximum recommended radius shown in Exhibit 9.3-H are based on a lateral acceleration rate of 0.07g; expressed as 2.3 ft/s^2 [0.7 m/s^2] in the following equations:

$R = 2.1511V^2/A$ (US Customary)

$R = 0.07716V^2/A$ (Metric)

where: R is the maximum radius, ft [m]

V is the design speed, mph [km/h]

A is the lateral acceleration rate, ft/s^2 [m/s^2]

Green Book Table 3-21 provides recommendations on the desirable length of spiral transition curves, corresponding to approximately 2.0 seconds of travel time at the design speed of the roadway. Based on consideration for anticipated operating speeds, aesthetics, and the unique conditions of FLH projects, the desired lengths of spiral transition curves for FLH projects are increased slightly from the values provided in the *Green Book*. The values shown in Exhibit 9.3-I correspond to 2.3 seconds of travel time. Spiral curve lengths longer than those shown may be needed. To determine the minimum spiral length use the longest of:

- The minimum length for superelevation runoff (L_r) determined by the *Green Book* using either Equation 3-23 or Table 3-17; or
- The minimum spiral length (L_s, min) determined by *Green Book* Equations 3-26 and 3-27; or
- The desired spiral length shown in Exhibit 9.3-I.

If necessary for especially tight alignment locations, the desirable spiral length shown in *Green Book* Table 3-21 may be used, if it is greater than the minimum spiral length and the minimum superelevation runoff length described above.

Green Book Equation 3-28 provides recommendations for the maximum length of spiral transitions, based on the observed steering behavior of drivers. For FLH projects it is also desirable to limit the spiral length to the distance traveled on the spiral in 4 seconds at the design speed. The maximum spiral lengths shown in Exhibit 9.3-I are based on the greater of this 4-second rule, or the superelevation runoff length (L_r) for the limiting superelevation rates (see *Green Book* Table 3-19). If the maximum spiral length determined by *Green Book* Equation 3-28 is less than these maximum lengths, limit the spiral length to the shorter length. If the minimum length of superelevation runoff determined by *Green Book* Equation 3-23 is greater than the maximum length of spiral transition determined by *Green Book* Equation 3-28, do not use a spiral transition for the curve.

Determine the appropriate superelevation rate (e_d) and length of spiral transition curve (L_s) based on the given design criteria (design speed, maximum and minimum superelevation rates, lane width, and curve radius). The calculated L_s is often associated with the minimum length of spiral transition applicable for the given criteria and superelevation rate. Where practical, use the longer desired length of spiral curve transition shown in Exhibit 9.3-I. Greater spiral lengths up to the maximum length may be used in certain situations, such as minimizing or closing short intervening tangents between reverse spiral transition curves where the superelevation transitions are merged.

Green Book Equation 3-29 and Table 3-23 provide recommendations for tangent runout length (L_t) for spiral curve transition design. For FLH projects, the length of tangent runout for a spiral curve transition should be based on the continuation of the same superelevation transition rate (relative gradient) that is applicable to the superelevation runoff and which is applied on the spiral curve transition.

Exhibit 9.3-I DESIRED AND MAXIMUM LENGTH OF SPIRAL CURVE TRANSITION

US Customary			Metric		
Design speed (mph)	**Desired length (ft)**	**Maximum length (ft)**	**Design speed (km/h)**	**Desired length (m)**	**Maximum length (m)**
15	50	125	20	13	36
20	65	130	30	19	38
25	85	170	40	26	51
30	100	200	50	32	61
35	120	215	60	38	67
40	135	235	70	45	78
45	150	265	80	51	89
50	170	295	90	57	100
55	185	325	100	64	111
60	200	350	110	70	122
65	220	380	120	77	133
70	235	410	130	83	144
75	255	440			
80	270	470			

Note: Minimum spiral length must equal or exceed the superelevation runoff length. Maximum spiral length should not exceed the length determined by Green Book Equation 3-28.

9.3.5.2.8 Location of Profile Grade and Superelevation Pivot Point

Typically, the profile grade and superelevation pivot point on the highway cross section is at the finished grade centerline for all two-lane highways. Alternatively, the superelevation pivot point may be located at the finished grade roadway shoulder on the low side of the superelevated section, for two-lane highways where conditions are appropriate (e.g., for drainage purposes in flat low-lying terrain or swampy conditions). In this case, the profile grade elevation at centerline will be adjusted.

For two-lane or multilane highways with flush, paved medians 12 ft [3.6 m] width or less, the center of the median should be used as the axis of rotation, with the entire roadway section rotated about the axis. For multilane highways with medians wider than 12 ft [3.6 m] the median may be held horizontal and the superelevation pivot points for the two roadway directions may be located at the finished grade roadway shoulders adjacent the median, which are on the low side of the outer lanes and on the high side of the inner lanes. In this case the full superelevation stations of superelevation runoffs for both roadways should be designed at the same (concentric) location. The type of terrain will influence the preferred median treatment. For medians greater than 30 ft [9 m] it may be preferable to develop the superelevation for each roadway independently. Also refer to Section 9.3.10.

9.3.5.2.9 Combination of Superelevation Transition and Grades

In areas of especially steep or flat grades, evaluate the gradients along the edge of traveled way and the shoulder profiles, and correct or minimize any irregularities resulting from combinations of the superelevation transitions and the vertical alignment.

Consider that superelevation transitions will increase the effective grade along the outside edge of the traveled way. This increase is significant, particularly for trucks and recreational vehicles. To minimize this effect on long continuous runs of near maximum grades, the designer should flatten the grade throughout the horizontal curve to compensate for the effect.

Consideration of the effect of superelevation transition on the maximum grade at the edge of roadway is especially important when the design contains climbing lanes, auxiliary lanes, or turnouts adjacent the roadway that are superelevated.

In areas of minimum grades, evaluate the edge of traveled way and shoulder profiles to reveal any level, or nearly level (less than 0.2 percent), areas on the roadway surface resulting from superelevation transitions. Level areas are undesirable from a pavement drainage standpoint and should be avoided or minimized. Coordinate the design of vertical and horizontal curves such that the flat profile of a vertical curve will not be located near the flat cross slope of the superelevation transition.

Consider the effect of superelevation transition on the ditch grades and in curb and gutter sections in areas of minimum grades, to provide at least 0.5 percent gradient.

Refer to Exhibit 9.3-E for a method of adjusting the location of the flat template section between reversing curves with a short tangent.

9.3.5.3 Risk Assessment and Mitigation

Consider that horizontal curves tend to be high crash locations. The average crash rate for horizontal curves is about 3 times the average rate for tangents, and the average run-off-the-road crash rate for horizontal curves is about 4 times that of tangents. Consider the AASHTO *Green Book* assumptions, together with reliable information on actual speeds, site crash history, roadside conditions in the vicinity of the curve, and available pavement friction in assessing risk relating to horizontal curvature. Refer to the AASHTO *Guide for Achieving Flexibility in Highway*

Design, Sections 3.2.2, 3.2.3 and 3.2.4 for guidance in applying flexibility in the AASHTO guidelines, assessing risk and mitigating tight curvature.

Risk is primarily related to the traffic volume exposed to the situation. Risk varies with the length of the horizontal curve and the central angle of the alignment deflection, with curve angles greater than 30 degrees representing substantially higher risk. Risk increases as operating speeds exceed the design speed. For roads with more than 10 percent commercial truck traffic, the safety risk increases substantially if the operating speed exceeds the design speed by 6 mph [10 km/h] or more. Other design elements (e.g., sight distance, superelevation, pavement friction, signing, and delineation) can affect curve safety.

The project plans should include mitigation (e.g., curve signs, turn signs, advisory speed plates, positive guidance, appropriate roadside design features) when a curve design is an exception to the standard for the posted or regulatory speed limit. The *MUTCD* specifies installation of advisory speed plates following a determination of the safe speed by an engineering study. Also refer to the *Horizontal Curve Signing Handbook*, TTI, 2007.

Also refer to NCHRP Report 559, *Communicating Changes in Horizontal Alignment*, 2006 for additional guidance on mitigating inconsistent horizontal curvature. Also see FHWA Report 07-002, *Low-Cost Treatments for Horizontal Curve Safety*, 2006.

9.3.6 VERTICAL ALIGNMENT

Refer to *Green Book* Section 3.4 for guidance applicable to the design of vertical alignments. As practical, minimize vertical grades within the terrain context. Refer to Section 9.3.1.3 for guidance on terrain classifications. In addition, consider the following design controls:

- Climate (snow, ice, rainfall)
- Topography and terrain,
- Functional classification,
- Design speed,
- Sight distance needs,
- Traffic volume
- Compatibility with existing slopes, approach roads and driveways adjacent the roadway,
- Length of grade,
- Horizontal alignment,
- Construction cost,
- Pedestrian and bicycle use,
- Drainage considerations,
- Surfacing type,
- Vertical clearances (if applicable),
- Vehicular characteristics, and
- Aesthetics.

9.3.6.1 Vertical Curves

Refer to *Green Book* Table 3-34 for minimum design controls (K values) for crest vertical curves, and Table 3-36 for design controls (K values) for sag vertical curves, based on minimum stopping sight distances. If the design vertical curvature does not meet or exceed the applicable standards for K value, treat the deviation as a formal design exception. When faced with a choice of design exception, use a short sag curve rather than a short crest curve.

FLH standard practice includes the following:

- For design speeds less than 40 mph [60 km/h], the minimum vertical curve length should be 300 ft [100 m], except for grade differences less than 3 percent the minimum vertical curve length may be 200 ft [60 m],
- For design speeds of 40 mph [60 km/h] or more, the minimum vertical curve length should be 400 ft [120 m], except for grade differences less than 3 percent the minimum vertical curve length may be 300 ft [90 m], and
- The above minimum vertical curve lengths are not applicable for approach roads or other minor roads.

Sag vertical curves that are visible on long horizontal tangents should be two or three times the length required for stopping sight distance to avoid an abrupt appearance.

For sag vertical curves with a low point in curbed sections, consider the requirements for pavement drainage. If possible, provide a minimum gradient of 0.3 percent within 50 ft [15 m] of the low point.

Broken-back vertical curves consist of two vertical curves in the same direction separated by a short tangent grade (i.e., less than 200 ft [60 m]). Avoid using broken-back vertical curves in sags where the view of both vertical curves and the intervening tangent is evident.

For design of minimal vertical curves for driveways or low water crossings, limit the minimum K value to accommodate the design vehicle clearances (undercarriage or tow hitch). In such locations provide a minimum vertical curve length of 30 ft [9 m] and minimum K value of 1.5 [0.5].

9.3.6.2 Maximum Grade

Refer to the subsection on “Control Grades for Design” in *Green Book* Section 3.4.2 for general guidance on maximum grades. Consider the functional classification, the type of terrain, design speed, effect on operating speeds of the mix of vehicle types, along with the information provided in the *Green Book* to determine the maximum allowable grades. For Park roads refer to the *Park Road Standards* Table 3 to determine maximum design grades. If the applicable maximum grade must be exceeded, treat the deviation as a formal design exception.

Also consider weather and climatic conditions, and surfacing type, when determining a maximum practical gradient for design.

FLH standard practice for areas with winter snow-packed conditions, or for aggregate surface roadways, is to not exceed a maximum sustained grade of 9 percent (7 percent maximum grade preferable).

Evaluate steep (over 5 percent) sustained grades of 0.5 mile [0.8 km] or more, which may affect traffic operation in both uphill and downhill directions. If the critical length of grade is exceeded, determine the speed profile for a loaded truck (see Section 9.3.6.4).

Recommended guidance includes the following:

- For sustained grades over 5 percent and over 1 mile [1.6 km] with design traffic volume ADT greater than 2,000, determine the feasibility and, if applicable, the safety and operational effects of providing a slow moving vehicle lane or turnout;
- On sustained downgrades over 7 percent and over 1 mile [1.6 km], for ADT greater than 2,000 and volume of trucks over 10 percent; determine the feasibility of providing a truck escape ramp; and
- On sustained, steep grades also consider using wider shoulders, clear zones and increased superelevation rates at the bottom of the grade.

Refer to the IHSDM and its references, or the HCM, or both, for guidance on determining the safety and operational effects of design grades.

9.3.6.3 Minimum Grade

Refer to the subsection on "Control Grades for Design" in *Green Book* Section 3.4.2 for general guidance on minimum grades. FLH standard practice includes the following:

- A level longitudinal grade (zero percent) is acceptable in tangent alignment along through-fill sections where the roadway has proper crown to drain the surface laterally, and is without curbing;
- A level longitudinal grade is acceptable in tangent alignment on uncurbed pavements in cut sections where the pavement is adequately crowned, and special ditch gradients are adequate to convey the surface drainage;
- Minimum grades (0.5 percent minimum, 1 percent desired) are applicable in all other cases for providing drainage of roadway ditches in cut sections, drainage of curb sections and to ensure pavement drainage on superelevation transitions;
    - ◊ The 1 percent desired minimum grade particularly applies where flat grades on crest and sag vertical curves have substantial lengths that are essentially level;
    - ◊ The 1 percent desired minimum grade also applies where superelevation transitions introduce sags in the ditch or gutter line;
    - ◊ Evaluate ditch or gutter profiles to identify and correct any drainage problems; special ditch grade profiles may be used to correct sags or minimum gradients in the ditch line; and

- Provide grades exceeding the 1 percent desired minimum gradient where superelevation transitions create a pavement edge profile grade less than 0.2 percent (0.5 percent for curbed streets) through the transition section.

In areas where heavy rainfall occurs, or winter snowpack and freezing conditions routinely exist for portions of the year, particularly avoid the combination of minimum grades, or high or low points in vertical curves, and superelevation transitions that result in locations with a level surface on the pavement.

Refer to the subsection on "Minimum Transition Grades" in *Green Book* Section 3.3.8 and Equation 3-30 for additional guidance.

Where curbing is used in conjunction with minimum grades, ensure the design of inlets and their spacing will keep the spread of water on the traveled way within tolerable limits. Refer to Section 9.5.5.4 for pavement drainage and FHWA, HEC-12, Chapter 2 for additional guidance on recommended roadway geometry to provide for pavement drainage.

See Section 9.5.5.1 for guidance on design of roadway drainage ditches.

9.3.6.4 Critical Lengths of Grade

Where applicable, evaluate the length of a sustained grade in relation to desirable vehicle operation and safety. The critical length of grade is the maximum length of a sustained upgrade on which a loaded truck can operate without a 10 mph [16 km/h] reduction in speed. Consider the guidance and recommendations for different conditions contained in "Critical Lengths of Grade for Design" in *Green Book* Section 3.4.2.

9.3.6.5 Intersection Considerations

At intersections, the grade should not exceed 6 percent (5 percent maximum is preferred). As practical, avoid designing crest vertical curves in the vicinity of intersections.

9.3.6.6 Hidden Dips

Avoid designing intervening sags in a vertical alignment that is otherwise a uniform grade, in combination with tangent horizontal alignment or flat curvature, which create hidden dips. Also avoid designing a rolling vertical alignment in combination with long horizontal tangents, as such roller coaster profiles are visually distressing and may create hidden dips that are misleading for passing on two-lane roads.

9.3.6.7 Switchbacks

Switchbacks may be necessary in mountainous areas with steep grades. Where practical, reduce the gradient through sharp switchback curves to facilitate braking and vehicle control in the vicinity of the switchback. For switchbacks with a curve speed of 20 mph [30 km/h] a maximum gradient of 4 percent is recommended, and for switchbacks with curve speed of 25 mph [40 km/h] a maximum gradient of 5 percent is recommended.

9.3.6.8 Drainage Considerations

Where the highway crosses a waterway, design the profile consistent with the design flood frequency and elevation. The following FLH standard practices apply:

- For drainage structure inlets determine the design headwater elevation, and design the roadway elevation to exceed the headwater elevation, and to provide sufficient clearance and cover for construction of culverts and other components of the drainage system.
- In swampy terrain and areas subject to overflow and irrigation, design the low point of the subgrade to be at least 1.7 ft [0.5 m] above the ordinary high-water elevation.
- In areas of grades less than 2 percent, ensure drainage at the low point of the subgrade and ditch grades in the area of horizontal curves, where superelevation may lower the edge of the subgrade shoulder relative to tangents.

For roads located along main streams and rivers, refer to Section 7.4 for the appropriate hydraulic controls.

9.3.6.9 Vertical Clearance

FLH standard practice is to provide sufficient vertical clearance for the largest design vehicle, for the interim and ultimate potential roadway and pavement configurations, and with consideration for the accommodation or management of occasional oversize vehicles. Also refer to Section 10.4.1.1 for vertical clearances for structures.

The following standards apply:

- For local and collector roads, provide a vertical clearance of at least 14 ft [4.3 m] over the entire roadway width, with an additional allowance for future resurfacing.
- For rural and urban arterials, provide 16 ft [4.9 m] clearance over the entire roadway width for any new or reconstructed structures; and existing structures that provide clearance of 14 ft [4.3 m] may be retained if allowed by local statute.
- For arterials in highly urbanized areas, a minimum clearance of 14 ft [4.3 m] may be provided if there is an alternate route with 16 ft [4.9 m] clearance. Provide additional clearance for future resurfacing.

Structures should provide an additional clearance of 3 in [76 mm] for future resurfacing of the underpassing road.

Also consider needs for falsework and construction vehicles in determining vertical clearances.

Structures over railroads should typically provide a minimum vertical clearance of 23 ft [7.1 m] over both rails. Refer to individual State requirements for vertical clearance over railroads, and coordinate with the railroad for any special requirements at the structure location such as the potential for future electrification of the line.

9.3.6.10 Risk Assessment and Mitigation

The vertical alignment directly affects sight distance. Any evaluation of the vertical alignment risks should consider the resultant sight distance that is available. Risk is primarily related to the traffic volume exposed to the situation. Combinations of other higher risk road conditions (e.g., intersections) with vertical curvature or steeper grades will also increase the relative risk. Risk related to vertical curves generally increases where grade differentials are greater than 6 percent; and risks are greatest at or near the crest of the vertical curve. Crest vertical curves with less than 300 ft [90 m] stopping sight distance are particularly related to greater risk.

Where steeper grades are used, evaluate the operational effects on heavy vehicles. Mitigation of steep downgrades can include increased shoulder widths and clear zones, increased superelevation rates, increased pavement friction and provision of truck escape ramps for extended sustained downgrades. Provide flatter horizontal curves at the bottom of steep downgrades, allowing for potentially higher operating speeds.

Where very flat grades are used consider using special drainage features, such as special ditch grades, and provide special attention to the design of pavement cross slopes and reversals of superelevation. Avoid or minimize flat spots on the pavement surface, particularly in regions that experience intense rainfall, periodic snowpack or ice.

9.3.7 SIGHT DISTANCE

Maximize the continuous length of roadway ahead that is visible to the driver, and provide sufficient preview of the roadway to safely accomplish various driving maneuvers. Coordinate the geometric elements such that adequate sight distance exists for safe and efficient operation. Determine the various sight distance requirements for all allowable maneuvers – emergency stopping, passing, making a left-turn at an intersection, etc. Although design requirements are expressed as a design distance, consider the component time requirements for the driver to recognize the situation, understand its implications, decide on a reaction and initiate the maneuver. Consider the effects of grade and speed on sight distance requirements, and on the maneuver itself.

Green Book Section 3.2 provides criteria and guidance on stopping sight distance, decision sight distance, passing sight distance, and sight distance for multilane highways. *Green Book* Chapters 5, 6, 7, and 9 each has specific subsections on sight distance for local roads, collectors, arterials, and intersections, respectively. Also, the ITE *Traffic Engineering Handbook* (1999), Chapter 11 Geometric Design of Highways, has a section on sight distance, with subsections on stopping sight distance, passing sight distance, decision sight distance, and intersection sight distance.

9.3.7.1 Determination of Sight Distance Requirements

FLH standard practice is to follow the *Green Book* recommendations for determination of sight distance requirements, including consideration of:

- Perception-Reaction Time (PRT)
- Maneuver Time (MT), and
- Operating speed.

Refer to *Green Book* Section 3.2. Additional guidance for determination of these components is provided in the following sections.

9.3.7.1.1 Perception-Reaction Time

Refer to *Green Book* Section 2.2.6 for guidance on determining perception-reaction time (PRT). Consider that actual PRT can vary widely depending upon many factors specific to the site.

Refer to the *Manual on Uniform Traffic Control Devices* (MUTCD) 2003, Section 2C.05, Placement of Warning Signs. Also refer to the ITE Traffic Engineering Handbook (1999), Chapter 2 Road Users, sections on perception-reaction time and sight distance, and the ITE Traffic Control Devices Handbook (2001), Chapter 2 Human Factors, sections on driver perception reaction time.

Also refer to the FHWA *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*, FHWA-RD-01-051 (2001), Rationale and Supporting Evidence section for perception-reaction time and sight distance requirements for older drivers.

9.3.7.1.2 Maneuver Time

Maneuver time (MT) is the interval from the initiation of the vehicle control response (i.e., end of the PRT) to the completion of the driving maneuvers (e.g., braking, turning, passing).

For braking MT refer to the “Braking Distance” discussion in *Green Book* Section 3.2.2 and Equation 3-1. For turning MT refer to *Green Book* Section 9.5.3 for maneuver time design values for the various control cases. For passing MT refer to the “Criteria for Design” inside *Green Book* Section 3.2.4.

Consider that the actual MT, and distance needed for the safe and comfortable completion of the maneuver, will vary with conditions of the site including tire-pavement friction, grade, vehicle performance capabilities, and individual driver characteristics.

The ITE *Traffic Control Devices Handbook* (2001), Chapter 2 Human Factors, also has guidance on maneuver time.

9.3.7.2 Stopping Sight Distance

Provide the minimum stopping sight distance (SSD) at all points along the roadway. Provide more generous stopping distances where practical.

Minimum stopping distance is the distance required to bring a vehicle traveling at the design speed to a stop before reaching a stationary object in its path. Consider the actual distance will vary, depending on the initial speed of the vehicle, the perception and reaction time of the driver, the gradient, and the coefficient of friction between tires and roadway for the prevailing conditions. The coefficient of friction is much lower for wet pavements; therefore, wet rather than dry pavement conditions apply for establishing minimum values.

Ensure that the minimum SSD control ("K" value) is provided at all vertical curves, and that the minimum SSD control (horizontal sightline offset) is provided at all horizontal curves.

Design controls for SSD are located in *Green Book* Section 3.2.2, Section 3.3.12, and both the "Crest Vertical Curves" and "Sag Vertical Curves" discussions inside Section 3.4.6.

For additional information on SSD, also refer to *Determination of Stopping Sight Distances*, NCHRP Report 400, 1997.

9.3.7.3 Decision Sight Distance

Decision sight distance (DSD) is the length of road a driver needs to receive and interpret information, select an appropriate speed and path and begin and complete an action in a safe maneuver. This distance is greater than the distance needed to simply bring a vehicle to a stop, and provides for a reasonable continuity of traffic flow.

If possible, provide decision sight distance in advance of any feature requiring increased driver awareness and action. This includes intersections, lane changes, congested areas, pedestrian crossings, turnouts, pullouts or other features. When decision sight distance is unavailable and relocation of the feature is not possible, provide suitable traffic control devices.

See design controls for DSD in *Green Book* Section 3.2.3. Refer to *Green Book* Table 3-3 for recommended DSD values.

9.3.7.4 Passing Sight Distance

Passing sight distance (PSD) is applicable to two-lane, two-way roads. PSD is the length of the highway ahead necessary for one vehicle to pass another before meeting an opposing vehicle that might appear after the pass begins.

Provide as many passing opportunities as possible in each section of road, and if practical ensure there are no long sections where passing is not possible. Evaluate the percentage and distribution of passing and no-passing zone markings, and their implication for traffic operations, in the geometric design of two-lane highways. Where operations indicate lack of PSD is a problem, consider design of passing lanes, truck climbing lanes, or intermittent slow-moving vehicle turnouts as described in Section 9.3.9.

Also consider PSD at the end of truck-climbing and passing lanes where traffic must merge. If practical, increase the sight distance in areas adjacent to passing zones where vehicles completing passing maneuvers may operate above the design speed.

Minimum passing distances for all classes of two-lane roads are given in *Green Book* Table 3-4. Also refer to the guidance in *Green Book* Section 3.2.4.

Current practice uses different PSD models in highway design and in marking of passing and no-passing zones. Geometric design for minimum PSD requirements should not be confused with values provided in the *MUTCD* for determining no-passing zone pavement striping. The *MUTCD* recommends much shorter distances for marking no-passing and passing zones than the *Green Book* recommends for developing a geometric design to provide PSD.

For developing a geometric design to provide PSD, consider the design vehicle characteristics, road grade and vehicle speeds at the specific location. The design for minimum PSD may be less than the minimum distances provided in the *Green Book* if consideration is given to the possibility that the passing maneuver can be aborted. Shoulder characteristics should also be considered in the geometric design for PSD. Also refer to NCHRP Report 605, *Passing Sight Distance Criteria* for additional guidance on geometric design to provide PSD.

9.3.7.5 Intersection Sight Distance

Intersection sight distance (ISD) is the minimum sight distance needed by drivers to safely negotiate intersections, including intersections with or without stop controls or traffic signals.

Provide sufficient sight distance to allow drivers to perceive the presence of potentially conflicting vehicles. If possible, provide decision sight distance (DSD) for the approach to intersections, if it is greater than the ISD.

FLH standard practice is to provide ISD based on *Green Book* Section 9.5. Also refer to the *Highway Capacity Manual*, which provides guidance on gap acceptance for vehicles departing from minor approaches.

For intersection sight distance in design of a left-turn from a stop based on gap acceptance refer to *Green Book* Table 9-5 and Equation 9-1. Determine the sight distances required for vehicles to turn left from a stop onto a two-lane highway and attain an average running speed without being overtaken by a vehicle going the same direction. Where practical, avoid using sight distances less than that required for the design vehicle, which will require the through traffic to reduce speed. For approach to at-grade intersection provide sufficient sight distance for an unobstructed view of the entire intersection and sufficient length of the intersecting roadway to discern the movements of vehicles. For intersections with stop signs on the minor road provide sight distance of the major highway to safely cross before a vehicle on the major highway reaches the intersection. Under some conditions, if it is impractical to provide adequate site distance for cross road traffic to safely enter the main road, it may be necessary to install traffic signals. (See Part IV of the *MUTCD*.)

Refer to *Green Book* Table 9-6, for minimum sight distance along the major road for level conditions, for left turns from a stop. Refer to *Green Book* Table 9-4, for adjustment of sight distance to reflect grades of the minor road approach.

Provide sight triangles along the intersection approach legs that are clear of obstructions that can block driver's view of oncoming traffic. The dimensions of the triangle are based on the design speed of the intersecting roadways and the type of traffic control used at the intersection, grades on the roadways, and the roadway width.

Within the sight triangle, remove, adjust or lower cut slopes, hedges, trees, signs, utility poles or anything large enough to constitute a sight obstruction (see *Green Book* Figure 9-15). Eliminate parking and offset signs to prevent sight distance obstructions.

Determine ISD for all applicable intersection maneuvers, including situations described in the *Green Book* for through, left and right-turning maneuvers at intersections with no control, four-way stop control, two-way stop control, yield control and signal control from the minor road; and for a left-turning maneuver from the major road.

Provide additional intersection sight distance wherever significant visual distractions, messages or driver workload exists, for example where there are:

- High traffic volumes on the major road;
- Complex signs (e.g. multiple destinations, route shield assemblies);
- Complex pavement markings (e.g. multiple turn lanes);
- Complex or unusual intersection geometry;
- Visual distractions in urban areas due to commercial signs and lighting; and
- A high percentage of unfamiliar or older drivers.

Also provide additional intersection sight distance wherever drivers are less likely to be expecting to respond to an intersection, such as for:

- A stop condition after having the right-of-way on previous road sections;
- An isolated stop or signal-controlled intersection; and
- Intersections with high traffic volume, but signals are not yet warranted. For these situations, ISD is a minimum and it is preferable to provide DSD.

For the following conditions, the sight distance for cross traffic to enter the roadway may need to be lengthened:

- Turning right through the minor angle of skew intersection (i.e., where drivers must turn their heads through a greater angle to assess the presence of oncoming vehicles);
- Crossing or turning at an intersection on a horizontal curve, especially where the main road curves behind the driver gap, may be more difficult to assess; and
- Crossing at an offset or skewed intersection, and

- Trucks turning.

Consider the need for additional sight distance where:

- The major road has complex signing, lane drops or other driver-attention demands prior to the intersection,
- Traffic conditions or site information indicates problems accommodating entering traffic, and
- At left-turn lanes where the decision to initiate the turn may occur significantly in advance of intersection.

At intersections, consider the driver's view of the intersection from all approaches. Of major concern are intersections where a driver may fail to recognize a potential conflict location. An example may be where an approach road intersects a divided roadway and the driver perceives the intersection across the median as the primary concern, and does not recognize the initial intersection. Evaluation of the driver's viewpoint with respect to the signing and pavement markings should be considered during the layout of the intersection.

9.3.7.6 Limiting Conditions and Restrictions

Provide adequate sight distance on horizontal curves by selecting the proper curve radius and arranging for the removal or relocation of obstacles. Refer to the "Stopping Sight Distance" discussion in *Green Book* Section 3.3.12 for guidance on evaluation of curve radius and horizontal sightline offset.

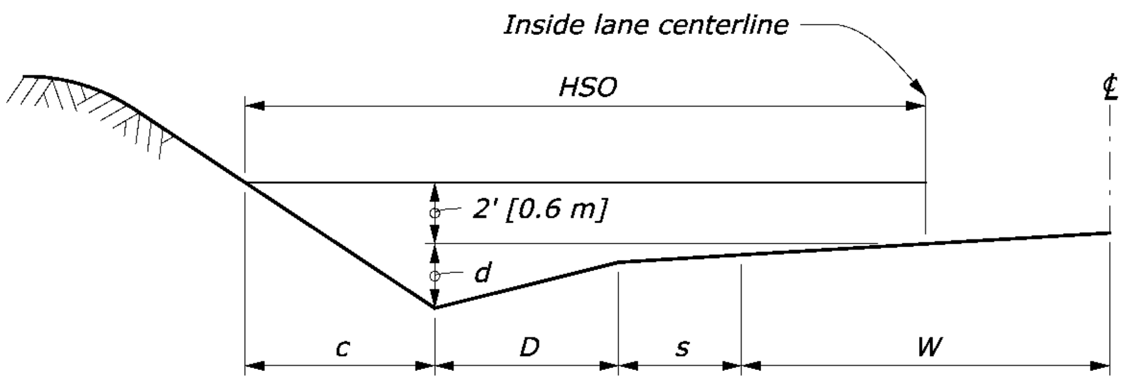
The sight distance available on horizontal curves is proportional to the radius of the curve, and depends on the location of obstacles to the line-of-sight across the inside of the curves. Verify the location of obstacles (e.g., cut slopes, tall grass on cut slopes, trees, shrubs, farm crops, buildings, bridge abutments and walls, bridge railing, traffic barrier) that may limit the sight distance across the inside of a curve. To facilitate safe operation, horizontal sight distance must equal or exceed the safe stopping distance for the selected design speed (listed in *Green Book* Table 3-1). To obtain the required sight distance, horizontal curves may be redesigned with larger radius or provide for the removal or relocation of obstacles.

See *Green Book* Figure 3-23 for a diagram illustrating horizontal sight line offset (HSO) to an obstruction. For geometric design to obtain sight distance determine the limiting HSO for the typical cut slopes and ditch configurations applicable for the project. See Exhibit 9.3-J for a diagram of a horizontal sight line offset (HSO) on a cut slope, and applicable design parameters.

Cut sections may restrict the horizontal sight distance, especially where crest vertical curves coincide with horizontal curves and there is a substantial change in grade. In this case consider using a longer vertical curve, flatter horizontal curve, wider and deeper ditch, flatter cut slope ratio, additional clear area beyond the ditch or shoulder, or a combination of these. Combinations of horizontal and vertical sight distance restrictions should be evaluated using a 3-dimensional design model and perspective views.

Consider sight distance restrictions created by the presence of other vehicles, such as at opposing left-turn lanes, or at right-turn lanes interfering with sightlines from the intersecting road.

Exhibit 9.3-J LATERAL CLEARANCE FOR STOPPING SIGHT DISTANCE



Horizontal Sightline Offset (HSO) = c + D + s + 0.5W

Where:

c = the drop (d) from the center of the inside lane to the bottom of the ditch plus 2 ft [0.6 m] multiplied by the cut slope ratio.

D = the total ditch width from bottom of ditch to edge of shoulder.

s = the shoulder width

W = width of the inside lane

Note: When vegetation is expected to grow on the cut slope, reduce the drop (d) by the estimated depth of the vegetation. When vegetation is not controlled on the cut slope, reduce c to zero.

9.3.7.7 Risk Assessment and Mitigation

In some situations the sight distance standards may be difficult to meet, or may be less than optimal. Trade-offs among competing requirements sometimes require compromising decisions. In some cases, time requirements may be less than those assumed in the criteria provided in the *Green Book*. In other situations, conditions may create a need to go beyond the minimum standards. Risk is primarily related to the traffic volume exposed to the situation. Combinations of multiple road conditions and additive demand for the driver’s attention and decision-making will also increase the relative risk. When faced with a choice (e.g., determining which of several back-to-back vertical curves to adjust), designers should use shorter sag vertical curve lengths in favor of providing the longest crest vertical curve that is possible.

Stopping sight distance should always be provided because any road location can become a hazard. If stopping sight distance is below standard at a number of locations then priorities for correction may need to be set. Examples of conditions, which are high priority with respect to the need for stopping sight distance, are the following:

- Change in lane width;
- Reduction in lateral clearance;
- Beginning of hazardous fill slope;
- Crest vertical curve;
- Horizontal curve;
- Driveway;
- Narrow bridge;
- Roadside hazards (e.g., fixed objects at driveways);
- Unmarked pedestrian crossings;
- Unlit pedestrian crosswalks;
- High volume pedestrian crosswalks;
- Frequent presence of parked vehicles very near the through lane;
- Slow moving vehicles; and
- Frequent pedestrian or bicycle presence.

Examples of roadway geometric elements that are high priority to provide decision sight distance include:

- First intersection in a sequence;
- Isolated rural intersections; and
- A change in cross-section (i.e., two-lane to four-lane, four-lane to two-lane, passing lane, climbing lane, lane drop, deceleration lane, channelization).

Geometric or visual complexity combined with any of the above elements increases the needs for decision sight distance. Frequent truck or recreational vehicle traffic, that block the view of traffic control devices and road geometric elements may be mitigated by increased sight distance for the specific area.

Sight distance problems may be evaluated by developing a sight distance profile that shows the available sight distance (SSD, PSD) at each increment of the alignment location, to visualize graphically the overall severity and extent of the problem, and potential interaction with other geometric design elements or roadway features.

Recognize the complex realities of driver perception and behavior when evaluating sight distance problems. Evaluate the sight distances available to support the various maneuvers (i.e., SSD, PSD, ISD, DSD). The highway location may be divided into component sections based on specific driving demands (i.e. to perform a task or maneuver). Then analyze each section in terms of its availability of sight distance to support the specific task or maneuver. Compare the available sight distance with the required sight distance to safely perform the driving task.

Potential alternatives or mitigation for limited DSD include the separation of decision points to different locations for the driver, simplify the decisions to be made, reduce the operating speed to provide additional time for decision-making and to provide additional advance information.

Potential mitigation for limited ISD includes:

- Clear sight triangles of all obstructions,
- Provide additional traffic control devices or restrictions,
- Adjust stop line placement,
- Use offset median left-turn lanes,
- Adjust length or offset of turn lanes to minimize potential obstruction by turning vehicles,
- Adjust roadway alignment, and
- Adjust intersection configuration.

Also refer to the AASHTO publication *A Guide for Achieving Flexibility in Highway Design*, Section 3.5.1.4, Section 3.5.2.3, Section 3.5.3.3 and Section 3.5.4.3 for additional guidance on mitigating insufficient sight distance.

9.3.8 GEOMETRIC CROSS SECTION

The highway cross section is defined as the finished or the proposed finished section between construction limits as shown in Section 4.3.2.2.

Provide roadway section configurations consistent with the functional classification criteria. Design cross-section characteristics of the roadway section based on, or State developed and approved classifications, the NPS *Park Road Standards* or other applicable agency standards.

For urban cross section design guidance, also refer to *Context Sensitive Solutions in Designing Major Urban Thoroughfares for Walkable Communities*, ITE, 2006.

9.3.8.1 Traveled Way (Lane) Width

Design the traveled way for the movement of through motorized and non-motorized vehicles, including through lanes, HOV lanes, and auxiliary lanes for through traffic. It does not include lanes for other purposes, such as turn lanes, acceleration lanes, deceleration lanes, or parking lanes, although the number and the width of those lanes influence the width of the traveled way. The *Green Book* and other agency standards show minimum recommended lane widths for each functional classification for various design speeds and traffic volume ranges. Refer to *Green Book* Table 5-5, Table 6-5 and Table 7-3, and the *Park Road Standards* Table 10.

When the percentage of trucks, tour buses or recreational vehicles is high in comparison to the ADT, consider increasing lane widths. Refer to *Green Book* Section 4.3 and the *Park Road Standards* Table 10 - footnote a/, as applicable for additional guidance.

A lane width should generally not exceed 12 ft [3.6 m], except where a wider outside lane up to 14 ft [4.2 m] is used for accommodating bicyclists, or where the center lane up to 16 ft [4.8 m] is reserved for left turns.

Provide traveled way widening on curves, as applicable.

9.3.8.2 Shoulder Width and Type

Design the shoulder width and type consistent with the functions that need to be provided, including accommodation of stopped vehicles, emergency use, support of the traveled way, and for use by pedestrians and bicyclists (where bicycle lanes and sidewalks or pathways are not provided). Higher functional classification, higher speeds and higher traffic volumes generally correlate with a need for wider shoulders.

The *Green Book* and other agency standards show minimum shoulder widths for each functional classification for various design speeds and traffic volume ranges. Refer to *Green Book* Table 5-5, Table 6-5 and Table 7-3 and the *Park Road Standards* Table 10.

In designing the shoulder width and type, consider needs for enhancing safety and enabling recovery from errant or evasive driving maneuvers, as well as the following operational functions:

- Contribution to capacity;
- Evasive maneuvers to escape potential crashes or reduce their severity;
- Space for stopping, emergencies, incidents, crash response, mail, trash pickup;
- Pedestrian and bicycle use;
- Law enforcement activities;
- Lateral clearance to roadside objects;
- Structural and lateral support of the pavement and base;
- Mail and other deliveries, garbage pickup
- Encroachment by oversize vehicles
- Routine maintenance activities;
- Flexibility for construction and maintenance of traffic;
- Needs for drainage off the roadway and in curbed sections; and
- Needs for snow removal.

When applicable, provide additional shoulder width beyond the minimum values for special circumstances (e.g., mailboxes, transit bus stops, heavy pedestrian, bicycle use). Refer to Table 3-2 of NCHRP *Report 254: Shoulder Geometrics and use Guidelines*, 1982 for recommended widths for various shoulder functions and highway functional classifications.

For divided arterial highways with one or two lanes in each direction, a 4 ft [1.2 m] paved left shoulder within the median is recommended. On divided arterials with three or more lanes in each direction, a full-width shoulder within the median is recommended.

Shoulders with a minimum of 4 ft [1.2 m] stabilized or paved surface should be provided along both sides of rural highways routinely used by pedestrians. For design of shoulders to accommodate use by bicyclists refer to the AASHTO *Guide for Development of Bicycle Facilities*.

In rural areas, paved shoulders should be included in all new construction and reconstruction projects on roadways used by more than 1,000 vehicles per day; see Sections 9.3.16 and 9.3.17. In urban areas, provide bicycle lanes or separate bicycle facilities. In lower-speed urban areas with posted speeds of 40 mph [60 km/h] or less, shoulders may be limited by adjacent development to only the width necessary to accommodate bicycle use, and may be further reduced or eliminated if separate bicycle and pedestrian facilities are provided, and curbs are used. For urban transitional roadways with posted speed of 45 mph [70 km/h], separate bicycle and pedestrian facilities should be provided, and shoulders also provided in undeveloped areas. For high-speed urban roadways with posted speeds of 50 mph [80 km/h] or more, separate bicycle and pedestrian facilities should be provided, and the standard shoulder width also provided in all areas.

In determining the shoulder type consider the needs for pedestrian and bicycle use, safety, structural stability, cross-slope for drainage, operational functions, traffic barrier installation, and construction and maintenance costs. Consider the following types and their performance in the design:

1. **Earth.** Earth shoulders are unstabilized soil generally without turf cover, and may be applicable for very low-volume local roads, particularly where rainfall is low. The soil should be well-graded and compactable material suitable for topping. Depending on use, they may occasionally require re-grading and re-compaction to maintain their usable width and to repair pavement edge drop-offs and rutting.
2. **Granular.** Granular shoulders are an aggregate base or surface course gradation which may also be mixed with topsoil to sustain a turf cover. Granular or turf shoulders may be applicable for low or medium-volume, low-speed roads and where the shoulder is designed only for emergency use. Turf shoulders may also be applicable for higher volume or high-speed roads where the turf is well maintained and is particularly desired for aesthetics. Granular or turf shoulders should not be subject to high amounts of surface runoff, vehicular use or off-tracking. With use, they typically require periodic re-grading and re-compaction to maintain their usable width and to repair pavement edge drop-offs and rutting.
3. **Recycled Asphalt Pavement (RAP).** RAP shoulders are pulverized asphalt pavement material which may be mixed with additional emulsion or a recycling agent. The same considerations should apply as for granular shoulders, except the RAP may be more stable and applicable for shoulders with slightly higher use.
4. **Surface Treatment.** Treated shoulders may be bituminous penetration treatment or other binder placed over aggregate material to reduce water infiltration and keep the aggregate in place. The shoulders should receive periodic crack sealing, or additional treatments, or both. Surface treatments may be applicable for shoulders subject to only infrequent operational use and light vehicular traffic, or pedestrian or bicycle use.
5. **Paved.** Paved shoulders consist of the same pavement material as the traveled way, and are generally preferred for all operational functions including pedestrian or bicycle use, and particularly safety performance. The opportunity to install rumble strips on paved shoulders further enhances their safety performance. A lesser structural section depth may be provided for paved shoulders; however, the constructability and long-term performance should be considered together with the lower material cost.
6. **Combination.** A combination of shoulder types and respective widths may be used, as appropriate to balance cost, stability, operational performance, or aesthetics. A minimum partially paved width of 2 ft [0.6 m] is recommended in all cases, and additional

width desired for pedestrian or bicycle use. Instead of a combination of types, a fully paved shoulder is particularly recommended for high-volume roads, arterials, or where the shoulder receives frequent use, or is regularly used by pedestrians or bicyclists. Any combination with an unstabilized shoulder type may result in eventual reduction of the useable shoulder width.

9.3.8.3 Horizontal Clearance to Structures

Provide the required minimum horizontal clearance to retaining walls (including cut and fill situations), and bridge structures in coordination with the Structural Design Unit.

A minimum offset of 18 in [500 mm] must be provided beyond the face of curbs, with 2 ft [0.6 m] preferred, and with wider offsets provided where practical. This offset distance is not considered the clear zone, although it must be clear of obstructions, but is needed for operational and capacity reasons. See Section 9.3.12.3 for lateral clearance and offset distance to features adjacent the roadway. Also see Section 8.5.3.3.4.

For roadside safety, the recommended clear zone and shy distances, or barriers, should be provided as appropriate in accordance with the guidance provided in the AASHTO *Roadside Design Guide*. When applicable, determine the requirements for clearance to railroad features or major utilities.

For bridge structures, refer to applicable sections of the *Green Book* for minimum horizontal clearance from the travel lanes to bridge railings, for the road functional classification and traffic volume. For local roads see Tables 5-6 and 5-7, and for collector roads see Tables 6-6 and 6-7, for minimum clear roadway widths for bridges; however, the full approach roadway width, plus 2 ft [0.6 m] lateral clearance on each side, is generally desired. For arterials the full approach roadway width, including lateral clearance, should normally be provided for new bridges; however, bridges having an overall length over 200 ft [60 m] may have a lesser width. For arterials, an existing bridge to remain in place should have a width at least equal to the traveled way plus 2 ft [0.6 m] clearance on each side. For a two-lane tunnel, the total clearance between the walls should be a minimum of 30 ft [9 m].

9.3.8.4 Cross Slope

9.3.8.4.1 Travel Lane

FLH standard practice is for the cross slope on tangents on paved highways to be from 1½ to 2 percent. Typically, normal crown cross slopes of 2 percent are used on paved surface roads.

Normally, the normal crown cross slopes on gravel surfaced roads should be 3 percent to facilitate roadway surface drainage.

9.3.8.4.2 Shoulder

For paved shoulders less than 5 ft [1.5 m] width, the shoulder cross slope should be the same as the adjacent traffic lane. Paved shoulders 5 ft [1.5 m] or wider may be sloped to drain away from the traveled way, and should be sloped to drain away from the traveled way in areas of routine snowplowing and on divided highways with a depressed median. In these cases, consider shoulder cross slopes of 2 to 6 percent. With curb sections or when the shoulder surface is an asphalt surface treatment, aggregate or turf, increasing the shoulder slope helps to facilitate drainage. In these cases, consider cross slopes of 4 to 6 percent for gravel or asphalt treated shoulders, and 6 to 8 percent for turf shoulders.

9.3.8.4.3 Differences in Cross Slope

Rollover is the difference in cross slope between two adjacent travel lanes or a travel lane and its adjacent shoulder. On normal crown sections the rollover between adjacent travel lanes should not exceed 4 percent, and between the travel lane and turf shoulder should not exceed 6 percent. On superelevated curves, the rollover in cross slope between the travel lane and shoulder must not exceed 8 percent. See *Green Book* Section 4.2.2 and Section 4.4.3 for additional guidance.

Typically, locate any breaks in cross slope at the edges of travel lanes or shoulders. Alternatively, for 10 ft [3.0 m] travel lanes the slope break for shoulders may be located 2 ft [0.6 m] outside the travel lane, and for 11 ft [3.3 m] travel lanes the slope break for shoulders may be located 1 ft [0.3 m] outside the travel lane.

The cross slope on the tops of base courses and the subgrade should be the same as on the finished pavement. For unpaved shoulders or shoulders wider than 7 ft [2.1 m], it is desirable to have a reverse slope on the subgrade (on the high side of curves and outside the edge of the pavement) to drain the shoulder surface away from the travel lane and drain moisture away from the base.

9.3.8.5 Pavements and Geometric Design Considerations

The pavement structure refers to the material and depth of base and pavement placed on the finished subgrade. Refer to Chapter 11 for guidance on developing the pavement structure design including the materials and minimum thickness. Consider the following for the geometric design of the roadway and pavement structure:

- Provide a smooth-riding, skid-resistant roadway surface,
- Minimize the necessary subgrade width and the overall depth of material necessary for the design service life of the pavement,
- Design the top portion of the subgrade to utilize the highest strength material available from the earthwork grading, and
- Design the roadway and overall geometric cross section to fully optimize, support and integrate the pavement structure design.

9.3.8.6 Risk Assessment and Mitigation

The traffic volume that is exposed to the condition primarily influences the safety and operational risks regarding the roadway cross section. Where roadway width is less than recommended, provide the safest roadside design possible, and provide enhanced delineation and warning devices. For narrow roadway widths, consider using centerline rumble strips and additional widening in curves beyond the normal guidelines.

Variations in the available shoulder width reduce the driver's expectations that the full shoulder width will be available when needed, and may affect driver behavior if evasive maneuvers are required. Consider adding more frequent pullouts where there are combinations of narrow shoulder width and severe terrain.

Also refer to the AASHTO publication *A Guide for Achieving Flexibility in Highway Design*, Section 3.6.1.3 for guidance on mitigating narrow travel lanes, and refer to Section 3.6.2.2 and Table 3-2 for additional guidance on mitigating narrow shoulder widths.

9.3.9 ROADWAY WIDENING

Consider the need for additional widening on curves, and the need for auxiliary lanes, turnouts, etc. These additional widening considerations and requirements are described in the following sections.

9.3.9.1 Traveled Way Widening on Curves

It is FLH standard practice to increase traveled way widths on curves, as recommended by *Green Book* Section 3.3.10. Traveled way widening values are shown in *Green Book* Tables 3-26 and 3-27.

When necessary, provide traveled way widening exceeding the minimum values. When applicable, provide additional traveled way widening on curves where lane widths are less than 10 ft [3.0 m], or if necessary to accommodate vehicle tracking and safe operations due to:

- Greater difficulty for drivers to control the vehicle in curves,
- "Overshoot" path behavior at tangent to curve transitions,
- Variations in speeds within the curve resulting in changing lateral accelerations,
- Variations in e, f, and R within the curve with resultant changing lateral accelerations,
- Difficulty in discerning the vehicle lane position, both own vehicle and opposing traffic,
- Difficulty in judging the clearance from objects along the roadway,
- Off-tracking (offset) of rear wheel to front wheel paths and towed vehicles, and
- Reduced lateral clearance due to vehicle overhangs in front and rear.

For simple (non-spiraled) curves, apply the total travel way widening on the inside of curves and transition it throughout the length of the superelevation runoff. The pavement joint and final centerline striping should be adjusted from the geometric centerline to split the roadway width and provide equal widening to both lanes.

For curves with spiral transitions, split the widening equally to both lanes and transition it on the spiral lengths.

Provide lane edge line striping consistent with the designed traveled way widening. Design the edge striping for the traveled way widening to apply the widening only to the travel lanes, and to maintain the same shoulder width in the curve as for the tangent section.

9.3.9.2 Auxiliary Lanes

Refer to the following sections for guidance on specific types of auxiliary lanes.

When evaluating the operational performance of alternatives to two-lane cross sections, including passing lanes, climbing lanes and short four-lane sections, or determining the need for passing lanes, consider the *IHSDM* Traffic Analysis Module, which uses the TWOPAS traffic simulation module to estimate traffic quality of service measures for an existing or proposed design under current or projected future traffic flows.

Coordinate signing and marking requirements of the *MUTCD* for the addition, continuation, or drop of travel lanes with the design for location of such signing along the roadway, and with the geometric design of the roadway and intersections. Refer to the *MUTCD*, Table 2C-4, Section 3B.09 and Figure 3B-12 for guidance on the minimum lengths and layout of lane reductions, speed changes, and similar auxiliary lane transitions.

9.3.9.3 Parking Lanes

Refer to *Green Book* Section 4.20, Section 5.3.2, Section 6.3.2 and Section 7.3.3 for criteria on design of parking lanes.

Exercise care in introducing any new on-street parking, as it affects operating speeds, capacity, and potential safety risk. On-street parking is not recommended where operating speeds are greater than 40 mph [60 km/h]. Parking lanes may be provided on lower-speed urban highways with 40 mph [60 km/h] or less posted or regulatory speed. The design of transitional (45 mph [70 km/h] and high-speed urban (50 mph [80 km/h] or more) arterial or expressway facilities should only accommodate emergency stopping. Do not add on-street parking to facilities with design or posted speeds of 50 mph [80 km/h] or more. Within lower-speed urban areas existing developed and developing land uses may require on-street parking lanes. Parking lanes may also be provided on rural highways passing through developed communities with urban cross-section elements. When adding on-street parking to low-speed facilities, consider:

- The effect on the highway's operating speed, safety and capacity,
- Sight distance requirements,
- Turning paths,
- Bicycle use,
- Needs for crosswalks, mid-block crossings and curb bulb-outs,
- Bus and transit use,
- Needs for access by emergency vehicles to adjacent buildings, and
- Snow removal and storage, if applicable.

When land use development requires parking lanes, consider only parallel parking. Do not use angle parking without a careful analysis of operational characteristics of the facility. Do not use angle parking in areas of operating speed greater than 25 mph [40 km/h]. Where angle parking is permitted and required to support adjacent land uses, back-in angle parking is the preferred treatment over head-in angle parking for visibility of motor vehicle and bicycle traffic, and safety of loading passengers and cargo.

The width of parallel parking lanes can vary from 7 ft to 12 ft [2.1 m to 3.6 m] depending on the roadway function and type of use. The desirable minimum width of a parking lane is 8 ft [2.4 m], particularly for areas with frequent parking turnover or loading activity. A minimum parking lane width of 10 ft [3.0 m] is desirable in areas where there is a need for lateral clearance from the traveled way, or there is substantial truck or recreational vehicle parking use, or for bus stops. Wider parking lanes up to 12 ft [3.6 m] are desired to provide better lateral clearance to the shoulder or traveled way, especially for higher function roadways, or to accommodate use of the parking lane as a through-travel lane during peak periods.

For design of bicycle routes, the combined width for bicycle travel and parallel parking should be a minimum of 14 ft [4.2 m]; 16 ft [4.8 m] being desirable. Refer to Section 9.3.17 for bicycle considerations and facilities.

Parallel parking stalls may be 22 ft to 26 ft [6.7 m to 7.8 m] long; 25 ft [7.6 m] being typical.

For angle parking provide a minimum width parallel to the roadway for parking of 17 ft [5.2 m] and preferably 20 ft [6 m]. Diagonal parking stalls may be 8 ft to 10 ft [2.5 m to 3 m] wide; 9 ft [2.7 m] being typical. Wheel stops may be provided to limit encroachment of parked vehicles; however, consider potential interference of wheel stops with snow removal operations if applicable.

The cross slope of parking lanes may be from 2 percent minimum to 4 percent maximum.

Avoid design of parking lanes within an 8 ft [2.4 m] offset from adjacent traffic barriers.

Consider parking requirements to accommodate persons with disabilities. Refer to the *Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities (ADAAG)* for the applicable standards. The *Green Book* contains information on sidewalk curb ramps in Section 4.17.3. Refer to Section 9.3.16.3 for accessibility requirements applicable to the design of parking areas and passenger loading zones. In general, accessible on-street parking should be located near facilities such as markets, post offices, drug stores, and medical facilities. Also consider designating passenger loading zones for accessible on-street parking. Where designing on-street accessible parking spaces consider the following:

- Design the cross-slope to not exceed 2.0 percent,
- If curbed, provide a curb ramp or locate accessible spaces adjacent to crosswalk,
- Provide an additional 5 ft [1.5 m] stall length to accommodate an access aisle,
- Avoid placing appurtenances adjacent to the accessible parking stall, and
- Avoid placing drainage inlets within the accessible parking stall.

9.3.9.4 Speed Change and Turning Lanes

When applicable, provide acceleration and deceleration lanes, including tapered areas, for vehicles entering or leaving the through traffic lanes. There are no definite warrants for providing speed change lanes; however many considerations are involved in the determination. The *Green Book* provides guidance on using these lanes in Section 9.7 and Section 10.9.6.

Consider providing speed change lanes for intersections on principal arterials. Also consider speed change lanes when recommended as the result of a safety and crash study. Speed change lanes should also be considered when:

- Operating speeds are 50 mph [80 km/h] or greater, and
- Daily peak hourly traffic volume of the through lane in the direction of travel exceeds 120 vph, and
- Turning vehicles frequently cause conflict with the through traffic, and
- The combined volumes of through traffic and vehicles entering or leaving the traffic lanes typically cause through vehicles to slow more than 10 mph [15 km/h].

Refer to Section 9.3.14.5 for specific considerations and design of left-turn acceleration and deceleration lanes, and Section 9.3.14.6 for right-turn lanes, at intersections.

9.3.9.5 Climbing Lanes

Evaluate the need for climbing lanes in areas with truck traffic and steep grades, or other areas subject to slow-moving traffic. Climbing lanes should be provided to assure a uniform level of service rather than as a necessity to avoid extreme congestion and disruption of traffic flow. Climbing lanes should be considered when the critical length-of-grade is exceeded (i.e., the length of grade causes a reduction of 10 mph [15 km/h] or more in the speed of a heavy truck) and the flow of traffic is significantly affected (DHV flow for LOS D is not attained). Refer to the *Highway Capacity Manual* or the *IHSDM* for methodology to analyze the traffic operations and effect of climbing lanes for specific locations.

Evaluate the effect of steep grades, both upward and downward, on capacity and safety for high traffic volumes and numerous trucks. In areas with especially long and steep grades, and high traffic volume, consider providing a truck lane (creeper lane) for slow-moving downhill traffic (e.g., trucks, vehicles with trailers, recreational vehicles), as appropriate. Design climbing lanes independently for each direction of travel.

Consider climbing lanes on two-lane highways under the following circumstances for the DHV:

- The upgrade traffic volume exceeds 200 vph,
- The upgrade truck volume exceeds 20 vph,
- LOS D is not attained on the grade,
- A reduction of two or more levels of service occurs when moving from the approach segment to the grade, or

- Trucks will experience a speed reduction of 10 mph [15 km/h] or greater.

For those unfamiliar with the level-of-service concept, it is difficult to visualize the operating conditions that characterize levels of service A through F. *Green Book* Table 2-4 presents a brief description of the operating characteristics for each level-of-service and type of highway.

Other factors to consider, on the upgrade, are the amount and location of left or right turns at intersections or driveways within the segment.

Refer to *Green Book* Section 3.4.3 for details on designing climbing lanes on two-lane highways. The *Highway Capacity Manual* also contains guidance and sample calculations.

For justification warrants and design criteria for climbing lanes on multilane highways, refer to Chapter 3 in the *Highway Capacity Manual* and *Green Book* Section 3.4.3.

If a climbing lane is provided, consider the following minimum criteria for design:

- The full width of the climbing lane should extend for the entire location where the truck speed is less than 10 mph [16 km/h] of the passenger car speed;
- The entering taper of the climbing lane should be at least 15:1 and preferably 25:1;
- The exiting or merging taper should be at least 30:1 and preferably 50:1 or more;
- Locate the ending merging taper of climbing lanes in areas where the available sight distance is maximized;
- The climbing lane width should equal or exceed that of the adjacent through lane, and preferably be at least 12 ft [3.6 m];
- Avoid locating the ending or merging taper within 500 ft [150 m] prior to an intersection or major side approach road;
- The merging taper should be located to avoid side approach roads or driveways on either side of the highway;
- Superelevate the climbing lane in the same manner as for a multi-lane highway;
- The shoulder width should be the same as the adjacent two-lane section and at least 4 ft [1.2 m];
- Provide the typical clear zone from the edge of the traveled way of the outer most lane (climbing lane); and
- Provide signing and markings in accordance with the *MUTCD*.

9.3.9.6 Passing Zones and Lanes

Consider the accommodation of passing maneuvers as an essential element of two-lane rural highway design. It is desirable to provide as many passing opportunities as possible, especially in areas where there are limited opportunities to pass or on highways that may have slow-moving traffic.

9.3.9.6.1 Passing Zones

FLH standard practice is to develop the roadway geometric design to provide passing sections based on the design controls for minimum passing sight distance found in the *Green Book* for the functional classification and design speed of the highway. Refer to *Green Book* Section 3.2.4 for guidance on the criteria for geometric design of passing sections (zones).

Consider the principles of design consistency in the geometric design of passing zones. The provision of short passing zones intermixed with long passing zones can violate a driver's expectations. Design of minimum passing zones may be necessary in mountainous or rolling terrain to permit passing of slow trucks and recreational vehicles when passing lanes or climbing lanes cannot be provided.

Signs, if used, and markings to designate passing and no-passing zones are designed in accordance with the *MUTCD* Sections 2B.29, 2B-30, 2C-35, and 3B-02.

9.3.9.6.2 Passing Lanes

Consider providing passing lanes in one or both directions of travel on a two-lane highway having inadequate passing opportunities, to:

- Improve passing opportunities,
- Enhance safety, and
- Improve traffic operations by breaking up traffic platoons and reducing delay.

Passing lanes differ from climbing lanes in that passing lanes are considered regardless of topography. Refer to Section 9.3.9.5 for guidance pertaining to climbing lanes.

Passing lanes can be used in either rolling or level terrain when passing restrictions exist because of limited sight distances or high volumes of oncoming traffic. Consider providing passing lanes particularly on highways with high traffic volumes (over 2,000 ADT) including slow-moving trucks and recreational vehicles, and that lack frequent sections with adequate passing sight distance, resulting in operational delays and potential safety conflicts. Consider passing lanes are less effective on sections that already provide good passing opportunities, at least during the off peak periods. Although potentially more costly, it may be desirable to locate passing lane sections in the rolling terrain at locations where passing sight distance is generally unavailable, rather than in level terrain sections. Passing should be allowed within passing lane sections for the opposing traffic if passing sight distance is available and access conditions are appropriate.

Refer to *Green Book* Section 3.4.4 and the *Highway Capacity Manual* for guidance on the design of passing lanes.

FLH standard practice for design of passing lanes includes the following:

- Design passing lanes to be at least 1,000 ft [300 m] long, excluding tapers,

- For two-way total DHV less than 600, the desirable length of a passing lane is 0.5 mile to 1 mile [0.8 km to 1.6 km], which does not include the taper length for the lane addition and lane drop,
- Design the lane addition taper at a ratio of 25:1,
- Design the lane drop taper in accordance with the *MUTCD*, Section 3B-8, or at a ratio of 50:1, whichever is longer,
- Superelevate the passing lane in the same manner as for a multi-lane highway; and
- Provide passing lane signing and markings in accordance with the MUTCD.

The lane addition and drop should be located in areas where sight distance is maximized, preferably where 1,000 ft [300 m] of sight distance is available, to allow a driver to anticipate the passing opportunity and also its end. The end of the merging taper should be visible from the lane reduction sign (W4-2R). Because of sight distance concerns, the merging taper should not be located just beyond the midpoint of a crest vertical curve.

The passing lane width should equal or exceed that of the adjacent through lane, and preferably be at least 12 ft [3.6 m]. The shoulder width should be the same as the adjacent two-lane section. The typical clear zone should be provided from the edge of the traveled way of the outer most lane (through lane).

Advance signing is beneficial to indicate to drivers that passing opportunities exist ahead (e.g., PASSING LANE 2 MILES AHEAD, PASSING LANE ½ MILE AHEAD).

The use of a passing lane is determined on a case-by-case basis. The justification for increasing the frequency of passing opportunities is usually based on an engineering study that includes judgment, operational experience and a capacity level-of-service analysis using procedures of the *Highway Capacity Manual*. Measuring traffic traveling in platoons (traffic with headway gaps of 5 seconds or less) can also be helpful in establishing need and identifying potential sites for passing lanes. Evaluating the need for passing improvements should consider traffic operations over an extended road length, usually at least 10 miles [16 km]. For additional information on passing lane warrants, see the FHWA publication *Low Cost Methods for Improving Traffic Operations on Two-Lane Roads*, Report No. FHWA-IP-87-2. It presents approximate adjustments that can be made to the capacity methodology in the *Highway Capacity Manual*. These adjustments can be used to estimate the level-of-service benefits from adding passing lanes to two-lane facilities.

When determining where to locate passing lanes, consider the following factors:

1. **Costs and Impacts.** Locate passing lanes to minimize costs and impacts. Difficult terrain will generally increase the costs and impacts for construction of passing lanes.
2. **Appearance.** The passing lane location, and its value, should appear logical and be obvious to the driver.
3. **Horizontal Alignment.** Where practical, avoid locating passing lanes on segments with lower-speed horizontal curves that restrict the speed for all vehicles.

4. **Vertical Alignment.** Where practical, construct passing lanes on a sustained upgrade. The upgrade will generally cause a greater speed differential between slow moving vehicles and passing vehicles. However, passing lanes in level terrain still should be considered where the demand for passing opportunities exceeds supply.
5. **Intersections.** Locations should be avoided that include major intersections or high-volume access points (over 500 ADT). Use special care when designing passing lanes through minor intersections and commercial entrances.
6. **Structures.** Avoid placing passing lanes where structures (e.g., large culverts, bridges) may restrict the overall width of the traveled way, passing lane and shoulder.
7. **Tapers.** Avoid locating the ending or merging taper within 500 ft [150 m] prior to an intersection or major side approach road. The merging taper should be located to avoid side approach roads or driveways on either side of the highway.

Separate left-turn lanes may be provided in a passing lane section when left turn volumes are significant. Refer to Section 9.3.14.5

When passing lanes are provided to improve the overall traffic operations over a length of roadway, they should be constructed systematically at regular intervals. Typical spacing for passing lanes may range from 3 to 8 miles [5 to 13 km] in the same traffic direction. Actual spacing of passing lanes will depend on the traffic volumes, right-of-way availability and existing passing opportunities. When spacing passing lanes in both directions, it is desirable to locate the first passing lane for the advancing traffic direction prior to a passing lane for the opposing traffic.

The design of three-lane roads with alternating passing lanes, in 0.5 mile to 1 mile [0.8 km to 1.6 km] increments, continuously over an extended section of road is known as "2+1" road design. This concept has been used to convert wide two-lane roadways, or narrow four-lane roadways, to a three-lane roadway with designated, alternating passing lanes in each direction to improve safety and operations. These roadways may be considered an intermediate solution to the ultimate future expansion to a four-lane highway constructed to full standards.

9.3.9.7 Bicycle Lanes

Bicycle lanes are portions of a highway or street that have been identified for bicycle travel by signs, pavement markings, or both. Consider bicycle lanes particularly for urban street designs. See Section 9.3.17 for guidance and details.

9.3.9.8 Slow Moving Vehicle Turnouts

Refer to the section on "Turnouts" in *Green Book* Section 3.4.4 for guidance on the design of slow moving vehicle turnouts.

When applicable, design slow moving vehicle turnouts to provide sufficient room for a slow moving vehicle to pull safely off the roadway, then re-enter the through lane after faster moving vehicles pass.

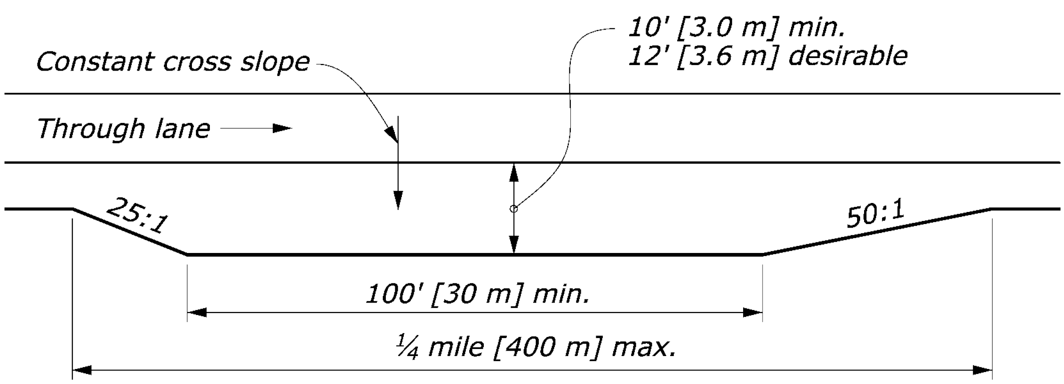
Consider the need for a turnout on paved roadways for the following situations:

- With limited passing opportunities,
- When slow-moving vehicles are prevalent but do not warrant climbing lanes, and
- Where the cost of an auxiliary lane is prohibitive.

Exhibit 9.3-K provides guidance for minimum dimensions of turnouts. Refer to *Green Book* Table 3-32 for recommended lengths of turnouts including taper. Greater turnout widths should be considered on curves and along steep fill slopes. Turnouts wider than 16 ft [4.8 m] are not recommended. The riding surface of a turnout should be similar to the adjacent travel way. Sign and mark all slow moving vehicle turnouts to identify their presence and purpose.

Turnouts should be located so that approaching drivers have a clear view of the entire turnout in order to determine whether the turnout is available for use. The available sight distance should be at least 1,000 ft [300 m] on the approach to the turnout. Provide adequate sight distance so the vehicle can re-enter the traffic stream safely. Slow-moving vehicle turnouts should not be located in areas where available sight distance is less than the length shown in the *Green Book* for decision sight distance for avoidance maneuvers C, D or E for the type of road.

Exhibit 9.3-K SLOW-MOVING VEHICLE TURNOUT



9.3.9.9 Parking Pullouts

Parking pullouts are advantageous for vehicle checks, orientation, brief driving breaks, vistas, recreation and other purposes. For operating speeds of 45 mph [70 km/h] or less, parking pullouts should be a minimum of 14 ft [4.2 m] wide and 50 ft [15 m] long, excluding tapers, for parallel parking beyond the normal roadway shoulder. For perpendicular or angle parking, pullouts should be a minimum of 40 ft [12 m] wide and 80 ft [24 m] long, excluding tapers, beyond the normal roadway shoulder. Tapers for parking pullouts should be at least 50 ft [15 m] in length. For operating speeds over 45 mph [70 km/h], the pullout and taper dimensions should be increased proportionately to the higher speed. Parking pullouts should not be located in areas where available sight distance is less than the length shown in the *Green Book* for decision sight distance for avoidance maneuvers C, D or E for the type of road.

9.3.9.10 Shoulder Widening for Barriers

Refer to the AASHTO *Roadway Design Guide* for recommended offset distance from the roadway to barriers such as guardrail, terminals, bridge railing, etc. Design sufficient shoulder widening to accommodate the barrier and the offset.

9.3.10 MEDIANS

Refer to *Green Book* Section 4.11 for guidance on the general design of medians. Specific guidance on the design of medians for collector roads, arterials and freeways is provided in the applicable sections of the *Green Book*.

9.3.10.1 Benefits and Disadvantages of Medians

The primary benefit of medians is to improve safety. Medians improve safety by separating opposing traffic thus reducing head-on and sideswipe crashes, and by providing a recovery area for errant vehicles, and by providing a refuge area for crossing and left-turning vehicles from intersecting roads. Medians also improve pedestrian and bicyclist safety by breaking up crossing distances and providing a refuge area for pedestrians and bicyclists crossing the roadway. Other benefits of medians include:

- Providing storage space for left-turning vehicles;
- Improving mainline traffic operations by controlling left turns from the mainline as well as from minor driveways, and channelizing traffic movements;
- Providing space for drainage and drainage facilities, bridge piers, and other structures;
- Providing a refuge area for disabled vehicles, and providing a snow storage area;
- Traffic calming; and
- Providing opportunities for landscaping and aesthetic treatments, which help buffer visual impacts and noise, and generally provide for increased driver comfort and ease of operation.

There are also disadvantages to medians. Raised medians may complicate snow plowing, storage and removal operations. In addition, plantings and other landscaping elements may obscure sight distance in horizontal curves and at intersections, and may constitute roadside obstacles. Such elements should be consistent with the AASHTO *Roadside Design Guide*.

For additional guidance on median width refer to NCHRP Report 375, *Median Intersection Design*.

9.3.10.2 Urban Medians

Medians for urban roadways are typically either raised or flush. Flush medians are typically 4 ft to 16 ft [1.2 m to 4.8 m] and should be well delineated by either painting or paving with a contrasting surfacing type, color or texture.

The raised area of urban medians should be curbed. Refer to Section 9.3.11. Raised medians in urban areas should be as wide as practical, with 30 ft [9 m] normally being the maximum width. Raised medians should be a minimum of 6 ft [1.8 m] width, which allows for a minimal 4 ft [1.2 m] width raised area with 1 ft [0.3 m] offset between the outside edge of the raised area and the travel lane. To accommodate left-turn lanes with a raised median and offsets for curb the raised median width in low-speed urban areas is 16 ft [4.8 m] minimum, and preferably 20 ft to 24 ft [6.0 m to 7.2 m]. For transitional speed urban roadways with 45 mph [70 km/h] posted speed, the recommended median width is 30 ft [9 m]. Raised, curbed medians are not recommended for high speed roadways, particularly for design speeds of 55 mph [90 km/h] or more. Instead, flush medians with traffic barriers are recommended, or widening the median to obtain sufficient separation width.

Provide a parabolic (desired) or semi-circular bullet nose at the end of all raised medians. Refer to *Green Book* Section 9.8 (including exhibits and tables) for design of median openings.

Consider a two-way continuous left-turn lane (TWLTL) if necessary to provide access in areas with frequent driveway spacing in highly developed or commercialized areas. A TWLTL should not be used on highways with more than two through lanes in each direction or average operating speed over 45 mph [70 km/h]. A center lane width of between 12 ft to 16 ft [3.6 m to 4.8 m] is suitable for a TWLTL; however 14 ft [4.2 m] minimum width is desired. Careful evaluation of individual sites is required for design of a TWLTL, as it may be inappropriate at many locations. A TWLTL may increase rather than control access opportunities. An alternative median treatment with dedicated left turn lanes where needed is preferable than a TWLTL for safety and access management.

Also refer to AASHTO *A Guide for Achieving Flexibility in Highway Design*, Section 3.6.4.2, for guidance on design of medians on urban highways.

9.3.10.3 Rural Medians

Medians for rural highways are typically either depressed or flush. In areas where there are no driveways or approach roads to cause left turn movements, a flush paved median width of 4 ft [1.2 m] or greater may be used. However, if there are regular turn movements a flush median width of 10 ft [3.0 m] or greater should be provided.

An appropriate median should be provided in the design for all new or reconstructed rural multi-lane arterials, including expansion of two-lane arterials to multi-lane facilities.

Depressed medians are generally used on rural divided highways for more efficient drainage and snow removal. Median side slopes should follow the recommendations of the AASHTO *Roadside Design Guide*. Careful consideration of longitudinal and transverse slopes, ditches and drainage features is necessary. Drainage inlets in the median should be designed either with the top of the inlet flush with the ground or with culvert ends provided with traversable safety grates.

Also refer to AASHTO *A Guide for Achieving Flexibility in Highway Design*, Section 3.6.4.1, for guidance on design of medians on rural highways.

9.3.10.4 Variable Medians and Independent Alignments

For median widths greater than 40 ft [12 m], variable medians and independent roadway alignments should be considered. Independent horizontal alignments and grades enable a closer fit of the roadway to the topography and typically reduce the overall clearing footprint and earthwork. With wider medians, especially with variable independent alignments, a desirable ease and freedom of operation is obtained, the noise and air pressure of opposing vehicle traffic is not noticeable, and the glare of headlights at night is greatly reduced. Additional opportunities for preservation of existing vegetation and landforms within the median are available, which enhances scenic beauty, environmental enhancements and wildlife crossings.

9.3.11 CURBS

The design of curbs and their offset should consider whether the highway cross-section is classified as rural or urban, and if urban whether categorized as lower-speed (40 mph [60 km/h] or less posted or regulatory speed) or transitional (45 mph [70 km/h]), or high-speed (50 mph [80 km/h] or more). The location of the highway within the corporate limits of a city does not determine if it should have an urban cross-section.

Curbs may be used for the following applications:

- On low-speed roadways for control of pavement drainage and to delineate and confine the edge of the roadway, for pavement edge support, right-of-way reduction, and aesthetics and for maintenance operations;
- In association with gutters or paved ditches for controlling drainage from a highway, especially in embankment areas with erodible soils or steep and high slopes or that drain into streams, lakes, wetlands and other bodies of water;
- With a paved foreslope ditch on the cut (uphill) side of a roadway for drainage control, instead of a graded roadside ditch, where rugged terrain, environmental impacts or other factors limit the space available for a conventional roadside ditch, and
- On low-speed roadways for channelization, access control, aesthetics, separation between pedestrians and vehicles, and to enhance delineation of the roadway.

Caution should be exercised when using curbs on high-speed rural highways. Where curbs are required for control of pavement drainage along high-speed rural highways, they should always be located at or beyond the outside edge of the shoulder, and should be the sloping faced type. The curb should be offset a minimum of 1 ft [300 mm] and preferably 2 ft [600 mm] outside the normal shoulder line, or as described in Section 9.3.11.3.

Curbs placed in front of traffic barriers can result in unpredictable impact trajectories, and should be avoided if practical. Curbs should not be used with concrete median barriers. The use of curbs with guardrail should be avoided, if not required for controlling drainage. Also refer to Section 8.5.3.3.3.

If a curb is required in conjunction with guardrail, the following applies:

- Do not use curb within 50 ft [15 m] of terminal sections,
- The height-of-curb should be 4 in [100 mm] or less, and it should be the sloping-faced type with batter 1V:3H or flatter, located flush with or behind the face of the guardrail; except, for speeds 50 mph [80 km/h] or less a 6 in [150 mm] or less sloping-faced curb may be used with strong-post (Type G) guardrails if the curb is located flush with or behind the face of the guardrail, and
- Curbs should not be located between the roadway and the face of the rail, except under the following conditions:
  - ◊ For low speeds 45 mph [70 km/h] or less, guardrails may be used behind sloping-faced curbs 6 in [150 mm] or less height if the face of the guardrail is located at least 8 ft [2.5 m] behind the curb.
  - ◊ For higher speeds up to 50 mph [80 km/h], guardrails may be used behind sloping-faced curbs 4 in [100 mm] or less height if the face of the guardrail is located at least 13 ft [4 m] behind the curb.

The above guidance results from crash testing; for additional guidance see NCHRP Report 537: *Recommended Guidelines for Curb and Curb–Barrier Installations*.

Coordinate with the Geotechnical Unit where the need for curb is to protect erodible soils. Coordinate with the Hydraulics Unit where curbing is used in conjunction with a closed storm drainage system.

When designing curbs, provide drainage inlets or waterways to collect and convey the concentrated water flow at low points, curb ends, intersections and prior to reversals in superelevation. Refer to Section 7.3.3 for pavement drainage design guidelines.

Curb with gutter pan may be used to prevent infiltration of water along the face of curb joint and to enhance the visibility of the curb and thus improve delineation. Gutter pans are typically 1.3 ft [0.4 m] wide but may be 1 ft to 4 ft [0.3 m to 1.2 m] in width, with cross slope of 1V:12H to 1V:20H to enhance the hydraulic capacity. Gutter pan cross slopes generally must be modified at curb ramps to meet accessibility requirements. When used on the high side of superelevation the gutter pan may be sloped away from the roadway to contain some of the gutter flow against the curb. Where the gutter pan is only used to enhance delineation and not to enhance the drainage function it should be on the same cross slope as the roadway.

Where curbs or gutters are used, particularly in areas of flat grades, sag vertical curves, and in through-cuts, consider the potential need for an edge drain or underdrain system where the base and subbase do not drain to daylight.

Curb designs are classified as either vertical or sloping, as described in the following sections.

9.3.11.1 Vertical Curbs

Vertical curbs should only be used on lower-speed roadways with posted speeds of 40 mph [60 km/h] or less. Vertical curbs are undesired on transitional roadways with 45 mph [70 km/h] posted speed, and instead sloping curbs are recommended if a curb is necessary. Avoid using vertical curbs with posted or operating speeds greater than 45 mph [70 km/h]. Vertical curbs are typically nearly vertical (approximate batter of 4V:1H) and are typically 6 in [150 mm] in height. Vertical curbs taller than 6 in [150 mm] should be avoided. Curbs or dikes for embankment drainage control are typically 4 in [100 mm] in height and are typically battered from 2V:1H to 1V:1H, and are typically placed at or preferably beyond the normal edge-of-shoulder. Vertical curbs within 7 ft [2.1 m] of the travel lane should be avoided in rural areas that are routinely snowplowed in winter.

9.3.11.2 Sloping Curbs

Sloping curbs are more easily traversed than vertical curbs. Sloping curbs have an approximate batter of 1V:4H or 1V:3H and are typically 3 in to 4 in [75 mm to 100 mm] in height. Sloping curbs with a gutter pan function to control drainage and delineate the edge of the roadway, foreslope or paved ditch while generally conforming to the cut slope behind it. Avoid using sloping curbs in conjunction with an attached sidewalk, particularly along a parking lane. If curbs are used on urban transitional roadways with 45 mph [70 km/h] posted speed, the sloping faced type is recommended. Although in general neither vertical nor sloping curbs are desired on high-speed roadways 50 mph [80 km/h] or more, if curb is necessary then use the sloping faced type.

9.3.11.3 Curb Offsets

This section provides guidance on minimum curb offsets from the roadway, for design speeds of 45 mph [70 km/h] or less.

FLH standard practice includes the following:

- Curbs should be offset 2 ft [0.6 m] from the normal edge of shoulder, or 1 ft [0.3 m] if a sloping curve is used,
- For roadways where shoulders are not provided, apply the minimum offset distance from the traveled way for vertical curbs as shown in Exhibit 9.3-L, and
- For roadways where shoulders are not provided, the left offset distance from the traveled way for sloping curbs may be 1 ft [0.3 m] less than shown in Exhibit 9.3-L.

Exhibit 9.3-L shows the minimum offset distances for vertical curbs. For sloping curbing installations, the minimum left offset distance may be 1 ft [0.3 m] less.

Where bicyclists are accommodated, provide at least 5 ft [1.5 m] and desirably 6 ft [1.8 m] offset from the traveled way to the face of the curb. Provide bicycle-safe inlet grates, or preferably recessed drainage inlets or curb inlets. For further information, see the AASHTO *Guide for the Development of Bicycle Facilities*.

Exhibit 9.3-L OFFSET DISTANCES FOR VERTICAL CURBS

Lane Width		Left				Right (Min.)	
		Rural		Urban		Rural and Urban	
(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)
12	3.6	1	0.3	1	0.3	2	0.6
11	3.3	2	0.6	1	0.3	3	1
10	3.0	3	1.0	2	0.6	3	1

9.3.11.4 Accessibility Issues with Curbing

Refer to Section 9.3.16.3 guidance on design of curbs and ramps for accessibility and accommodation for the disabled.

9.3.12 ROADSIDE DESIGN CONSIDERATIONS

The roadside is the area between the shoulder and the construction limits. See Exhibit 4.3-A. The roadside design should blend the roadway with the surrounding natural or man-made community.

As practical, design the roadside to provide:

- A safe area for errant vehicles to recover,
- Separation of motorized and non-motorized travel,
- Areas for landscaping and for the control, storage, and filtration of drainage runoff, and
- A cohesive transition between the roadway facility and the environmental context beyond the highway corridor.

The design of clearing, earthwork, drainage, approach roads, pedestrian facilities and similar elements that extend outward from the roadside and interact with the surrounding context must especially strive to match and blend with their natural, or manmade, counterpart elements outside of the immediate roadway corridor. During the final design, emphasis should be placed on minimizing the overall footprint of the immediate roadway corridor, which may tend to result in a minimized and abrupt termination of the roadside design at the slope catch. However, a similarly high level of emphasis should be placed on creating a smooth and un-noticeable transition between the roadside design and the natural landscape, or the man-made community, beyond the immediate roadway corridor. This may result in extending the construction limits beyond what is minimally needed for the roadside design, and may create additional short-term impacts; however, the goal of this work is always to provide a more sustainable design with less overall impact in the long term. This design goal is achieved through attention to the details of quality roadside design; and by placing emphasis on restoring vegetation, improving vehicular and pedestrian access points, providing enhancements of the roadside, and otherwise blending the roadside at its interface with the adjacent landscape. See Section 9.5.4 for guidance on landscaping and restoration of vegetation.

Green Book Section 4.8 provides general guidance on roadside design. Refer to the AASHTO *Roadside Design Guide*, and *A Guide for Transportation Landscape and Environmental Design*, AASHTO 1991, for specific guidance on the roadside design. Also refer to the AASHTO *Guide for Achieving Flexibility in Highway Design* Section 3.6.3 for guidance on design considerations and associated flexibility regarding treatment of the roadside.

9.3.12.1 Forgiving Roadside Concepts

Wherever practical, design the roadside to provide a margin of safety for driver error, and to forgive driver errors when they occur. Ideally, the roadside should feature recoverable side slopes free of fixed objects. Where practical, avoid or minimize the design of embankment slopes steeper than 1V:3H. Slopes steeper than 1V:3H are non-traversable, and an errant vehicle is likely to overturn on them. Barrier protection should be considered when these slopes are located within the clear zone. While a 1V:3H slope is technically traversable by a passenger vehicle, it is of marginal safety value compared to recoverable slopes. Errant drivers trying to recover control of their vehicles often cannot successfully steer or brake on a 1V:3H slope. Slopes of 1V:3H become potentially dangerous when other features (e.g., drainage features, devices, trees, ditches) are located on or adjacent to the slope. Provide a recoverable slope (i.e., 1V:4H or flatter) adjacent the roadway where practical. Locate roadside hardware outside the recoverable clear zone or use breakaway devices. Relocate, redesign, or shield fixed objects, and provide effective delineation of the roadside, especially of any hazards that cannot be removed. Where practical, implement the concepts of the forgiving roadside beyond the clear zone. Give special attention to provide a forgiving roadside where a design exception or a variance from FLH standard practices is required for other geometric features such as alignment, sight distance or roadway width. Refer to Section 8.1.4 for additional guidance. Also refer to the AASHTO *Roadside Design Guide*, Chapter 1.2.

9.3.12.2 Clear Zone

As possible, provide an unobstructed, recoverable clear zone distance beyond the edge of the traveled way, as recommended by the AASHTO *Roadside Design Guide* (RDG) for the applicable functional classification in urban or rural areas, traffic volume, speed, curvature, embankment and back slopes. Determine a recommended range of clear zone distance using Table 3.1 or Figure 3.1 of the RDG.

Determine minimum clear zone distances commensurate with traffic volumes and speeds; however, the prescribed range of clear zone values represent only a general approximation of the needed clear zone distance. The effect of longitudinal grade, horizontal curves, drainage channels, and transverse slopes may influence the recommended clear zone distances. Use engineering judgment to determine how much clear zone distance to provide throughout the highway corridor. Document the applicable clear zone as a supplemental standard, and document any exceptions. The minimum clear zone distance values should be increased for horizontal curvature; and for areas where there is a crash history, or a relatively high potential for future crashes, or both, as appropriate and practical. The minimum clear zone distance should be increased at the outside of horizontal curves using RDG Table 3.2.

In cut areas the clear zone should be extended to the back of the ditch, which may be a greater distance than is recommended elsewhere. Where minimum sight distance lines extend beyond the clear zone in rural areas, or in undeveloped urban areas, the design should be adjusted to maintain the necessary sight lines.

For high-speed urban roadways with 50 mph [80 km/h] or more posted speeds, the recommended clear zone distances apply. For low-speed urban roadways, the recommended clear zone distance should be provided wherever possible, such as in undeveloped areas. For low-speed urban roadways where adjacent development constrains the clear zone, and curbs are used, provide the maximum practical clear zone and the following guidance also applies:

- For lower-speed urban roadways with 40 mph [60 km/h] or less posted speeds and parking lanes, the clear zone should extend at least to the minimum offset distance beyond the face of curb as described in Section 9.3.12.3;
- For lower-speed urban roadways without parking lanes, the clear zone should extend at least 4 ft [1.2 m] beyond the edge of traveled way or turning lanes, or at least to the minimum offset distance beyond the face of curb, whichever is greater;
- For urban transitional roadways with 45 mph [70 km/h] posted speed, in undeveloped areas, the recommended clear zone distance should be provided wherever possible; and
- For urban transitional roadways in developed areas, the clear zone should extend at least 7 ft [2.1 m] beyond the edge of traveled way or auxiliary lanes, or at least to the minimum offset distance beyond the face of curb and preferably 4 ft [1.2 m] beyond the face of curb, whichever is greater.

Refer to the Section 9.3.11 for design of curbs and offsets. Refer to Section 8.5.2 for additional clear zone guidance.

9.3.12.3 Lateral Clearance and Offset Distance

Provide a minimum of 2 ft [0.6 m] lateral clearance from the edge of shoulder to any features over 6 in [150 mm] height, such as guardrail, bridge rail, barriers, walls, signs, utilities, parking, etc. Any lesser lateral clearance reduces the effective usable shoulder width by that amount.

For low-speed urban roads where curbs are used, provide a minimum offset distance of 18 in [500 mm] beyond the face of the curb for clearance to obstructions, and preferably 2 ft [0.6 m], with wider offsets provided where practical. For intersections provide a minimum lateral clearance and offset distance beyond the face of curb of 3 ft [1 m] and preferably 4 ft [1.2 m], at the corner turning radii. For high-speed urban roadways where curbs are used, provide a minimum offset distance of 4 ft [1.2 m] beyond the face of curb, with wider offsets provided where practical.

See Section 9.3.8.3 for horizontal clearance to structures. Also see Section 8.5.3.3.4 regarding shy distance to traffic barriers. Refer to *Green Book* Section 4.6.2 for additional guidance.

9.3.12.4 Considerations for Existing Features

In determination and application of clear zone concepts, consider the presence and value of existing unique mature vegetation, natural and historic features, consistency of driver expectations and safety risk assessment.

9.3.12.5 Access Management

Apply access management techniques according to the function of the roadway and the context of the area through which it passes. Access management includes a wide range of regulatory and design techniques to ensure that both access to adjacent land and regional mobility are provided by highway facilities. Varying degrees of access control are appropriate depending on the conditions. The roadside design should be consistent with established access management guidelines of the land management agency and the highway facility owner. Most State highway agencies have design standards for the provision of access onto State highways. For additional guidance refer to the TRB *Access Management Manual*.

9.3.12.6 Driveways

Driveways and non-public approach roads are not considered intersections; however the requirements and criteria for design of turning movements are similar.

As practical, locate driveways away from intersections and other driveways. Consider driveway spacing guidelines recommended by the TRB *Access Management Manual*. Locate driveways to provide:

- Favorable visibility, sight distance, and horizontal and vertical alignment conditions for users of the driveway and the highway;
- Safety and convenience for all highway users;
- Non-interference with nearby driveways, intersections, or auxiliary lanes;
- Control and conveyance of drainage from the highway and from the driveway;
- Conformance with applicable State or local standards, or access management plan.

Driveways are intended for low-speed vehicle operation, and should have corner radii reflecting low speeds. Single-lane driveways are appropriate for two-way traffic for single-family residential uses and for small groups (less than 10) of residential units, and for small commercial uses with employees only (no retail customers or regular visitors). For larger groups of residential units, or commercial uses with retail customers and regular visitors, a two-lane driveway is appropriate. Maximum grades for residential driveways are 10 to 15 percent depending on climate and terrain, and maximum 8 to 10 percent for commercial uses. Provide a flatter landing area at the connection to the mainline.

Provide clearance to the design vehicle chassis for the design of driveway profiles, particularly where there is curb, gutter or sidewalk. For a passenger car (P) design vehicle, the minimum clearance consists of vertical departure angles of 12 degrees from the front and rear wheels, and undercarriage clearance of 6 in [150 mm]. Limit the minimum K value of vertical curves to accommodate the design vehicle clearances (undercarriage or tow hitch). For driveway profiles provide a minimum vertical curve length of 30 ft [9 m] and minimum K value of 1.5 [0.5].

Sidewalks and bikeways must be considered in the geometric design of driveways. A minimum 4 ft [1.2 m] wide path of 1.5 to 2.0 percent maximum cross slope must be provided where a driveway crosses a sidewalk. Where possible provide continuity of the sidewalk paving material across the driveway, rather than continuity of the driveway paving material across the sidewalk. Where paving materials are the same, the sidewalk should be outlined with joints or saw cuts across the driveway. Provide minimal change to grade and cross slope of the sidewalk, even if this requires a break in the driveway grade.

9.3.13 FORESLOPES

FLH standard practice is to design the foreslope ratio (i.e. the slope ratio from the edge of the surfaced shoulder to the edge of the subgrade shoulder) in accordance with guidelines of the AASHTO *Roadside Design Guide* (RDG). Although the RDG describes the foreslope as the entire shape of the embankment from the edge of the roadway to an intersection with natural ground or a backslope, FLH terminology describes the foreslope as the initial slope from the edge of the surfaced roadway shoulder to the edge of subgrade shoulder on the embankment. When using the RDG consider the entire shape of the embankment for evaluation of the roadside geometry.

The slope ratio from the edge of the subgrade shoulder to the bottom of the ditch should normally be an extension of the foreslope ratio.

Consider the foreslope to backslope ratios when designing foreslopes that are within the designated clear zone, in accordance with the RDG.

9.3.13.1 Recoverable Foreslopes

Within the designated clear zone, FLH standard practice is to design slopes to be 1V:4H or flatter and free of fixed objects, to the maximum extent practical. Flatter slopes of 1V:6H or 1V:10H are desirable, as they are easier to maintain and safer to negotiate. Foreslopes steeper than 1V:4H are not considered recoverable and should be avoided within the clear zone.

When the existing roadway geometrics are retained and the foreslopes are steeper than 1V:4H, reshaping to provide a 1V:4H foreslope or flatter is recommended.

9.3.13.2 Traversable Foreslopes

Where practical beyond the clear zone, it is preferable to design slopes to be traversable (i.e., 1V:3H or flatter) and free of fixed objects. The design of traversable 1V:3H fill slopes should also provide for removal of fixed objects and a clear zone in the vicinity of the toe. Consider available right-of-way, environmental concerns, aesthetics, economic factors, safety performance and future safety needs in determining the width of a clear recovery area at the toe of traversable slopes.

Refer to the *Roadside Design Guide*, Chapter 3 for roadside safety design guidance.

9.3.13.3 Pavement Edge Transitions

It is FLH standard practice to design pavement outside edge transitions that are either:

1. Sloped between 30 to 35 degrees; or
2. Sloped at the same ratio as the adjoining recoverable foreslope of 1V:4H (14 degrees) or flatter, with a truncated edge less than 2 in [50 mm] high.

Avoid designing pavement outside edge transitions sloped steeper than 35 degrees or between 1V:4H (14 degrees) and 30 degrees. Design the adjoining graded slope or unpaved shoulder to match and "shoulder up" with the top surface of the pavement edge transition with less than a 1 in [25 mm], and preferably an indiscernible, drop-off following the completion of construction.

For transitions listed in item 1 above, the adjoining graded slope or unpaved shoulder should be designed either at the same cross slope as the roadway or within 6 to 8 percent rollover, for a minimum distance of 2 ft [0.6 m] from the edge of pavement, before beginning the ditch slope or embankment foreslope. See Section 9.3.8.4.2 for shoulder rollover. Provide recoverable foreslopes within the clear zone.

Refer to The Safety Edge from FHWA for more information.

9.3.13.4 Pavement Drainage Considerations

Design roadway foreslopes to provide surface drainage away from the pavement. Provide pavement drainage with consideration for safe traffic operations, control of drainage away from sidewalks, driveways, adjacent slopes and developed private property and public land uses. Paved foreslopes and paved ditches may be used where right-of-way or topography restrict the use of normal graded ditches. Isolation of drainage away from the subgrade and base layers of the pavement also should be provided. Refer to Section 7.3.4 for considerations, criteria, and guidance on procedures for design of roadway pavement drainage. Also refer to Chapter 11 for recommendations regarding drainage of the subgrade and structural pavement section.

9.3.13.5 Foreslope Considerations at Intersections

It is desirable to flatten crossroad or road approach foreslopes to 1V:10H. Provide at least a 1V:4H minimum slope. Move the crossroad or road approach drainage away from the mainline to maintain the integrity of the clear zone and minimize the length of culvert pipe required crossing the approach road.

9.3.14 DESIGN OF INTERSECTIONS

This section provides guidelines for design of at-grade intersections. Refer to *Green Book* Chapter 9 for additional guidance. For information on intersections with grade separation and interchanges, see Chapter 10 of the *Green Book*.

The intersection design should accomplish the following general objectives:

- Provide adequate sight distances,
- Minimize points of conflict,
- Limit conflict frequency,
- Minimize severity of conflicts,
- Simplify the conflict areas,
- Minimize delay, and
- Provide acceptable capacity for the design year.

Consider the type of traffic control in developing the intersection geometry. Consider the traffic characteristics, driver characteristics, driver expectations, physical features and economics in the design of channelization and traffic control measures.

The intersection includes the areas needed for all modes of travel: pedestrian, bicycle, motor vehicle, and transit. All users are affected by the intersection design. Therefore the intersection design includes not only the roadway area, but also may include bicycle and pedestrian facilities, bus stops and other multi-modal features and considerations. See Section 9.3.14.10.

Where a traffic engineering study is appropriate, it should include recommendations for channelization, turn lanes, acceleration and deceleration lanes, intersection configuration and traffic control devices. Coordinate with the safety and traffic engineer in the design of all such intersection features. Refer to Section 8.6 for information on traffic engineering studies.

Consider the primary factors that determine the minimum dimensions of intersection design are the speed at which vehicles approach and move through an intersection, and the type of the design vehicle. The intersection design criteria (e.g., minimum sight distance, curve radii and lengths of turning and storage lanes) directly relate to speed and design vehicle.

Refer to Section 9.3.7.5 for determination of minimum sight distance requirements for design of intersections.

9.3.14.1 Intersection Characteristics

The intersection characteristics include both the intersection itself, as well as the approach to the intersection. The functional area of the approach to an intersection or driveway consists of three basic elements:

- Perception reaction distance;
- Maneuver distance; the maneuver distance includes the length needed for both braking and lane changing when there is a left or right-turning lane. In the absence of turn lanes, the maneuver distance is the distance to brake to a comfortable stop; and
- Queue storage distance.

Evaluate the intersection characteristics for determination of appropriate treatment. Consider and address the following factors in the intersection design:

- Physical characteristics (e.g., roadway width, sight distance, curbs, sidewalks, medians, islands, drainage features, obstacles),
- Operational characteristics (e.g., lane use, lane delineation, speed, traffic controls, turn prohibitions, pedestrian controls, crosswalks, accessibility),
- Traffic characteristics (e.g., traffic volumes, vehicle composition, peaking characteristics, pedestrian and bicycle volumes),
- User characteristics (e.g., driver familiarity, age, experience), and
- Location characteristics (e.g., functional classification, rural or urban, roadside development, access control, proximity to traffic generators).

9.3.14.2 Intersection Types

The three-leg, four-leg, multi-leg, and modern roundabout configurations are the basic types of intersections. See *Green Book* Section 9.3.

For new construction or reconstruction of intersections having traffic controls on the mainline, particularly those having low speeds and traffic volumes, a roundabout configuration should be analyzed as an alternative to other proposed or existing intersection types; unless the intersection has no current or anticipated safety, capacity, or operational problems. Roundabout design and analysis of their operation should be done using specialized roundabout design software, such as SIDRA, RODEL or ARCADY. For detailed information on modern roundabouts see the FHWA publication *Roundabouts: An Informational Guide* (FHWA-RD-00-67) and NCHRP Report 572, *Roundabouts in the United States*. Also refer to *Green Book* Section 9.3.4 and the *Highway Capacity Manual*, Chapter 17, pages 45-48.

9.3.14.3 Intersection Design Vehicle

The design vehicle for any intersection depends on the roadways involved, the location of the intersection and the types and volume of vehicles using the intersection. Exhibit 9.3-M provides a guide to determine the design vehicle appropriate for various intersections.

Design an intersection so the design vehicle can make all turning movements without encroaching on adjacent lanes, opposing lanes, curbs or shoulders. Design the intersection with consideration that oversize vehicles, on necessary occasions, need to maneuver through the intersection with an encroachment, if allowed by the State's vehicle code. Using a taper at the exit end of the right-turn corner will reduce the radius and the pavement area. For the recommended right-turn lane corner design described in Section 9.3.14.6.

For urban streets with parking lanes, or bike lanes, or both, consider the effective turning radius. Refer to *Green Book* Section 5.3.5 and Figure 5-3.

Exhibit 9.3-M INTERSECTION DESIGN VEHICLE

Intersection Type	Design Vehicle		Inside Radius	
	Desired	Minimum	Desired	Minimum
US Customary				
Junction of Major Truck Routes	WB-67	WB-62	130 ft	100 ft
Junction of State Routes	WB-62	WB-40	100 ft	65 ft
Ramp Terminals	WB-62	WB-40	100 ft	65 ft
Other Rural	WB-40	SU-30	75 ft	50 ft
Urban Industrial	WB-40	SU-30	75 ft	50 ft
Urban Commercial	SU-30	P	50 ft	30 ft
Residential	SU-30	P	50 ft	30 ft
Metric				
Junction of Major Truck Routes	WB-20	WB-19	40 m	30 m
Junction of State Routes	WB-19	WB-12	30 m	20 m
Ramp Terminals	WB-19	WB-12	30 m	20 m
Other Rural	WB-12	SU-9	23 m	15 m
Urban Industrial	WB-12	SU-9	23 m	15 m
Urban Commercial	SU-9	P	15 m	9 m
Residential	SU-9	P	15 m	9 m

Note:

P = Passenger car, including light delivery trucks
SU-30 [SU-9] = Single unit truck, overall wheelbase of 30 ft [9 m]
WB-40 [WB-12] = Semitrailer truck, overall wheelbase of 40 ft [12 m]
WB-62 [WB-19] = Semitrailer truck, overall wheelbase of 62 ft [19 m]
WB-67 [WB-20] = Semitrailer truck, overall wheelbase of 67 ft [20 m]

9.3.14.4 Intersection Alignment

Refer to guidance in *Green Book* Section 9.4 on intersection alignment. Specific considerations that should be addressed in the intersection design are discussed in the following sections.

9.3.14.4.1 Horizontal Alignment and Skew

Design Intersection angles between 75 degrees and 105 degrees, and desirably as near 90 degrees as practical, to facilitate traffic control, good visibility, and safe operation by drivers and pedestrians. When the desirable alignment is not attainable for an intersection, suitable curves introduced into the horizontal alignment of the less important road will reduce the angle of the intersection. The horizontal alignment approaching a stop sign may be designed to a lower speed, consistent with the deceleration, comfortable rate, shown in *Green Book* Figure 2-25. Any adjustment must provide the minimum stopping sight distance, and preferably decision sight distance, for the intersection approach at the normal design speed. *Green Book* Figure 9-14 shows some examples of intersection horizontal realignments.

For highways with a maximum superelevation rate greater than 6 percent, the horizontal curvature of the main road through intersections should be designed such that the superelevation rate is 6 percent or less. For highways in areas where snow and ice routinely accumulate in winter, and with a maximum superelevation rate greater than 4 percent, the horizontal curvature of the main road through intersections should be designed such that the superelevation rate is 4 percent or less.

9.3.14.4.2 Lane Shifts

Avoid lane shifts through intersections. When lane shifts are unavoidable, provide a smooth alignment consisting of horizontal curves and interconnecting tangent meeting the design speed of the approach. Because pavement markings are often not placed through the intersection, the shifting of traffic can be confusing to the driver. Pavement markings through the intersection may be needed to ensure the following vehicles have a clearly delineated path to follow.

9.3.14.4.3 Vertical Alignment

Provide intersection approach alignment grades as flat as possible. Provide a flatter area for the minor road approach grade where vehicles are stopped.

When the gradient of an intersecting approach roadway exceeds the cross slope of the through pavement, it is desirable to adjust the vertical alignment of the approach using suitable grades and vertical curves. The vertical alignment approaching a stop sign may be designed for a lower speed, consistent with a braking deceleration rate of 11.2 ft/s^2 [3.4 m/s^2]. Any adjustment must provide the minimum stopping sight distance, and preferably decision sight distance, for the intersection approach at the normal design speed.

In areas of ice or snow conditions, it is desirable that the grade and cross slope be less than 3 percent through the intersection, and the grade and cross slope should not exceed 5 percent. Provide a minimum grade of ½ percent (1 percent desired) for drainage at the intersection.

Where the cross slope of the main road is in the same direction as the gradient of the intersecting cross road, adjust the vertical alignment of the cross road to meet the pavement cross slope of the highway.

If possible, avoid or realign intersections where the cross slope of the superelevated main road is not in the same direction as the grade of the intersecting cross road. If this is unavoidable, adjust the vertical alignment of the cross road far enough from the intersection to provide a smooth junction and proper drainage. Provide a vertical alignment that enables the mainline and approach road traffic to view the entire layout of the intersection sufficiently in advance, and provides adequate decision sight distance for the approach to the intersection.

9.3.14.4.4 Intersection Lane Widths

Lane widths may need to be increased at intersections to enhance safety and operations. Refer to Exhibit 9.3-N for recommended minimum lane widths at intersections.

Exhibit 9.3-N MINIMUM RECOMMENDED INTERSECTION LANE WIDTHS

Roadway Functional Classification	Through Lanes		Turn Lanes		Bicycle Lane	
	(ft)	(m)	(ft)	(m)	(ft)	(m)
Arterial (Rural)	12	3.6	12	3.6	5	1.5
Arterial (Urban)	12	3.6	12	3.6	4	1.2
Collector (Rural)	12	3.6	11	3.3	5	1.5
Collector (Urban)	11	3.3	11	3.3	4	1.2
Local (Rural)	10	3.0	10	3.0	5	1.5
Local (Urban)	10	3.0	10	3.0	4	1.2

9.3.14.4.5 Intersection Cross Slopes

Refer to Section 9.3.14.3 for guidance to design the intersection approach vertical alignment, as applicable for situations described below.

When both the mainline and the approach roadways are at normal crown (or the approach roadway does not require superelevation) the intersection cross slopes should be treated as follows:

- If the approach is a stop condition, or is a signalized crossing with a design speed less than 45 mph [70 km/h] through the intersection, maintain the normal crown on the mainline roadway. Transition the approach edge of travel lanes to match the longitudinal gradient of the mainline roadway, not exceeding the maximum relative gradient for the design speed of the approach roadway.
- If the approach is a signalized crossing with a design speed of 50 mph [80 km/h] or greater through the intersection, transition the mainline cross slope to a plane section through the intersection. The mainline may be designed with a cross slope between zero and 2 percent to best accommodate the approach crossing grade. Maintain a minimum mainline longitudinal gradient of 0.5 percent and preferably 1 percent. Transition the edge of travel lanes on all approaches to match the intersection plane, not

exceeding the maximum relative gradient for the design speeds of the mainline and approach roadways, respectively.

When the mainline roadway is superelevated and the approach is either normal crown or does not require superelevation, maintain the design superelevation rate of the mainline. Transition the edge of travel lanes of the approach to match the longitudinal grade of the mainline roadway and not exceed the maximum relative gradient for the design speed of the approach roadway.

When both the mainline and approach roadways require superelevation, adjust the horizontal and vertical alignments of either the mainline or the approach, or both, such that the cross slope of the approach can match the longitudinal grade of the mainline roadway, and can also meet allowable superelevation or side friction design criteria. In extreme cases, a broken back curve may be needed.

9.3.14.4.6 Turning Roadways at Intersections

Turning roadways include separated turn lanes, connections for channelized intersections, and ramps. As applicable, determine the appropriate design speed, radii, width, superelevation, and stopping sight distance for turning roadways based on the design vehicle, and consideration for accommodating a larger oversize vehicle with encroachment. Refer to the following sections of the *Green Book*:

- Section 3.3.7 for guidance on selection of design speed for the turning roadway and use of compound curves,
- Section 3.3.11 for the design widths of turning roadways,
- Section 9.6.6 for superelevation guidelines, and
- Section 9.6.7 for stopping sight distance.

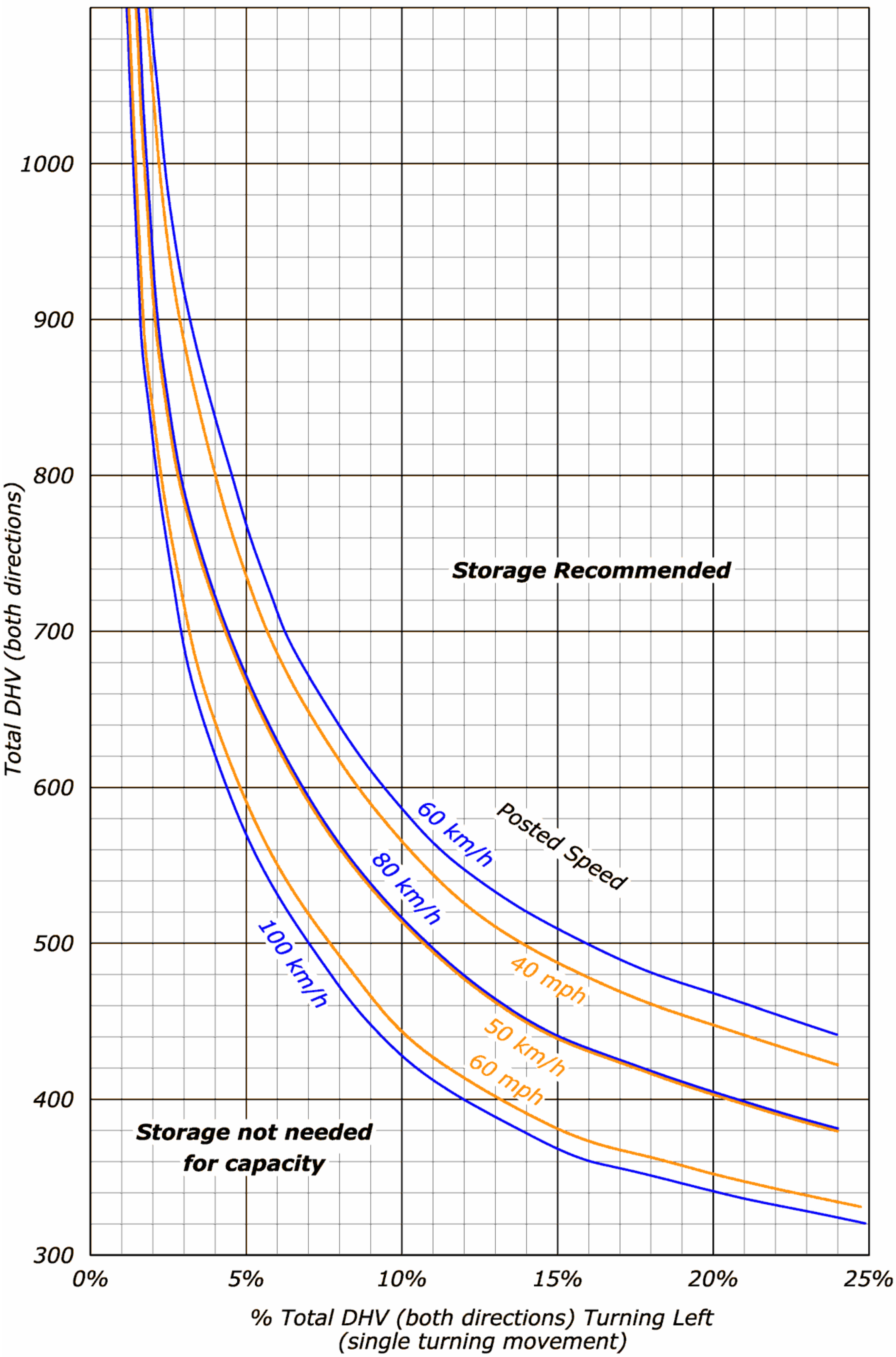
Determine the operational classification as one of 3 cases (I, II, or III), and determine the design traffic condition as one of 3 conditions (A, B, or C), as described in the *Green Book* to allow for passing a stalled vehicle on the turning roadway. The recommended design pavement widths of turning roadways for typical conditions of mixed traffic and various radii are provided in *Green Book* Table 3-29. Determine the width of the shoulders or equivalent lateral clearance outside the traveled way using *Green Book* Table 3-30.

9.3.14.5 Left-Turn Lanes

Left-turn lanes should be used for the major road approaches of 3-leg or 4-leg intersections where significant turning volumes exist or to reduce crashes related to left-turning vehicles.

Determine the volumes of left-turning and opposing vehicles for the major approaches, which are critical factors in the evaluation of intersection capacity, delays, queuing and traffic signal timing. Design left-turn channelization with enough operational flexibility to function under peak loads and adverse conditions. Also see Section 9.3.9.4.

Exhibit 9.3-O LEFT-TURN STORAGE GUIDELINES FOR UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS



At unsignalized intersections on two-lane highways, use Exhibit 9.3-O for guidance on the need for left-turn lanes. Criteria for left-turn lanes are also provided in *Green Book* Table 9-23, Section 9.3, Section 9.7, and the “Speed-Change Lanes” portion of Section 10.9.6. Also refer to NCHRP Report 279, *Intersection Channelization Design Guide* (1985), and the left-turn lane guidance in the *Highway Capacity Manual*.

Consider the need for additional decision sight distance approaching the intersection, in advance of left turn maneuvers, and where possible avoid beginning design of left turn lanes on crest vertical curves or horizontal curves where sight distance is limited. Also consider that left-turning vehicles may not slow to a stop (*Green Book* Case F), and may decide to begin turning in advance of the intersection coupled with the need for additional decision sight distance to judge the presence or gap of opposing traffic from a location significantly in advance of the intersection.

Consider a left-turn acceleration lane when operating speeds are 50 mph [80 km/h] or greater and daily peak hourly traffic volume, i.e. vehicles per hour (vph) of the through lane in the direction of travel exceeds 120, turning vehicles from the approach frequently cause conflict with the through traffic, or when the turning volume from the approach exceeds 100 vph.

At unsignalized intersections, the storage length must accommodate the number of turning vehicles expected to arrive in an average 2-minute period within the peak hour. The minimum storage length should be 100 ft [30 m], or longer if necessary to store at least one car and one truck representing the design vehicle if there are over 10 percent trucks. Provide a 6 ft [1.8 m] space between queued vehicles. At signalized intersections, the left-turn storage length is dependent on capacity and level-of-service criteria found in the *Highway Capacity Manual*. For signalized intersections a capacity analysis should be performed to determine the storage requirements. Specialized software such as Vissim or Synchro or Sim Traffic should be used for such capacity analyses. Exhibit 9.3-P provides additional left-turn storage for trucks to accommodate a left-turn lane. For left turn volumes over 300 vph consider double left-turn lanes. See *Green Book* Section 9.7 for additional design guides and for left-turn treatments on multilane facilities.

FLH standard practice is to determine the minimum length of acceleration and deceleration lanes based on the AASHTO *Green Book* guidelines for acceleration and deceleration lanes and transition tapers, including grade adjustment factor, plus queuing. Refer to the “Deceleration Length” discussion in *Green Book* Section 9.7.2; and Tables 10-3 to 10-5. The deceleration or acceleration is typically for a stop condition from or to the highway design speed.

FLH standard practice is to design the taper length based on the AASHTO *Green Book* guidelines, and the following:

- In urban areas, a 10 mph [16 km/h] deceleration is permissible in the through lane before entering the taper, and
- In rural areas, all deceleration should be accommodated within the taper and deceleration lane.

Exhibit 9.3-P ADDITIONAL LEFT-TURN STORAGE FOR TRUCKS AT UNSIGNALIZED TWO-LANE HIGHWAY INTERSECTIONS

Standard Storage Length	Trucks in Left-Turn Movement				
	10%	20%	30%	40%	50%
	Additional storage length to be added to standard values of left-turn lengths.				
US Customary					
100 ft	25 ft	25 ft	50 ft	50 ft	50 ft
150 ft	25 ft	50 ft	50 ft	75 ft	75 ft
200 ft	25 ft	50 ft	75 ft	100 ft	100 ft
Metric					
30 m	7.5 m	7.5 m	15 m	15 m	15 m
45 m	7.5 m	15 m	15 m	22.5 m	22.5 m
60 m	7.5 m	15 m	22.5 m	30 m	30 m

Refer to *Green Book* Figure 9-49 for recommended taper design for auxiliary lanes; however, the following also applies:

- Do not use the straight line taper and instead use either a partial tangent taper or reverse curve taper design,
- A 15:1 approach taper rate should be used in rural areas with design speeds above 30 mph [50 km/h],
- A 100 ft [30 m] minimum approach taper length is applicable for urban areas, and
- Provide a 25:1 departure taper at the end of acceleration lanes.

9.3.14.6 Right-turn Lanes

Right-turn lanes should be considered for the major approaches of intersections where significant turning movements exist, or to reduce crashes involving right turns. Also see Section 9.3.9.4. Consider the following factors for right-turn lane design, and right-turn lane applicability to a particular location:

- Speeds,
- Traffic and pedestrian volumes,
- Design vehicle,
- Percentage of trucks,
- Type of highway,
- Volumes and capacity, and

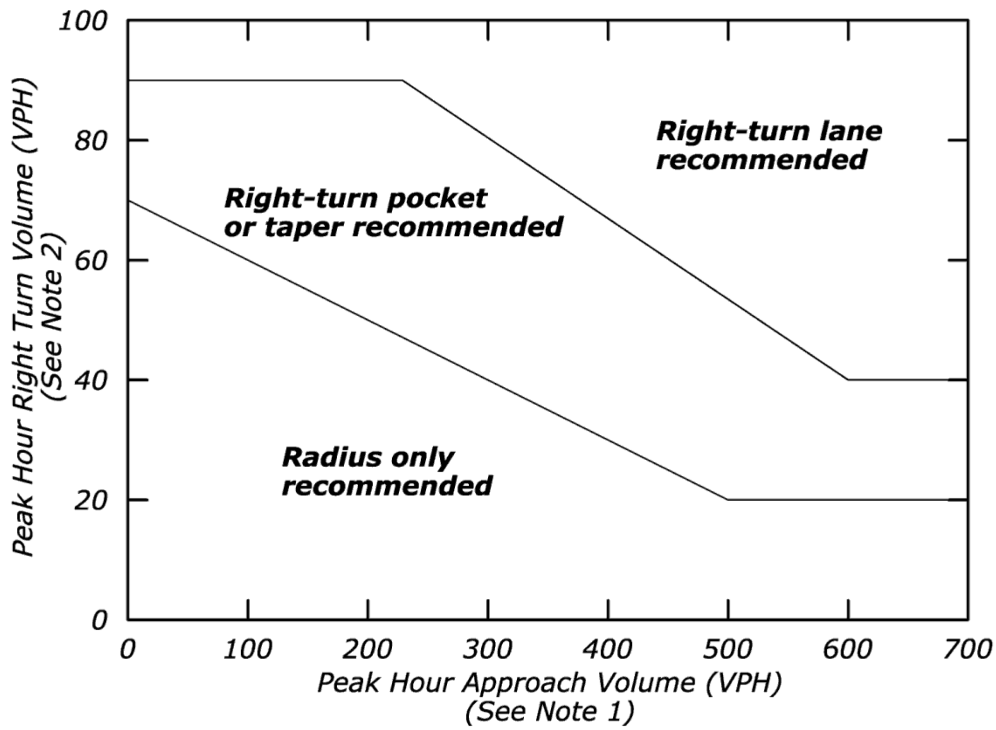
- Arrangement and frequency of intersections.

Right-turn movements at intersections influence intersection capacity, although not usually to the same extent as left-turning movements. Conflicts between the opposing traffic and the right-turning vehicle are usually not a factor. Pedestrian movements, especially those in the crosswalk of the leg into which the turn is being made, affect right-turning vehicles.

Consider right-turn lanes at unsignalized intersections when:

- Approach and right-turn traffic volumes are high (see Exhibit 9.3-Q),
- Presence of pedestrians requires right-turning vehicles to stop in the through lanes,
- Restrictive geometrics require right-turning vehicles to slow considerably below the speed of the through traffic,
- The decision sight distance is below minimum at the approach to the intersection, and
- Crashes involving right-turning vehicles are high.

Exhibit 9.3-Q RIGHT-TURN LANE GUIDELINES



Notes:

1. For two-lane highways use the total peak hour approach volume. For multi-lane, high Speed (posted at 45 mph [70 km/h] or above) highways use the total peak hour approach volume per lane.
2. Reduce peak hour right-turn volume by 20 VPH when all three of the following conditions are met:
   - Posted speed ≤ 45 mph [70 km/h],
   - Right-turn volume > 40 VPH, and
   - *Total* approach volume < 300 VPH.

Consider a right-turn acceleration lane at unsignalized intersections when operating speeds are 50 mph [80 km/h] or greater, and daily peak hourly traffic of the through lane in the direction of travel exceeds 120 vph, right-turning vehicles from the approach frequently cause conflict with the through traffic, or the right-turning volume from the approach exceeds 50 vph.

At signalized intersections, perform a capacity analysis using the *Highway Capacity Manual* or specialized traffic software to determine if right-turn lanes are necessary to maintain the desired level-of-service.

For the design of right-turn lanes refer to *Green Book* Section 9.6.4 and Figure 9-42. Also refer to the right-turn guidance in NCHRP Synthesis 299, *Recent Geometric Design Research for Improved Safety and Operations*.

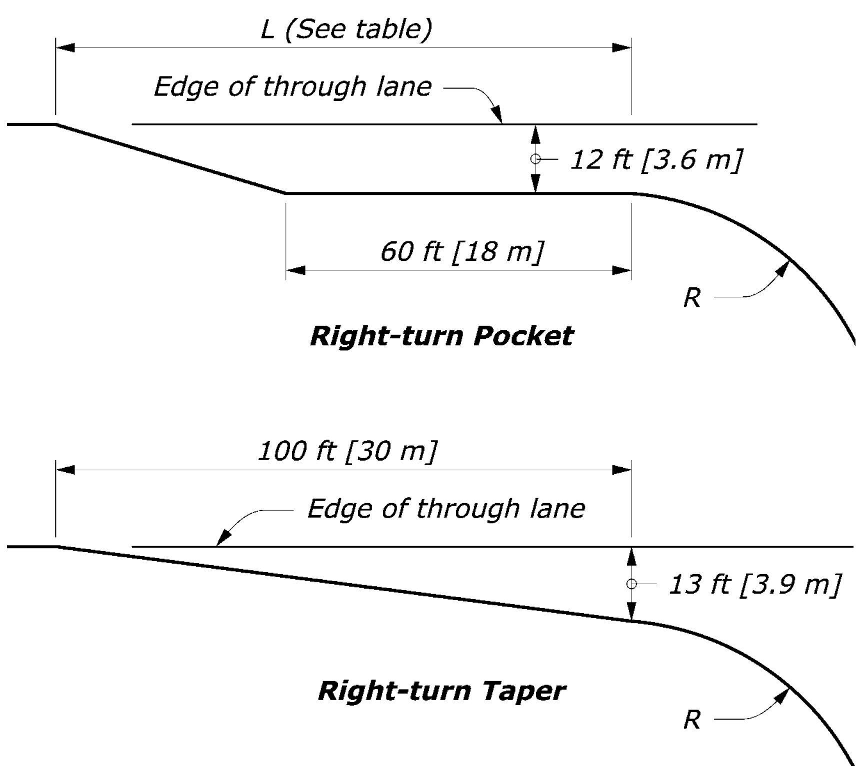
Design right-turn lanes to provide space for the deceleration, storage of turning vehicles and turning maneuvers to occur outside of the normal flow of highway traffic. Design of right-turn lanes includes the taper and deceleration area.

Right-turn corner designs should allow the design vehicle to turn without encroaching on adjacent lanes, curbs, shoulder edges or opposing traffic lanes. Also consider the largest size vehicle that may periodically use the roadway, with allowable encroachments.

Exhibit 9.3-R shows typical design details for a right-turn pocket and a right-turn taper. At signalized intersections, some encroachment on adjacent lanes of the approach leg is usually acceptable to obtain an adequate radius for oversize vehicles.

Exhibit 9.3-R RIGHT-TURN POCKET OR TAPER

Posted speed limit	*L*
Below 35 mph	***100 ft***
Below 60 km/h	***30 m***
35 mph or above	***175 ft***
60 km/h or above	***50 m***



Note: See Exhibit 9.3-M for right-turn "R" values.

See the subsections on “Minimum Edge-of-Traveled-Way Designs” and “Design for Specific Conditions (Right-Angle Turns)” in *Green Book* Section 9.6.1 for guidance on use of compound curves and other guidelines for corner radius returns.

Consider that the corner radius also affects the pedestrian crossing time and provision of islands. FLH standard practice for design of corner radius includes the following:

- For passenger cars provide a corner radius of from 15 ft [4.5 m] minimum to 25 ft [7.5 m] desired,
- For SU-30 [SU-9] truck or motor home provide a corner radius of from 25 ft [7.5 m] minimum to 40 ft [12 m] desired, and
- For WB-40 [WB-12] truck or bus provide a corner radius of from 40 ft [12 m] minimum to 50 ft [15 m] desired, if minor encroachment is allowable. If no encroachment is allowable outside a single approach and departure lane, a corner radius of 80 ft [24 m] may be needed for a WB-40 [WB-12] truck design vehicle. In this situation, a 3-radius corner or a turning lane with a corner island may be preferable.

Refer to Section 9.3.14.9 for design of corner islands.

FLH standard practice is to base the minimum length of right-turn acceleration and deceleration lanes based on AASHTO *Green Book* guidelines for acceleration and deceleration lanes and the transition tapers, including grade adjustment factor, plus any storage length for queuing if applicable (e.g., for pedestrian movements at signalized intersections). The following also applies:

- In urban areas, a 10 mph [16 km/h] deceleration rate is permissible in the through lane before entering the taper.
- In rural areas, all deceleration rates should be accommodated within the taper and deceleration lane.

Refer to the “Deceleration Length” discussion in *Green Book* Section 9.7.2; and Tables 10-3, 10-4 and 10-5. The deceleration or acceleration is typically for a stop condition from or to the highway design speed.

FLH standard practice is to design the taper length based on AASHTO *Green Book* guidelines. Refer to *Green Book* Figure 9-49 for recommended taper design for auxiliary lanes; however, the following also applies:

- Do not use the straight line taper and instead use either a partial tangent taper or reverse curve taper design,
- A 15:1 approach taper rate should be used in rural areas with design speeds above 30 mph [50 km/h],
- A 100 ft [30 m] minimum approach taper length is applicable for urban areas, and
- Provide a 25:1 minimum departure taper at the end of acceleration lanes.

Storage for turning traffic is advantageous and provides improved intersection capacity and safety performance. Storage length calculations should consider the queue from the adjacent through-movement might affect entry to the right-turn lane. If right-turn lanes are necessary at a signalized intersection, the storage requirements should be determined by a capacity analysis. Specialized software such as Vissim or Synchro or Sim Traffic should be used to perform such signalized intersection capacity analyses.

9.3.14.7 Bypass Lanes

Bypass lanes may be used on rural two-lane highways to accommodate occasional left-turning vehicles at unsignalized Tee intersections, if needed to address speed differential or improve safety. Where frequent queuing of left-turning vehicles may be expected, a dedicated left-turn lane may be necessary instead of a bypass lane, to address capacity. Use of a bypass lane may be justified, in lieu of a left-turn lane, to reduce crashes or improve traffic operations. Consider a bypass lane where:

- The sight distance in advance of the intersection is less than the decision sight distance for avoidance maneuver B shown in *Green Book* Table 3-3,
- Opposing traffic volume often cause a delay for the left-turn movement, or
- A crash history is identified at the location that may be alleviated by separating left-turning traffic from through traffic.

A bypass lane should only be designed if a left-turn deceleration and storage lane is not practical. A bypass lane should not be a substitute for a conventional left-turn lane as part of a reconstruction or major redesign project where right-of-way is available and construction is feasible. Provide the same shoulder as the rest of the roadway for the bypass lane.

The length recommended for bypass lanes varies with the posted speed of the highway. Refer to Exhibit 9.3-S for recommended lengths of bypass lanes.

Exhibit 9.3-S RECOMMENDED MINIMUM LENGTHS FOR BYPASS LANES

(US Customary)					
Posted Speed (mph)	Approach Taper (ft)	Approach Lane (ft)	Departure Lane (ft)	Departure Taper (ft)	Total Bypass Length (ft)
30	180	180	180	180	720
35	245	210	190	245	900
40	320	240	200	320	1080
45	540	270	210	540	1570
50	600	300	220	600	1740
55	660	330	230	660	1910
60	720	360	240	720	2080

(Metric)					
Posted Speed (km/h)	Approach Taper (m)	Approach Lane (m)	Departure Lane (m)	Departure Taper (m)	Total Bypass Length (m)
50	58	55	55	58	226
60	84	70	60	84	298
70	157	82	64	157	460
80	179	90	67	179	515
90	201	101	70	201	573
100	224	110	73	224	631

Note: Taper lengths are based on the MUTCD taper design for lane reduction, Section 3B.09 for 12 ft [3.6 m] lane. For narrower lane widths, reduce taper length proportionately.

9.3.14.8 Channelization

When applicable, provide channelization to separate traffic into definite paths of travel using combinations of pavement markings, markers, rumble strips, contrasting pavement, or raised islands, to facilitate the safe and orderly movement of vehicles, bicycles and pedestrians.

It is FLH standard practice to use curbing for channelization only on urban and suburban highways with a design speed of 45 mph [70 km/h] or less. On these types of highways, drivers expect to encounter confined facilities and raised channelization is applicable.

Preferably, use pavement markings consisting of painted stripes reflectorized with glass beads to delineate travel paths. Raised Pavement Markers (RPM), reflectorized and non-reflectorized, may supplement pavement striping when increased visibility is desirable. RPM may replace painted stripes when climatic or traffic conditions warrant as described in Section 8.7.1.3.

The use of curbing or raised islands for channelizing traffic should be kept to a practical minimum, as they can present problems, especially for winter maintenance. Curbing for channelization is undesirable at any location where painted pavement markings with or without reflective lane markers attain the same objective.

Curbing is permissible for channelization under the following conditions:

- Low design speed,
- Prevention of mid-block left-turns,
- Raised divisional and directional islands,
- Raised islands with luminaries, signals or other traffic control devices,
- Pedestrian refuge islands, and
- Landscaped areas within the roadway.

The two general classifications of curbing for channelization are sloping curbs and vertical curbs of the types shown in *Green Book* Figure 4-5. Use sloping curbing for channelization when vehicles may occasionally mount the curb (e.g., inscribed radius of roundabouts). Use vertical curb for raised islands with traffic control devices or luminaries and for pedestrian refuge.

9.3.14.9 Islands

An island is a defined area between traffic lanes for channelization. The use of raised islands should be limited to those urban and suburban highways with a design speed of 45 mph [70 km/h] or less. Provide the minimum curb offsets to raised islands as described in Section 9.3.11.3 and *Green Book* Figures 9-38 and 9-39. Provide the required lateral clearance and offset distance within raised islands, and where possible, provide the recommended clear zone. See Sections 9.3.12.2 and 9.3.12.3.

Consider islands when needed to perform the following functions:

- Control and direct traffic movement,
- Separate opposing or same direction traffic streams,
- Provide refuge for pedestrians, and
- Provide for proper placement of traffic control devices.

Traffic separation islands are normally elongated and should be at least 4 ft [1.2 m] wide and 20 ft to 25 ft [6 m to 8 m] long. For pedestrian refuge islands with crosswalks provide a minimum width of 6 ft [1.8 m], and preferably 8 ft [2.4 m], to accommodate pedestrians (including ADA requirements such as detectable warnings and landing) and bicyclists. When practical, the beginning of raised median islands should be offset 4 ft to 8 ft [1.2 m to 2.4 m] from the travel lane and transitioned to a normal curb offset, typically 2 ft [0.6 m] desired. See *Green Book* Figure 9-41.

Corner islands may be used to reduce conflicts and to delineate turning path where large (50 ft [15 m] or more) radii or oblique intersections lead to large areas of pavement. Corner islands are typically triangular with one side curved concentric with the corner radius and the noses rounded and offset from the travel lanes. In rural areas, they should contain an area of at least 75 square feet [7 m^2] with 100 square feet [9 m^2] as a desirable minimum. In urban areas where speeds are low, raised islands should be a minimum size of 50 square feet [5 m^2], with 100 square feet [9 m^2] as a desirable minimum. Raised islands with traffic control devices or luminaries, and islands crossed by pedestrians, require 200 square feet [18 m^2] as a minimum area.

Design triangular shaped islands as shown in *Green Book* Figures 9-38 and 9-39 for urban or rural locations, respectively. For painted islands in rural areas, the offset distances from the through lane are not required if the lane width is 12 ft [3.6 m]. Where a curbed corner island is proposed on a roadway with shoulders, the face of curb on the corner island should be offset by an amount equal to the shoulder width. If the corner island is preceded by a right-turn deceleration lane, the shoulder offset should be at least 8 ft [2.4 m].

Corner islands should accommodate turning roadway widths of 14 ft [4.3 m] minimum and allow turning vehicles to keep their wheel tracks within the traveled way by approximately 2 ft [0.6 m] on both sides. If large trucks are used as design vehicles this may result in wide lanes that could encourage the driver to use the facility as if it had two lanes. Paint or other flush markings can delineate the desired path and discourage this behavior. Refer to *Green Book* Section 9.6.5, Figure 9-43 and Table 9-18.

The offset from the edge of through travel lanes must be no less than the shoulder, and should be offset from the normal roadway edge, especially if no gutter pan is used. Refer to Exhibit 9.3-L for the minimum offset distances recommended for vertical curbs. For sloping curbing installations, the left offset distance is optional. Avoid roadway offset distances wider than 5 ft [1.5 m] as this gives the appearance of an added lane. Retro-reflective (preferably), or reflective, raised pavement markers may supplement island pavement markings.

Raised islands at crosswalk locations require barrier-free access for the disabled, including curb ramps, detectable warnings, and maneuver or refuge platforms. Pedestrian refuge platforms in islands or raised medians should be elevated a minimum of 2 in [50 mm] above the pavement surface. See Section 9.3.16.3.

Design approach ends of islands to provide adequate visibility and advance warning of their presence. A sloping curb should typically be used on the approach nose to minimize damage to errant vehicles or to snowplows. Also see *Green Book* Figure 9-40 for nose ramping. Islands should not cause a sudden change in vehicle direction or speed. Transverse lane shifts should begin far enough in advance of the intersection to allow gradual transitions. Avoid introducing islands on a horizontal or vertical curve. When islands on curves are unavoidable provide adequate sight distance, and illumination, or extension of the island, or both. Consider using a flexible raised delineator, or a rumble strip, or both.

Avoid using islands to channelize mid-block access “right-in, right-out” turning movements, unless a physically closed, depressed or raised median is used for the main roadway.

See *Green Book* Section 9.6.3 for additional design criteria for islands and Part III of the *MUTCD* for markings for the islands.

9.3.14.10 Pedestrian, Bicyclist and Transit Considerations at Intersections

Pedestrian crossing distances should be minimized at intersections. Crossing locations should correspond to the placement of sidewalks along approaching streets, and likely crossing locations. Balance intersection widening for vehicle turning lanes and clearances at the curb returns against the need to keep the pedestrian crossing distances to a minimum. In urban areas with parking lanes and curbs, consider ending the parking lane ahead of the intersection and adjusting the curb returns to be just offset to the travel lane or bike lane. These intersection curb “bulb-outs” have the effect of narrowing the overall roadway, slowing traffic and reducing the distance of the pedestrian crossing. Pedestrian facilities must meet the requirements of the disabled. Pedestrian facilities include curb ramps and sidewalks, adequate longitudinal slopes and cross slopes, and detectable warnings. New signal installations at intersections with pedestrian facilities must include accessible pedestrian signals, with well-placed locations of pushbutton activation controls. For design of intersections use a maximum walk speed of 3.0 ft [0.9 m] per second over the entire length of crosswalk plus the length of one pedestrian curb cut ramp. See Section 9.3.16.3 for additional information.

Consider how bicyclists will negotiate intersections. Approach roadways may include provision for bicyclists, including: separate off-highway multi-use paths, designated (striped with special markings) bicycle lanes or undesignated (striped without special markings) bicycle lanes. These will need to be accommodated through the intersection. Bicyclists may position themselves for their intended destination regardless of the presence of bike lanes or shoulders. If bicycle lanes are not provided, the bicyclist may use either the shoulder or the traffic lane. If bicycle lanes are present, provide that bicyclists can merge to the proper location for any travel direction. Consider the needs of the bicyclist as well as the interaction of bicycle traffic with the motorized vehicle users.

Transit stops are typically located at intersections, particularly where transit routes cross. The design vehicle for most types of transit service is the AASHTO City-Bus, which is 40 ft [12 m] length. Transit stops may be located at intersections either as a near-side stop on the approach to the intersection, or as a far-side stop on the departure leg. For a near-side intersection bus stop provide a minimum length of 70 ft [21 m] and preferably 100 ft [30 m] space. For far-side intersection bus stop, provide a minimum length of 50 ft [15 m] and preferably 70 ft [21 m] space. Consider providing bus turnouts based on the volume and turning movements of both the bus and through traffic, the distance between bus stops, and right-of-way limitations.

9.3.14.11 Signalization

Refer to Section 8.7.2 for information on warrants and design for signalization. For highway design purposes, consider the following options to the installation of signalization at intersections:

- Improve the sight distance of the mainline, or approaches, or both;
- Revise the geometry at the intersection to channelize vehicular movements and reduce the time required for a vehicle to complete a movement;
- Add lanes on the minor approach to reduce the number of vehicles queued for each movement;
- Relocation of the stop line(s) to reduce crossing maneuver time;
- Install advance warning signs of the intersection on the mainline;
- Install advisory or regulatory speed limit signing to encourage lower speeds on the approaches;
- Install a flashing warning beacon;
- Install roadway lighting for nighttime operations;
- Restrict one or more turning movements if alternate routes are available, or possibly on a time-of-day basis;
- Install multi-way STOP sign control if the warrant is satisfied; and
- Construct a modern roundabout.

9.3.15 RAILROAD-HIGHWAY GRADE CROSSINGS

Refer to the *FHWA Railroad-Highway Grade Crossing Handbook*, FHWA-SA-07-010. Also, refer to *Green Book* Section 9.12 for guidance on the design of railroad crossings. Refer to Section 12.4 for agreements and right-of-way considerations and requirements in design of railroad crossings. Refer to Section 8.7.4 for traffic control and protection at railroad-highway grade crossings. Coordinate with the Division Traffic Safety specialist and the railroad company for design of all railroad-highway grade crossings. Even if no improvements are made to the railroad crossing, coordination is needed early with the railroad company in regard to temporary traffic control that may affect the railroad. Include the special considerations and coordination in the Temporary Traffic Control Plan and in the Special Contract Requirements.

Sight distance is of primary consideration at grade crossings. If possible, avoid designing a grade crossing on a horizontal curve of either the highway or the track. The condition at a railroad grade crossing is comparable to that of intersecting highways where a corner sight triangle must be kept clear of obstructions. Where feasible remove obstructions that reduce the desired sight distance. The corner sight distance should allow a driver approaching the grade crossing to see an approaching train at such a distance to either allow the vehicle to cross prior to the train's arrival, or to comfortably stop in advance of the crossing. For either case, establish both the vehicle and train speeds to determine the necessary corner sight distance. Stopped vehicles require additional sight distance to safely proceed across a crossing. This is measured along the track and is determined by establishing both the train's approach speed and the time required for the motor vehicle to accelerate and clear the crossing as shown in *Green Book* Table 9-32. The ITE *Traffic Control Devices Handbook* (2001), Chapter 11 "Highway-Rail Grade Crossings" also contains discussion of sight distance requirements for at-grade crossings.

When any of the sight distances are insufficient at a crossing, either:

- Increase available sight distances (corner, stopping, or clearing) by clearing obstructions or modification of the horizontal alignment of the crossing;
- Establish a posted approach speed for the highway that provides sufficient time for the sight distance; or
- Provide applicable crossing protection such as automatic flashing light signals, either with or without gates.

Consider the need for providing an additional stopping lane for vehicles that are required to stop at the crossing, particularly if the crossing is a high-speed, multi-lane highway. If provided, the stopping lane geometry should meet the following minimum guidance:

- The approach taper to the stopping lane should be at least 165 ft [50 m] long and the width may vary from zero to 12 ft [3.6 m];
- The length of the full width stopping lane should be at least 100 ft [30 m] in advance of the centerline of the first set of tracks to 85 ft [25 m] beyond the last set of tracks;
- The acceleration taper should be at least 200 ft [60 m] long and the width may vary from 12 ft [3.6 m] (full width) to zero; and

- The shoulder along the stopping lane should be a minimum width of 3 ft [0.9 m].

The decision to add stopping lanes is made on a project-by-project basis after review of the site and after determining legal requirements under the applicable State regulatory authority.

Establish the grade and cross slope of the roadway to match the grade along and across the track rails, corresponding to the alignment, gradient and superelevation of the railroad. Provide an approach section with vertical alignment having a maximum deviation of 3 in [75 mm] at a distance of 30 ft [9 m] from the rails as shown in *Green Book* Figure 9-75. For vertical alignments with minimum K values greater than 15 [5], a lesser deviation may be necessary.

Provide a smooth, high-friction surface as an important part of the railroad-highway grade crossing that contributes to the safety of crossing vehicles. Typical types of crossing surfaces for railroad/highway grade crossings include:

- Asphalt concrete,
- Concrete,
- Steel,
- Timber,
- Rubber (elastomeric) panels,
- Linear high density polyethylene modules, and
- Epoxy-rubber mix cast-in-place.

Provide adequate drainage to channel runoff and subsurface water away from the crossing, including adjusting the vertical grades of the roadway, special ditch grades, underdrains, controlling pavement drainage, curb and gutter, inlets or a storm drain system.

For crossings with gates, consider providing at least 100 ft [30 m] of vertical face curb in each direction, extending to 12 ft [3.6 m] from the track centerline, to discourage traffic from passing around the gates.

Consider that the railroad crossing protection devices may be a fixed object hazard that warrants the use of a traffic barrier or a crash cushion. Design all traffic barriers or crash cushions to be installed outside the minimum railroad clearance as shown in the *MUTCD*.

Consider providing illumination of railroad crossings to improve visibility and supplement other traffic control devices for nighttime railroad operations. Consider lighting where train speeds are low, where crossings become blocked for long periods, or where crash history shows that motorists experience difficulty in seeing the crossing, trains or control devices at night.

As early in the preliminary design process as possible, provide highway design plans, profiles, cross-sections and structure clearance, if applicable, to the owner agency and request their review and comments. A request to begin preparation of the formal agreement can accompany this submittal. Check with the railroad company if any future tracks are proposed, to ensure that the project clears both existing and planned tracks.

Plan and profile on both the railroad and highway should show for a minimum of 500 ft [150 m] on both sides of the crossing. Extend the roadway profile as necessary to show all important vertical alignment data. Also, show other important features that may affect the design of traffic operation of the crossings. These features include proximity of crossroads or city street intersections, nearby driveways or entrances, highway structures, vehicular ADT (including percentage of trucks and number of school buses) and train ADT.

The railroad stationing and curve data, including beginning and ending of the curves through areas affected by encroachment or crossing, must be shown on the highway plans. Show on the plans all railroad and highway right-of-way lines and widths, including easements. Compute the ties at right angles from the highway centerline and show all intersecting corners of the right-of-way. Show the ties at the beginning and the end of each encroachment and at the points of maximum encroachment. Show all railroad drainage structures and other topographic data pertaining to railroad buildings, head blocks and other points of control.

If the railroad track is superelevated, the highway profile must conform closely to the grade across the top of the rails.

For a new crossing of the railroad tracks, prepare a special profile on either side of the crossing along the track centerline for several hundred feet [meters]. An adjustment in the railroad line (e.g., raising or lowering tracks to accommodate highway construction) is occasionally necessary. In this case, a special profile along the railroad alignment will show the full extent of the raising or lowering of tracks. Carry the profile a sufficient distance outside of the adjusted area to give a complete picture of the proposed adjustment.

On the highway design plans, show the basic roadway dimensions of shoulders, medians, traffic lanes, stopping lanes and acceleration lanes, including pavement markings requirements. Show the angle of crossing, number of tracks, location of signals and other railway facilities (e.g., signal power lines, signal control boxes, switch control boxes). The name of the railroad and whether the track is a mainline or branch line should be noted.

Include typical sections in the highway design railroad crossing plans to show roadway and lanes widths, stopping lanes if provided, shoulders, crossing surfacing, and other roadway details.

Provide profiles for any proposed special drainage or waterway channels affecting the railroad property.

The final PS&E package review should ensure that the contract contains all conditions listed in the approved railroad agreement.

9.3.16 PEDESTRIAN CONSIDERATIONS AND FACILITIES

The FHWA guidance entitled *Accommodating Bicycle and Pedestrian Travel* includes a DOT policy statement that walking facilities will be incorporated into all projects, unless exceptional circumstances exist. In rural areas, paved shoulders should be included in all new construction and reconstruction projects on roadways used by more than 1,000

vehicles per day. In urban areas, provide sidewalks or separated paved pathways in new construction and reconstruction projects unless:

- Pedestrians are prohibited by law from using the roadway,
- The cost exceeds 20 percent of the project, or
- There is well demonstrated absence of potential need.

Pedestrians include persons of all ages and abilities, and their actions are less predictable than motorists. Designers must be sensitive to this situation and keep their needs in mind in the design of pedestrian facilities. Pedestrian needs can conflict with the requirements for vehicular travel, particularly when crossing, but pedestrian facilities may provide safe and efficient solutions. Pedestrian facilities consist of adequate shoulders, sidewalks, crosswalks, pedestrian refuge areas, hiking or walking trails, shared use paths, and pedestrian grade separation structures. Sidewalks are generally located immediately adjacent to the highway or parking area. Walking and hiking trails are independently aligned and usually serve recreational activities (e.g., paths from parking areas to scenic overlooks). Refer to *Green Book* Section 2.6 and Section 4.17 for pedestrian considerations, as well as the *Guide for the Planning, Design and Operation of Pedestrian Facilities* (AASHTO, 2004). Pedestrian separation structures are not discussed here. *Green Book* Section 4.17.2 addresses pedestrian structures. Also see *How to Develop a Pedestrian Safety Action Plan*, FHWA-SA-05-12, and the Pedestrian and Bicycle Information Center.

9.3.16.1 Sidewalks

As applicable, provide paved sidewalks along the edges of roadways suitable for pedestrian use in areas where pedestrian activity is present, expected or desired. Consider sidewalks to increase the safety of pedestrians along the roadway, improve access, and reduce conflicts. Refer to *Green Book* Section 4.17.1 and the references described in Section 9.3.16 for additional guidance on the design of sidewalks.

All sidewalk designs must accommodate persons with disabilities, unless it is not technically feasible; see Section 9.3.16.3.

It is FLH standard practice to provide continuous sidewalks along both sides of urban area highways, particularly where there is a need for pedestrian access to schools, parks, commercial areas, transit stops and where there is frequent pedestrian activity. In suburban residential areas, provide a continuous sidewalk on at least one side of the highway and locate it close to the right-of-way line, if possible.

Sidewalks must have a minimum width of 4 ft [1.2 m]; however 5 ft [1.5 m] minimum width is preferred. Sidewalks in residential areas should have 5 ft [1.5 m] minimum width.

In lightly populated suburban areas and in rural areas, consider sidewalks at points of community development (e.g., schools, businesses, industrial plants, transit stops).

In urban and in major residential areas, sidewalks should be raised above the roadway. Sidewalks that are adjacent to the back of curb should be 6 ft [1.8 m] minimum width. To provide a planting strip between the sidewalk and curb allow a minimum of 2 ft [0.6 m], and additional width that may be needed to provide horizontal clearance to obstructions. For design of sidewalks adjacent curb parking, widen the sidewalk 2 ft [0.6 m] more than the minimum width elsewhere, to accommodate open doors of parked vehicles.

Sidewalks in areas of high pedestrian traffic (e.g., schools, businesses, industrial areas) should be wider than the minimum. In areas of very high pedestrian traffic (e.g. transit stops, entrances to schools or businesses) sidewalks should be paved to the curb in most cases.

Sidewalks on bridges should be 6 ft [1.8 m] minimum width, and 12 ft [3.6 m] if it is designed for shared use with bicycles.

Design of raised sidewalks should slope to drain toward the roadway at 1.5 to 2.0 percent. A slope of 1.5 percent is recommended for design, for accessibility and to allow a construction tolerance and lessen the potential for violating the ADAAG requirement of maximum cross slope of 2.0 percent.

In many cases where pedestrians may use the roadway shoulder for walkways, there are no special markings or signs for pedestrian use. In rural, low-speed areas of pedestrian use, an additional 4 ft [1.2 m] of paved shoulder width may satisfy the purposes of a sidewalk. A wider shoulder is desirable when there is significant truck traffic or higher traffic speeds. An 8 in [200 mm] solid white stripe should mark the edge of the traveled way at these locations.

Pedestrian crosswalks are regularly marked in urban areas. In residential and rural areas, marked crosswalks are normally not necessary except in locations of regular pedestrian use such as pedestrian routes to schools. In the vicinity of schools, convalescent centers, local parks or community centers, marked crosswalks should be considered. For multi-lane highways consider geometric features that improve the pedestrian environment, such as crossing islands or curb extensions. Align crosswalks with connecting curb ramps and sidewalks. For additional details on pedestrian crosswalks see the *MUTCD* and the ITE *Traffic Control Handbook*. Also refer to NCHRP Report 562, *Improving Pedestrian Safety at Unsignalized Crossings*.

9.3.16.2 Walking and Hiking Trails

These pedestrian facilities usually provide connections with existing trails, lead to roadside points of interest, allow access to streams or permit leisurely walks. They often have a natural surface, except in high-use locations. These locations may require paving to protect existing environmental conditions.

The design standards for shared use paths and trails are specific to the function of the path or trail:

- Shared use paths and pedestrian trails that function as sidewalks shall meet the same requirements as sidewalks. Where shared use paths and pedestrian trails cross highways or streets, the crossing also shall meet the same requirements as street crossings, including the provision of detectable warnings.

- Shared use paths and pedestrian trails that function as trails should meet the accessibility guidelines proposed in the Access Board's Regulatory Negotiation Committee on Accessibility for *Outdoor Developed Areas Final Report*. This report also has guidelines for Outdoor Recreation Access Routes (routes connecting accessible elements within a picnic area, camping area, or a designated trailhead).
- Recreational trails primarily designed and constructed for use by equestrians, mountain bicyclists, snowmobile users, or off-highway vehicle users, are exempt from accessibility requirements even though they have occasional pedestrian use.

Typically, trailside and trailhead structural facilities (parking areas, restrooms) must meet the ADAAG standards.

Prior to designing walking/hiking trails, verify with partner agency and owner that non-ADA compliant trails are acceptable. The following guides for walking and hiking trails apply when persons with disabilities do not require accommodations:

- The clear area around walking and hiking trails should encompass 8 ft [2.4 m] laterally and 10 ft [3.0 m] vertically. Any trees or brush removed from this area must be flush cut at ground level and intruding branches trimmed flush with the tree trunk.
- Walking trails should be a minimum of 4 ft [1.2 m] wide and have a maximum grade of 10 percent. The trail should have independent horizontal and vertical alignment. Always locate a trail outside the clear recovery zone or behind guardrail when it parallels the main roadway. If behind guardrail locate the trail beyond the guardrail deflection zone.
- Hiking trails should have a minimum surface width of 2 ft [0.6 m] and a maximum sustained grade of 10 percent. The grade may be up to 20 percent for short distances. A hiking trail constructed in a riprap slope, talus slide or other rock slope should have all voids filled at least 2 ft [600 mm] below the rock surface. Provide a 3 in [75 mm] cover of soil or small rock for a final surface.

For guidance on design of shared-use trails, refer to the *Evaluation of Safety, Design, and Operation of Shared-Use Paths,* FHWA-HRT-05-139, 2006.

9.3.16.3 Accommodation of the Disabled

Pedestrian access is required by the *Rehabilitation Act* - Section 504, 1973 and the *Americans with Disabilities Act* (ADA) – Title II, 1990. Where pedestrian access is provided it must also accommodate those with disabilities. This includes providing continuous unobstructed sidewalks, and curb cuts with detectable warnings at highway and street crossings. There are no exceptions to this policy, unless a solution is determined to be not technically feasible. Unit cost is typically not considered the primary factor in such feasibility determinations. For information on ADA refer to the U.S. Department of Justice *ADA Home Page*.

The *Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities (ADAAG)* contains most of the applicable standards. The *Revised Draft Guidelines for Accessible Public Rights-of-Way* (PROWAC) are recommended for use as current best practice for highway design; however these have not yet been officially adopted by the FHWA. When the guidelines for public rights-of-way are completed and adopted by the US DOT and DOJ as standards under the ADA and Section 504, they will supersede the currently used standards and criteria.

The *Green Book* contains information on sidewalk curb ramps in Section 4.17.3. Refer to the AASHTO *Guide for the Planning, Design and Operation of Pedestrian Facilities*, 2004, and the FHWA *Designing Sidewalks and Trails for Access, Part II: Best Practices Design Guide*, 2001. Also see the Access Board alterations guide *Special Report: Accessible Public Rights-of-Way Planning and Design for Alterations.*

All sidewalk curb transitions and ramps require installation of a tactile and visual device known as a detectable warning surface (truncated domes) to warn disabled persons that they are leaving the sidewalk and about to enter the roadway. Refer to the Access Board PROWAC Section R304 for guidance on design of detectable warning surfaces. FHWA guidance is also provided by the FHWA Memorandum, *ADAAG Detectable Warnings*, May 6, 2002, the FHWA Memorandum, *ADAAG and Detectable Warnings*, July 20, 2004; and the US DOT Final Rule, November 29, 2006, *Transportation for Individuals With Disabilities; Adoption of New Accessibility Standards*.

As with new construction, incorporate accessibility improvements to existing pedestrian facilities for any alterations that may affect access, circulation, or use by persons with disabilities; or changes that could affect the structure, grade, function, or use of the roadway. This includes reconstruction, rehabilitation, structural resurfacing (e.g. mill and overlay), widening, signal installation, pedestrian signal installation, and projects of similar scale and effect.

Design facilities to maintain existing pedestrian access during construction, including accommodation of those with disabilities. This includes provision for removal of snow, debris and surface disruptions, and maintenance of a safe, accessible and detectable pedestrian access route in work zones.

9.3.17 BICYCLE CONSIDERATIONS AND FACILITIES

The FHWA guidance entitled *Accommodating Bicycle and Pedestrian Travel* includes a DOT policy statement that bicycle facilities will be incorporated into all projects, unless exceptional circumstances exist. In rural areas, paved shoulders should be included in all new construction and reconstruction projects on roadways used by more than 1,000 vehicles per day. In urban areas, provide bicycle lanes or separated paved paths in new construction and reconstruction projects unless:

- Bicyclists are prohibited by law from using the roadway,
- The cost exceeds 20 percent of the project, or
- There is well demonstrated absence of potential need.

In rural areas, for design of a shared-use facility that both bicycle and motor vehicle travel are designed to share the roadway, a combined lane and shoulder width of at least 14 ft [4.2 m] should be provided, which is the minimum necessary for a motor vehicle and bicycle to operate side by side. In rural areas with motor vehicle design ADT greater than 1,000 and bicycle ADT greater than 25, a paved shoulder width of 5 ft [1.5 m] is recommended to accommodate bicycle use.

Where applicable, design bicycle lanes specifically for bicycle use, to provide a dedicated space for bicycle travel along the roadway, and a consistent separation between bicyclists and passing motorists, and pedestrians. Design striping and signing to designate bicycle lanes in accordance with the *MUTCD*.

Bicycle lanes that are not physically separated from the highway should be located between the travel lane and the roadway shoulder. A minimum width of 4 ft [1.2 m] is required for a bike lane; however 5 ft [1.5 m] bicycle lanes are preferred for most conditions, especially when the lane is adjacent to a curb, curbside parking, or guardrail. Exclude the width of gutter from the bicycle lane design width. Where parking is permitted, the combined width for bicycle travel and parking should be a minimum of 14 ft [4.2 m], and 16 ft [4.8 m] desired. Where motor vehicle operating speeds exceed 45 mph [70 km/h], or the volume of trucks and buses is 30 or more per hour, the minimum bicycle lane width is 5 ft [1.5 m], and 6 ft [1.8 m] bicycle lane width is desirable. Bicycle lanes wider than 6 ft [1.8 m] are generally not used since they may encourage inappropriate use by motor vehicles. Designate bicycle lanes with a 6 in [150 mm] solid white line on the right edge of the motor vehicle travel lane, bicycle lane pavement markings, and signs at periodic intervals. The solid lane marking should change to a broken white line before any intersections on the right side, providing sufficient distance for motorists to merge to the right side of the roadway before making a right-turn. A 4 in [100 mm] solid white line, or parking space markings, on the right edge of the bicycle lane should be used when adjacent to parking areas or parking lanes.

Provide bicycle-safe drainage grates for all inlets adjacent to bicycle facilities. Design all grates and utility covers to be set flush with the pavement surface. Design the pavement cross slope to not exceed 10 percent, and avoid design of an abrupt pavement edge at the inlet. Where shoulder width, or a bike lane, adjacent to a curb is less than 5 ft [1.5 m], recessed drainage inlets or curb inlets should be used.

Where the corridor is constrained and a separate bicycle lane or path is beneficial, it may be practical to provide the facility in only one direction of travel.

When applicable, consider including a separate two-way bikeway or shared-use path in the overall design of the highway project when the level of bicycle use is high and safety, operational or other benefits to the mix of facility users are sufficient to justify a designated bicycle facility, either on a separate independent alignment or parallel to the roadway. See 23 CFR 652. Provision of shared-use paths is particularly suited to high-speed, high-volume highways where the traffic characteristics or the roadway geometry is incompatible with typical bicycle and pedestrian use. However, exercise care in the design of shared-use paths to minimize the conflicts between bicyclists and pedestrians. Two-way bikeways and shared-use paths should always be physically separated from the roadway by a significant terrain feature and at least 5 ft [1.5 m] width, or by a crashworthy barrier system. The paved width of a two-way bike path should be a minimum of 8 ft [2.4 m]. Where pedestrians will routinely share the path with bicyclists it should be a minimum width of 10 ft [3.0 m], and 12 ft [3.6 m] desired. The presence of a bikeway or shared-use path near a highway does not eliminate the need to consider the presence of bicyclists in the design of the highway, unless bicycle use is specifically prohibited on the facility.

The AASHTO *Guide for Development of Bicycle Facilities* provides criteria for the design of bikeways. For guidance on design of shared-use trails, refer to the *Evaluation of Safety, Design, and Operation of Shared-Use Paths,* FHWA-HRT-05-139, 2006. Also see *Bikesafe: Bicycle Countermeasure Selection System*, FHWA-SA-05-006, and the Pedestrian and Bicycle Information Center.

9.3.18 TRANSIT CONSIDERATIONS AND FACILITIES

The design of public transit facilities requires specialized planning and operational expertise. Refer to *Green Book* Section 2.1 for bus characteristics and turning paths; Section 4.19 and Section 7.3.18 for design of bus stops, turnouts, and lanes; and Section 84.8 for accommodation of transit. Also refer to the *Interim Geometric Design Guide for Transit Facilities on Highways and Streets*, AASHTO, 2002 for applicable design guidance. Also refer to the *Guide for High-Occupancy Vehicle (HOV) Facilities*, AASHTO, 2004 and the *Guide for Park-and-Ride Facilities*, AASHTO, 2004.

9.3.19 PARKING LOT LAYOUT CONSIDERATIONS

Parking lot stalls should be a minimum of 9 ft [2.7 m] wide and 18.5 ft [5.6 m] length; however, preferably 10 ft [3.0 m] wide and 20 ft [6.0 m] length, if practical. For short-duration high-turnover parking, or where loading of vehicles is common, a 10 ft [3.0 m] stall width should be provided. Parallel parking stalls should be a minimum of 22 ft [6.7 m] and preferably 25 ft [7.6 m] length, if practical. Parking access aisles should be a minimum of 13 ft [4.0 m] width for one-way traffic flow and 20 ft [6.0 m] width for two-way traffic flow; however, preferably 14 ft [4.3 m] width for one-way traffic flow and 24 ft to 26 ft [7.3 m to 7.9 m] width for two-way traffic flow, if practical.

For angle parking, design parking stalls as rectangles with the above dimensions, with no encroachments or overhang into the parking access aisles. For end stalls, provide a return area sufficient for maneuvering and backing.

Bus parking stalls should be a minimum of 10 ft [3.0 m] wide and 50 ft [15 m] deep; however, for parallel bus parking provide a minimum of 100 ft [30 m] length for the first bus stall and 50 ft [15 m] length for a second bus stall. For multiple bus stalls, provide angled (11.3 degrees) bus parking with 12 ft [3.6 m] wide and 60 ft [20 m] long stalls, with a 8 ft to 10 ft [2.4 m to 3.0 m] clearance offset from the access aisle for maneuvering and backing. Where longer, articulated buses are used: add 20 ft [6 m] for all the above length dimensions.

The inside turning radius in parking lots should be a minimum of 20 ft [6 m] for passenger cars and 30 ft [9 m] for busses; however, desirably 30 ft [9 m] for passenger cars and 40 ft [12 m] for busses, where practical.

Provide and locate pedestrian walkways in parking lots to avoid conflict with vehicles, to the maximum extent practical.

See Section 9.3.16.3 for applicable requirements, dimensions, and number of required accessible spaces and access aisles.

Refer to Section 9.3.9.3 for design of parking lanes.

For additional guidance on parking lot design refer to the *Guide for Park-and-Ride Facilities*, AASHTO, 2004.

9.4 RESURFACING, RESTORATION AND REHABILITATION (RRR) DESIGN

See Section 4.4.2 for the RRR projects design approach. Also see *FHWA Technical Advisory T 5040.28* and TRB Special Report 214, *Designing Safer Roads* for additional guidance. Also refer to the Technical Practices described in Chapter 5 of FHWA-SA-07-001, *Good Practices: Incorporating Safety into Resurfacing and Restoration Projects*.

Before beginning design on RRR projects perform a site inspection (see Section 4.3.3).

9.4.1 APPLICATION OF DESIGN STANDARDS

The design policy applicable for RRR projects is the same as for new construction and reconstruction, unless a separate FHWA approved State or local RRR design policy is applicable to the project (see Section 4.4.1). Identify all substandard features and document each exception to the standards as outlined in Section 9.1.3.

9.4.2 IMPROVEMENT OF SAFETY PERFORMANCE

Use a safety conscious design process for RRR improvements. See T 5040.28. Also see pp. 190-193 of TRB Special Report 214, *Designing Safer Roads*. Evaluate the safety performance of RRR projects based on analysis of the facility's crash history. Collect and analyze crash numbers, types and rates for the project to identify safety problem areas (Section 4.3.2.4). Also refer to FHWA-SA-07-001. For RRR projects on local roads, also refer to *Low Cost Local Road Safety Solutions*, ATSSA, 2006.

All safety elements of an RRR project require specific consideration. During site inspections and field reviews identify and evaluate potentially hazardous conditions, and include practical, low-cost safety enhancements in all RRR projects. These may include the following:

- Roadside obstacle removal,
- Traffic barriers and terminal sections,
- Bridge rails and transitions,
- Traffic control devices,
- Shoulder improvements,
- Minor widening,
- Minor horizontal or vertical alignment adjustments,
- Minor intersection improvements,
- Sight distance improvements,
- Longitudinal rumble strips,
- Skid-resistant surface texture,
- Railroad-crossing improvements, and
- Illumination.

Many of these items will enhance the traffic operation as well as safety performance. Refer to Section 9.4.5 for guidance on traffic operation improvements, and signing and marking requirements for RRR projects.

When applicable, consider the predicted safety performance of the facility over the project's anticipated design service life when making decisions regarding the above safety enhancement items, based on evaluation of:

- Past safety performance,
- Future traffic conditions,
- Existing roadway geometry, and
- Roadside conditions.

Consider using the crash prediction module of the IHSDM in such evaluations.

9.4.3 EVALUATION OF EXISTING GEOMETRIC DESIGN

Evaluate existing geometric design elements (Section 4.3.2.2) that are not performing in a satisfactory manner. As applicable, evaluate geometric deficiencies in the following areas:

- Horizontal and vertical alignment,
- Cross-sectional elements,
- Sight distance,
- Pedestrian facilities including ADA compliance, and
- Bicycle facilities.

It is FLH standard practice to restore the normal crown cross slope on tangent sections to at least 1.5 percent and preferably 2.0 percent.

Select a maximum superelevation rate, e_{max}, (Section 9.3.1.11) that is practical to apply for the project, and determine applicable superelevation rates for horizontal curves.

It is FLH standard practice to provide the standard superelevation (Section 9.3.5.1.3) and transitions (Section 9.3.5.2), to the maximum extent practical. The maximum practical depth for correction of superelevation deficiencies is equivalent to, or less than, the nominal pavement thickness. If the existing conditions or the ability to provide the standard superelevation rate of curves cannot be verified during the design process, provide construction contract provisions specifying that the superelevation rate will be verified and corrected during construction operations, to the maximum extent practical. When standard superelevation rates are impractical, the highest practical rate applies, subject to approval through the design exception process. Even if it is not possible to construct the standard superelevation rate for a particular curve, it is essential to design a consistent superelevation rate uniformly throughout the entire curve, with proper transitions. Where exceptions are necessary, engineering studies should be performed to identify locations for advisory speed and warning sign installations and other mitigation techniques.

The superelevation deficiencies of an asphalt surface may be improved by providing a leveling course. This additional course depth may increase the pavement structure capabilities and should be considered in the pavement structural design when leveling is relatively uniform over the length of the project. If adequate field measurements for calculating leveling course quantities are not practical, increase asphalt concrete pavement quantities approximately 20 to 25 percent for use as leveling material. When considering an additional leveling course, ensure that sufficient roadbed bench width exists to support the additional foreslope width, without creating a pavement edge drop-off or reduction in the standard ditch capacity.

Provide the standard superelevation and transitions particularly where the inferred design speed of a horizontal curve is less than the average running speed. In addition to improving superelevation, consider flattening horizontal curves when crash data indicates that geometrics are a contributing factor.

When horizontal curvature is the probable cause of crashes, consider corrective action. This can range from positive guidance (e.g., placement of additional warning signs and markings) to reconstruction. If existing substandard horizontal and vertical alignments do not warrant reconstruction, evaluate improvements to signing and marking, longitudinal rumble strips, or other cost beneficial safety enhancements. Consider alignment improvements when crash experience is high and previously installed warning signs, markings or other devices have been ineffective.

When the operating speed for a horizontal or vertical curve is less than 15 mph [20 km/h] below the operating speed of the adjacent sections, and has a low crash history, improvement of signs and marking may be applicable in lieu of reconstruction. When the difference in operating speed is 15 mph [20 km/h] or more, or the operating speed of the horizontal or vertical curve is less than 20 mph [30 km/h], or if the location has higher crash history, corrective action is essential. In this case consider cost-effective geometric improvements to the curve site, including curve flattening, lane or shoulder widening, additional roadside recovery area, additional superelevation, enhanced sight distance, slope flattening, removal of obstructions, selective clearing, or other physical modifications, even if such modifications exceed the normal roadbed bench width. Where the ADT is greater than 750, and the difference in the average running speed and the inferred design speed of the horizontal curve is more than 15 mph [20 km/h], also evaluate spot reconstruction of the horizontal curve. If improvement to correct the difference in operating speed is not possible, provide the appropriate signs and markings and other provisions to best facilitate proper speed transition.

Evaluate the need for restoration or improvement of sight distance on the inside of horizontal curves and at intersections. Include practical, low-cost corrective measures such as relocating signs and sight obstructions, selective clearing, minor widening of ditches, flattening minor cut slopes, etc. on RRR projects as needed.

Generally, grades cannot be flattened significantly on RRR projects. However, steep grades combined with restricted horizontal or vertical curvature, or crash history, may warrant corrective action in the form of spot improvements of the geometry, roadway cross section, or roadside safety features. For crest vertical curves where the ADT is greater than 1,500 and the difference in the average running speed and the inferred design speed of the vertical curve is more than 20 mph [30 km/h], and the crest hides from view a major hazard such as an intersection, sharp horizontal curve, or narrow bridge; evaluate spot reconstruction of the vertical curve.

If alterations adjoin pedestrian facilities, they must meet current ADA standards and be reconstructed, if necessary for compliance (Section 9.3.16.3).

As applicable, adjust existing features that are affected by the resurfacing, such as pavement drainage spillways, inlets and grates, catch basins, manholes, and utility access covers.

9.4.4 IMPROVEMENT OF ROADSIDE CONDITIONS

See Section 8.1.4 for general approach to roadside safety applicable to RRR projects.

Design the final surface of unpaved shoulders and roadway foreslopes to match the finished edge of pavement, to prevent a pavement edge drop-off and to provide a stable surface, after construction.

Evaluate existing traffic barrier rail and end treatments, bridge rail and transitions, guardrail and terminal sections, for crash worthiness and compliance of hardware with current standards (NCHRP Report 350 evaluation criteria). Include upgrading all substandard barrier hardware elements, or document their retention as a formal exception. Alternatively, guardrails meeting NCHRP Report 230 evaluation criteria may be retained for RRR projects; however, include upgrading all terminal sections not meeting current standards. Refer to Section 8.5.4. As applicable, adjust guardrail height to meet current standards.

Evaluate the widths and consistency of the existing clear zone throughout the project. Establish a minimum clear zone for the project that is as wide as practical, considering the guidelines in the AASHTO *Roadside Design Guide*, and the width of the existing roadbed bench including the foreslope and ditch. During field reviews visually inspect the established clear zone for potential roadside hazards; see Section 8.4.2.1. Give particular attention to the clear zone at identified high roadside crash locations (fixed object crashes), and the outside of sharp horizontal curves, and at the bottom of downgrades on horizontal curves. Determine the severity of identified roadside hazards and analyze appropriate countermeasures (e.g., do nothing, remove, protect) to address or mitigate the hazardous conditions. On the basis of these analyses, determine the appropriate remedial action.

Consider the following roadside safety enhancements on all RRR projects:

- Extending cross pipes outside of the clear zone, if practical,
- Removing headwalls or non-traversable end sections within the clear zone and replacing with traversable end sections,
- Relocating, protecting or providing breakaway features for sign supports and luminaires located in the clear zone,
- Shielding exposed bridge piers and abutments within the clear zone,

- Modifying raised drop inlets that present a hazard within the clear zone, and
- Clearing vegetation within the clear zone for lines of sight to meet the standard sight distance requirements.

Consider widening to provide additional clear distance through short sections of rock cuts. In longer rock cuts, isolated protrusions should be cut back or protected where warranted.

Review crash data to define dangerous obstructions as applicable. Apply engineering judgment, cost effectiveness, analysis of operational and safety effects, and consideration of environmental and community impacts in improvement decisions.

In cases where the existing roadbed bench width will not accommodate recoverable foreslopes of 1V:4H or flatter, and ditch filling to provide width or widening of foreslopes is restricted; consider strengthening the existing pavement structure through a recycling-in-place process rather than overlaying the existing pavement. Depending on the type of traffic and existing roadbed width, reducing the overall pavement structure thickness to maintain a 1V:4H recoverable foreslope and prevent an undesirable edge drop-off may be a reasonable compromise.

Provide a minimum lateral clearance of 2 ft [0.6 m] from the edge of shoulder to any obstructions. Where curb is used, the minimum lateral clearance for obstructions should 2 ft [600 mm] behind the curb and a minimum lateral clearance of 18 in [500 mm] must be provided behind the curb, in all cases. Where there are sidewalks, it is desirable to locate the obstructions behind the sidewalk.

9.4.5 IMPROVEMENT OF TRAFFIC OPERATIONS

Sign and mark all RRR projects in accordance with the *MUTCD*.

It is FLH standard practice on RRR projects to correct existing non-conforming, substandard or deficient signing and markings, and to replace sign panels not meeting minimum retroreflectivity standards and sign posts that are not crashworthy.

It is FLH standard practice to use edge line pavement markings on all RRR projects.

Refer to Section 8.7 for guidance on the evaluation of existing traffic operations and low cost traffic operations improvements. As applicable, consider low-cost enhancements of traffic operations including:

- Enhanced guide signing,
- Raised pavement markers,
- Post delineation,
- Enhanced directional and recreational signing,
- Minor improvements of intersections, approach roads and driveways,
- Channelization,
- Illumination, and

- Access management features.

Refer to Section 9.3.4.2 for evaluation of design consistency including existing operating speed variations, variations in theoretical inferred design speed, variations in template width, superelevation, etc. When advisory speed plates are warranted, design curve signs, turn signs and advisory speed plates based on the theoretical design speed criteria of the existing geometry, in relation to the posted or regulatory speed limit. Normally, show the design of signing and pavement markings on the plans; however, supplemental studies may determine the need to forward additional engineering data to the field.

If engineering data is unavailable for design of curve signs, provide construction contract provisions to specify a field method of measuring speed for horizontal curvature using a slope meter, more commonly referred to as the ball bank indicator, after construction of cross slope corrections. See the subsection on "Side Friction Factor" in *Green Book* Section 3.3.2 for a discussion on the relationship of ball bank readings and curve speeds.

Where applicable, provide signing and markings for pedestrian crossings, bicycle facilities, school areas, and highway-rail crossings, as recommended by the MUTCD.

9.4.6 EVALUATION OF PAVEMENT AND DRAINAGE STRUCTURES

See Section 11.6 for guidance on evaluation of existing pavement performance and rehabilitation methods, and details on the design of asphalt and concrete pavements. Refer to Section 11.7 for guidance on pavement preservation.

See Section 6.3.3 for guidance on performing site and subsurface investigations to identify subgrade problems, subsurface drainage problems, etc.

Refer to Section 7.1.6.3 for guidance on evaluation and treatment of existing and rehabilitated drainage structures.

Refer to Section 10.3.6 for guidance on evaluation of bridges within RRR projects.

9.4.7 MITIGATION OF SUBSTANDARD DESIGN FEATURES

When reconstruction of substandard design features to current standards is not feasible, determining the appropriate design criteria to be applied for the roadway, including lane and shoulder widths, is sometimes difficult. In some cases, the project may be the only improvement on a route for many years. In other cases, the maintaining authority may have a policy that only resurfacing projects will be applicable to a route, to conserve available funding for other higher priority transportation facilities. In these instances, the compatibility with adjacent sections of the highway may be the primary consideration. When compatibility with adjoining roads is the controlling factor, a design exception may be appropriate to establish the specific design criteria for the RRR project such that a consistent and uniform approach is taken for the corridor design.

Extraordinary cost or adverse environmental impacts could also result in design exceptions for the incorporation of substandard design features. When the highway operating agency's approved transportation plan specifies less than the standard lane and shoulder widths for a route, this width also requires documentation as a design exception. Exceptions to geometric design controlling criteria other than widths are usually limited to site-specific locations. The designer must mitigate these design exceptions through the established design exception process, as described in Section 9.1.3.

Refer to applicable portions of Section 9.3 for guidance on mitigation of substandard design features. Guidance for assessing risks and identifying appropriate mitigation of geometric design features and safety considerations is also available in Chapter 3 of the AASHTO *Flexibility Guide*. For mitigation of substandard design features, also refer to FHWA-SA-07-011.

9.5 OTHER HIGHWAY DESIGN ELEMENTS

The following sections address highway design elements other than the geometric design.

9.5.1 EARTHWORK DESIGN

As applicable, consider the following when developing an earthwork design:

- Clearing and grubbing,
- Removal of structures and obstructions,
- Excavation and embankment,
- Earthwork computation,
- Borrow and waste,
- Rock blasting,
- Watering,
- Structural excavation and backfill,
- Conservation of materials,
- Subgrade treatments and stabilization,
- Linear grading, and
- Roadway obliteration.

Also refer to the *FP-XX*, Division 200.

9.5.1.1 Clearing and Grubbing

FLH standard practice is to design clearing widths to extend a minimum of 5 ft [1.5 m] beyond the outer limit of slope rounding for cuts and 5 ft [1.5 m] beyond the toe of fill.

For shallow cuts and fills, and daylight sections, extend the clearing width beyond the edge of the slope intercept as necessary to provide the designated clear zone. Refer to the *Roadside Design Guide* for information on determining clear zone widths and recommended slope ratios.

Evaluate the needs for additional intersection and decision sight distance near intersections, and evaluate sight distance restrictions on the insides of horizontal curves, which may require wider clearing than normal. See Exhibit 9.3-J and *Green Book* Figure 3-23 in determining lateral offset and widening needed to provide adequate sight distance. When wider clearing is necessary to provide horizontal sightline offset, determine the location of sight lines and designate the wider clearing dimensions on the plans.

In heavily forested areas, consider selective thinning methods for a more natural appearing edge of clearing and a natural transition effect of the forest edge. Consider scalloped clearing lines and vista clearing to promote and frame scenic views will enhance the roadway aesthetics. In selected areas, the design should retain vegetation close to the roadway clear zone. Design slopes and clearing to emphasize variations in the clearing width, slope ratios, and proximity of vegetation patterns on either side of the roadway.

When applicable, widen the clearing to create openings and irregularities in a long straight clearing line, to emulate natural conditions. Designate varying clearing treatments with the type, size and density of the trees and ground cover, and on the terrain.

Consider additional clearing and grubbing width for the following situations:

- Selective thinning of vegetation at the top of high cuts,
- Scalloping and opening vistas to improve visual interest,
- Accommodation of utilities, and
- Solar exposure to assist in melting snow in high elevations.

Clearing and grubbing widths may be reduced in sensitive environmental areas and limited right-of-way.

9.5.1.2 Removal of Structures and Obstructions

Identify and specify the removal and disposal of all buildings, fences, structures, old pavements, abandoned pipelines and other obstructions that interfere with construction or otherwise cannot remain in place.

9.5.1.3 Design of Excavation and Embankment

The design of excavation and embankment should vary with the characteristics of the material. The designer should refer to the Geotechnical Report for recommended slope ratios. Cut and fill slope treatments are addressed in Section 9.5.2.

During earthwork design analyze the earthwork distribution to consider haul lengths, haul direction (upgrade or down), and the capabilities of typical earthmoving equipment. In general, strive to minimize the length of individual cuts and fills for efficient earthmoving operations. Consider that long cuts and fills over 1,000 ft [300 m] may require use of dump trucks loaded by front-end loaders or hydraulic excavators, instead of direct movement by track or wheel type bulldozers. Determine the location of earthwork divisions and identify areas and quantities where the haul length is over 2,000 ft [600 m], and evaluate possible alignment, grade or slope adjustments to minimize the volume and length of long hauls, particularly where they are upgrade.

9.5.1.3.1 Roadway Excavation

Design the roadway excavation to include all material excavated from within the right-of-way or easement areas, except subexcavation (see Section 9.5.1.16.1) and structure excavation. Roadway excavation volume includes all type material encountered regardless of its nature or characteristics.

Although not included in the roadway excavation quantity, consider the disposition of subexcavation and structure excavation materials for culverts, bridges and retaining wall structures. Consider the disposition of all excavated materials that affect the earthwork design, whether directly part of the roadway or for associated work adjacent the roadway.

9.5.1.3.2 Embankment

Identify the needs for embankment construction and compaction of roadway or borrow excavation, including:

- Preparing embankment foundations;
- Benching for side-hill embankments;
- Constructing dikes, ramps, mounds and berms; and
- Backfilling subexcavated areas, holes, pits and other depressions.

Account for all embankment materials in the earthwork design, whether directly part of the roadway or for associated work adjacent the roadway.

Embankment is normally not measured or paid for separately as a bid item. However, when the volume of embankment is much greater than the roadway excavation, consider measurement and payment for embankment in lieu of measurement and payment for roadway excavation and borrow excavation.

9.5.1.4 Determination of Excavation and Embankment Volumes

9.5.1.4.1 General

In cases where there is a preponderance of curvature in one direction, or large cuts and fills are greatly offset from centerline, in sharp curvature, consider the effect of curvature on the earthwork volumes.

Account for miscellaneous excavations and embankments in addition to the roadway prism excavation and embankment, for determination of the total excavation and embankment quantities.

9.5.1.4.2 Shrink and Swell Factors

See Section 6.4.6.2 and coordinate with the Geotechnical unit for determination of specific project site material shrink/swell factors.

9.5.1.5 Balancing Earthwork

The earthwork is balanced when the volume of excavation (with the appropriate allowances made for shrink and swell) approximately equals the volume of embankment.

Consider the disposition of all materials that will be incorporated in the earthwork construction (e.g., subexcavation removed and topsoil conserved) in determination of the earthwork balance.

Consider the effect of materials that are imported from outside the roadway and used within the prism, or that are exported for use outside the roadway prism.

The Geotechnical Unit should evaluate the sites and provide recommendations on classification of borrow material or slopes and depth of embankment allowed in disposal sites. Appropriate environmental considerations apply to reclamation or rehabilitation plans for any borrow or waste disposal sites. Coordinate with the site landowner to ensure reclamation and rehabilitation plans are in conformance with the owner's requirements.

9.5.1.6 Haul

The designer should consider haul when developing the earthwork design of grading projects, and strive to minimize the overall haul volume and cost. When applicable, the cost for haul should be estimated, based on equipment needs and labor rates to move the material, for development of the pay item unit price analysis.

9.5.1.7 Mass Diagram

As applicable, a mass diagram should be used to evaluate and optimize the earthwork design to minimize the overall excavation, embankment and haul. When appropriate, provide a mass diagram in the plans to represent the earthwork design.

9.5.1.8 Borrow and Offsite Borrow Areas

As applicable, borrow areas may be designated and included as part of the overall design and PS&E preparation. Roadway guidance for grading, drainage, slope treatment, restoration of vegetation, etc., is also applicable to offsite borrow areas.

9.5.1.9 Waste and Offsite Waste Areas

As applicable, waste areas may be designated and included as part of the overall design and PS&E preparation. For purposes of drainage, slope treatment, restoration of vegetation, etc., the same guidance for the roadway is applicable to offsite waste areas. Provide site-specific details for grading, slope ratios, and any compaction requirements.

9.5.1.10 Rock Blasting

Coordinate closely with the Geotechnical Unit for the design of materials and slopes that are anticipated to require rock blasting.

9.5.1.11 Watering and Water Sources

Consider the need for watering and water sources to facilitate the compaction of embankment materials and for dust control during grading operations. Water may also be needed for irrigation during plant establishment periods for restoration of vegetation. The water quantity needed should be evaluated as part of the design process. When applicable, adequate water sources should be designated and included as part of the overall design and PS&E preparation.

9.5.1.12 Structural Excavation and Backfill

When applicable, determine the quantity of structure excavation for pipe culverts, box culverts or other drainage structures. In this case, prepare a cross section at the structure location, showing the roadway template and the structure grade line.

Consider the volume and costs of structural excavation and backfill in developing the unit price analysis for the drainage structure.

9.5.1.13 Conservation of Materials

Consider the conservation of materials for selected uses in the earthwork design to minimize the cost of importing materials and to improve the quality and durability of the overall roadway construction. When applicable, evaluate the materials within the proposed construction limits for use as topsoil, subgrade topping, riprap, crushed aggregate, select backfill, reinforced fill for mechanically stabilized embankment, and other special uses. Coordinate with the Geotechnical Unit to investigate, sample and test materials that are of value above their use in general roadway embankments. When applicable, designate in the design and PS&E that the proven materials be conserved and used for these purposes.

9.5.1.14 Roadway Obliteration

Roadway sections no longer needed for traffic and located outside the cuts or fills should be obliterated by restoring the ground to approximately the original contour to produce a natural appearance by forming naturally shaped slopes. In obliteration areas evaluate existing drainage pipes regarding need for removal, or to be plugged, or to remain in place. Natural drainages should be restored to their original condition. Evaluate salvaging existing base rock or other surfacing materials from obliteration areas for incorporation into the new construction.

9.5.1.15 Linear Grading

When applicable, consider linear grading in lieu of the design, control and measurement of roadway excavation quantities. Consider linear grading for light re-grading of existing roads where the close adherence to a designed alignment and grade is not essential, and a reasonable roadway finished product can be anticipated without precise surveys or normal geometric design engineering processes. Linear grading should not be used where the existing roadway geometry is unsatisfactory.

9.5.1.16 Subgrade Treatments and Stabilization

When applicable, consider subgrade treatments that may be necessary, or simply cost-effective to improve the subgrade. Coordinate closely with the Geotechnical Unit to determine the need for any subgrade treatments or stabilization. The Geotechnical Report should identify the location of and propose a solution for any subgrade problems. When applicable, incorporate appropriate corrective measures into the design including any Special Contract Requirements and special drawings into the PS&E package. Refer to Chapter 6 for additional guidance using earthwork geotextiles.

Consider the techniques described in the following sections.

9.5.1.16.1 Subexcavation

When applicable, consider subexcavation of material from below subgrade elevation in cut sections or from below the original groundline in embankment sections. Consider the need to remove topsoil, humus material, or loosely compacted materials. Consider that subexcavation may be needed to remove unsuitable material, or to remove otherwise suitable material that must be dried, screened, crushed or processed for appropriate use in the roadway. Subexcavated materials may be replaced with granular backfill or topping to improve the subgrade.

Coordinate with the Geotechnical Unit for the need and design of any subexcavation areas.

9.5.1.16.2 Subgrade Stabilization

When applicable, consider stabilizing poor quality subgrade materials in-situ with additives (e.g., lime, fly ash, cement). Consider that subgrade stabilization in-situ may be an economical alternative to removal of the poor quality materials, waste and backfill with imported materials; or to the design of a stronger pavement structural section for the poor quality subgrade materials. Coordinate closely with the pavements and geotechnical units when considering the development and design of in-situ subgrade stabilization measures.

9.5.1.16.3 Topping

Where applicable and cost-effective, consider topping with a quality granular soil material in the upper layer of the subgrade to increase subgrade strength and bearing capacity, and reduce the pavement structure or to increase its durability. When applicable, topping may be placed in the upper 6 in to 12 in [150 mm to 300 mm] of the subgrade, in excavation areas after excavating below the subgrade or subexcavation, and in embankment areas after finishing the normal embankment to a lower subgrade elevation. Topping material may be either conserved from the roadway excavation in areas where the material meets the quality requirements, or furnished from offsite borrow areas.

9.5.1.16.4 Earthwork Geotextile Stabilization

Where applicable, consider using earthwork geotextiles to increase support values of the subgrade or base materials, and to enhance the function of roadway materials when conventional local materials are of lesser quality, or if higher material performance is needed. Coordinate closely with the Geotechnical and Pavements Units when geotextile applications are considered. Refer to Chapter 6 for additional guidance on using earthwork geotextiles.

9.5.1.16.5 Subgrade Drainage and Underdrains

Where applicable, consider using subgrade drainage systems including drainage blankets, underdrains, sheet drains and pavement edge drains. Consider subgrade drainage systems when needed to facilitate the interception and removal of water from the subgrade to improve the strength and bearing capacity, and to improve long-term performance of the base and pavement. As applicable, consider subgrade drainage and underdrains where subsurface water is apparent and abundant. In addition to subgrade drainage systems, consider widening and deepening shallow ditches in cut areas. Also consider longitudinal subgrade drainage systems in cut areas where side slope stability is a concern. Coordinate closely with the Geotechnical Unit in the location, depth, materials and other aspects of the subgrade drainage design, as described in Chapter 6.

9.5.2 SLOPE TREATMENTS

Slope treatments are essential roadside design elements and affect safety, stability, and the restoration of vegetation, cost, aesthetics and environmental impacts. To the extent practical, flatten and shape slopes to fit the existing topography and to provide a pleasing, natural appearance consistent with effective revegetation, erosion control, and drainage. Specific considerations and requirements to be included in the design are discussed in the following sections.

9.5.2.1 Safety Considerations

Within the designated clear zone, it is FLH standard practice to design slopes to be recoverable (i.e., 1V:4H or flatter) and free of fixed objects, to the maximum extent practical. Where practical beyond the clear zone, preferably design slopes to be traversable (i.e., 1V:3H or flatter) and free of fixed objects. Refer to Section 8.1.4 for general guidance on roadside safety design and Section 9.3.13 for design of foreslopes.

9.5.2.2 Geotechnical Considerations

Geotechnical reports may not be available for the project when beginning a design. If this is the case, then design cut and fill slopes based on available survey or field review data. When a geotechnical report becomes available, the designer must review the slopes initially used and make any necessary adjustments in the earthwork design.

9.5.2.3 Grading Techniques

FLH standard practice is to use variable slope ratios for both cut and fill slopes. Avoid using constant slope ratios. When varying slopes, a rule-of-thumb is at minimum to vary one unit of the horizontal slope ratio over one cross-section interval of 50 ft [20 m] of linear roadway distance, e.g. a transition from a 1V:2H slope to a 1V:4H slope should be over a minimum distance of two cross-section intervals or 100 ft [40 m], for constructability.

Use slope rounding at the top of cuts.

Design slopes for stability, to balance material quantities, as well as to enhance the roadway corridor appearance.

Evaluate the proposed slope and grading design, both in-office and during on-site reviews, for opportunities to enhance natural features that are adjoining or will be affected during the grading operations, and adjust the grading design accordingly. Whenever possible, use an interdisciplinary design approach with expertise from specialists in landscape architecture, geotechnical, restoration of vegetation, construction, and other applicable disciplines to assist in the grading design and to optimize the use of the grading techniques that are described.

Whenever practical, warp and blend slopes to emulate the existing landforms. Slope blending is done in addition to variable slope and rounding techniques. The intent of slope molding is to create natural variations instead of an engineered uniformity of a finished slope.

Warp slopes around existing large boulders and preserve stable rock outcrops as practical.

In areas with natural draws, lay back or flatten the cut slope to match that of the draw. This additional flattening only generates a relatively small amount of additional material but greatly enhances the appearance of the cut slope. This material can be used to flatten fill slopes or mold them into more natural appearing landforms representative of the project vicinity.

To the maximum extent practicable accent ridges by designing steeper slopes adjacent to these locations, in conjunction with rounding slopes. Stable slopes are a primary objective for any slope treatment, so the steeper slope design should not exceed Geotechnical recommendations.

For large or extended cuts, merely laying back the slopes into draws and accenting existing ridges may not be sufficient to produce the natural appearance desired. Consider additional excavation of flatter slopes to exaggerate existing small draws, and exaggerate the creation of steeper slopes in slight ridges, to recreate the natural diversity of the landforms; however, these exaggerated grading techniques could result in a substantial increase in the roadway excavation or environmental impact if the flattening is overdone, or create surface slides if the steepened material is not stable at the steeper designed slopes.

9.5.2.3.1 Slopes of Cuts and Fills

Design slopes to be as flat as is reasonable. Cut and fill slope design is a compromise between aesthetics, safety, stability, and economics. Generally, low cuts and fills are economical to construct on relatively flat slopes and will enhance aesthetics, safety, and maintenance. Where practical, embankment slopes should be 1V:4H or flatter. Slopes 1V:3H are generally traversable by an errant vehicle that has run off the road but do not provide for vehicle recovery. Since a high percentage of errant vehicles will reach the toe of these slopes, the recoverable area should be extended beyond the toe of slope. Refer to the AASHTO *Roadside Design Guide* for methods of determining the preferred extent of the runout area. Slopes 1V:3H and flatter are also traversable by self-propelled mowers, and should be used at locations where the grass will be regularly cut. High cuts and fills normally have steeper slopes.

For higher speed roadways over 45 mph [70 km/h], a slope of 1V:6H or flatter is recommended whenever achievable, and 1V:10H embankment slopes are desirable for safety. Recoverable slopes are slopes 1V:4H or flatter. Motorists who encroach on recoverable slopes can generally stop their vehicles or slow them enough to return to the roadway safely.

Regardless of the slope steepness, it is desirable to round the top of intersecting slopes so an errant vehicle is more likely to remain in contact with the ground. Where runout distance exists, the toe of intersecting slopes should be rounded to prevent vehicles from nosing into the ground.

Right-of-way, excavation, borrow and environmental impacts typically influence the decision of slope width and steepness. In some cases, the cost and difficulty of effectively stabilizing, vegetating and maintaining steep slopes may exceed the initial cost and short term impact of additional grading and right of way to provide a flatter slope.

In level or gently rolling terrain with grassy vegetation, it may be desirable to use a constant distance to the slope catch point and a continuously varying slope may be appropriate to blend to the natural landscape.

In steep terrain, the slopes may be varied slightly from standard slopes in order to better fit the topography or eliminate high "sliver" cuts or fills. Transition slopes between common material and rock require special consideration. Blend the ends of cut slopes into the natural terrain by rounding, flattening, or otherwise shaping the ground line.

Exhibit 9.5-A lists commonly used slopes for cuts and fills in earth materials. Use this table as a guide for preliminary slope design of projects. Use the recommended slope ratios provided by the geotechnical engineer, or in the geotechnical report as soon as it is available, to then design the slopes on the project. The fill slope ratios listed as desired should be used as the recommended maximum slope ratio for roadways with design speeds of 50 mph [80 km/h] or higher. All fill slopes steeper than 1V:4H should be evaluated for safety. See the *Roadside Design Guide*, Chapter 3 for additional guidelines.

9.5.2.3.2 Transitioning Cut and Fill Slopes

If possible, transition fill slopes from the main portion of the fill into the cut section. Transitions between flat and steep slopes should be sufficiently long to provide a pleasing appearance. When varying slopes, a rule-of-thumb is at minimum to vary one unit of the horizontal slope ratio over one cross-section interval of 50 ft [20 m] of linear roadway distance, e.g. a transition from a 1V:2H slope to a 1V:4H slope should be over two cross-section intervals or a minimum distance of 100 ft [40 m], for constructability.

At culvert inlets in cut sections, transition the ditch width and depth and cut slope ratio to provide a smooth transition and to emulate natural draws.

Exhibit 9.5-A DESIRABLE AND MAXIMUM SLOPES

Cut and Fill Slope Ratios for Soil Materials								
Height		**Slope Type**	**Flat**		**Rolling**		**Mountainous**	
(ft)	**(m)**		**Des.**	**Max.**	**Des.**	**Max.**	**Des.**	**Max.**
0-3	0-1	Cut Fill	1V:6H 1V:6H	1V:4H 1V:4H	1V:6H 1V:6H	1V:4H 1V:4H	1V:6H 1V:6H	1V:3H 1V:4H
3-10	1-3	Cut Fill	1V:4H 1V:4H	1V:3H 1V:4H	1V:3H 1V:4H	1V:2H 1V:4H	1V:3H 1V:3H	1V:2H 1V:3H
10-15	3-4.5	Cut Fill	1V:3H 1V:4H	1V:2H 1V:3H	1V:3H 1V:4H	1V:2H 1V:3H	1V:3H 1V:3H	1V:2H 1V:2H
15-20	4.5-6	Cut Fill	1V:3H 1V:3H	1V:2H 1V:2H	1V:2.5H 1V:3H	1V:2H 1V:2H	1V:2H 1V:2H	1V:1.5H 1V:1.5H
> 20	> 6	Cut Fill	1V:3H 1V:3H	1V:2H 1V:2H	1V:2H 1V:3H	1V:1.75H 1V:1.75H	1V:2H 1V:2H	1V:1.5H 1V:1.5H

Note: Cut and fill slopes steeper than 1V:2H should be avoided in clay or silty soils subject to erosion. Fill slopes steeper than 1V:1.5H may be used in critically tight areas with geotechnical guidance when the fill material is composed of quality rock.

9.5.2.3.3 Slope Rounding

It is FLH standard practice to use slope rounding at the top of cuts on all grading projects.

The amount of cut slope rounding may depend on the environmental impact and on the desires of the agency having jurisdiction. A general recommendation is to extend the clearing limits and provide additional width for slope rounding beyond the slope catch point for a distance of approximately 1/3 the vertical height of the cut slope, or for a distance of 10 ft [3.0 m].

Where applicable, consider using fill slope rounding to transition the toe of fill slopes with the natural terrain, within the clearing limits. Fill slopes that are within the clear zone should be rounded beyond their intersection with the natural ground for a distance of at least 6 ft [1.8 m]. Fill slope intersections parallel to the roadway and within the clear zone (e.g. at culverts, driveways, intersections) should be rounded longitudinally for a total distance of 20 ft [6 m].

9.5.2.3.4 Slope Roughening and Terracing

Slope roughening is applicable to slopes in medium to highly cohesive soils or in soft rock, which can be excavated without ripping. When applicable, design slope roughening to provide flatter spots and small pockets on the slope to facilitate seed germination and plant establishment, and to help control erosion. All slopes steeper than 1V:4H and greater than 7 ft [2.1 m] of vertical height should be designed for slope roughening. As applicable, these types of slopes should also be designed for more intensive terracing or pocketing to provide larger planting areas, yet still achieve a random and natural appearance.

Only minor slope roughening is recommended for slopes 1V:1.5H or steeper overall. Slopes steeper than 1V:1.75H are generally inaccessible by tracked equipment except during the time that the slope is being constructed in lifts. Materials that would normally be stable on a 1V:1.5H slope may be designed for 1V:1.75H or 1V:2H with slope roughening techniques. Slopes steeper than 1V:2H should be designed to be randomly terraced or stair-stepped with short, intermittent, benches only wide enough to retain sediment that may erode from the steeper slope above.

Where practical, slopes steeper than 1V:4H up to 1V:2H, and greater than 10 ft [3.0 m] vertical height, should be designed with allowance for a series of compound, gradient terraces to emulate adjacent natural slopes and to reduce runoff velocity and minimize erosion. Gradient terraces should not be designed on slopes steeper than 1V:2H or in areas with sandy or un-cohesive soils. If used, the design for gradient terraces should be included on the plans and cross sections or typical details, as a general feature to be incorporated during the construction of the slopes to suit local conditions. The gradient terraces should be designated as intermittent for a random appearance, rather than designed as continuous benches. In special circumstances, compounded slopes may be designed in cuts or fills and controlled as part of the slope construction.

9.5.2.3.5 Embankment Slope Benching

Consider the need for embankment slope benching consisting of excavation of a series of benches into the existing terrain to interlock and found the new embankment into the existing natural ground. Embankment slope benching may also be necessary for the construction equipment to grade and compact narrow embankments that are less than 15 ft [5 m] horizontal width from the outside of the embankment to the existing ground.

Embankment benching should be designed for construction of embankments placed on existing ground that is sloping 1V:3H or steeper, and for narrow embankments. The bench height should be an increment of one or more layers of the embankment lift thickness as applicable for material type and conditions encountered.

As applicable, consider the compaction of material excavated for benching in the design of earthwork volumes, shrinkage factor and balancing of earthwork quantities.

9.5.2.3.6 Slope Daylighting

In shallow cuts, it is recommended to daylight the excavation slope to facilitate drainage, roadside safety, visibility and future maintenance activities, when practical. Daylight slopes are typically constructed at a 1V:20H or 1V:10H slope similar to an embankment slope, and may extend outward as much as approximately 20 ft [6 m] horizontally to intersect the natural ground that is sloping downward away from the roadway. Slopes should normally daylight from the normal ditch flow line elevation, or from a slightly deeper ditch in transitions from cut to fill.

In locations where the view of the road from other locations is a concern, slope daylighting may not be appropriate.

9.5.2.3.7 Slope Snow Drifting and Storage Considerations

In areas subject to frequent winter snow and wind, consider providing an aerodynamic cross section that allows the roadway to be naturally swept clear by the wind. Also consider adjusting slopes to provide snow storage upwind from the road. Where applicable, consider the following recommendations to improve snow storage and alleviate drift-prone areas:

- Flatten backslopes and foreslopes to at least 1V:6H ratio and preferably flatter,
- Widen ditches as much as practical,
- Raise the road profile to 2 ft [0.6 m] above the ambient snow cover,
- Provide a ditch section that is adequate for storing snow plowed off the road,
- Widen cuts to provide increased snow storage,
- Flatten slopes to eliminate the need for traffic barrier, and
- If traffic barrier is necessary, consider cable or box-beam rail in lieu of W-beam rail.

9.5.2.4 Slope Waterways and Catchment Basins

As applicable, adjust the design of cut and fill slopes and ditches at the location of slope waterways and catchment basins to emulate natural waterways. Design cut slope waterways to intercept natural drainages that are undercut by excavation slopes, and design embankment slope waterways to convey pavement or ditch drainage over or along embankment slopes. Design catchment basins to collect drainage from ditches or slope waterways at inlets to culverts. Refer to Section 7.3.2 for channel lining design and permanent erosion protection for slope waterways and catchment basins.

9.5.2.5 Rock Cut Slopes

9.5.2.5.1 General

Consider presplitting along a rock slope face or along a number of benched rock faces may be beneficial for slope stability; however, presplitting may not be appropriate in all locations. In these locations consider using other than presplit blasting techniques, using irregular drill hole patterns following the natural joints and strata along natural rock fractures.

Consider designing rock cuts to produce a staggered bench effect to emulate the natural terrain and accent natural fracture lines in the rock. When presplitting is necessary to create stable rock slopes, consider design of staggered benches, at varying elevations in the cut slope, to break up the appearance of uniform and closely spaced vertical drill holes.

When soil or highly weathered rock overlays the solid rock, consider designing overburden benches at the top of the solid rock. The overburden slope should range from 1V:1.3H to 1V:2H, depending on the type and depth of overburden and the steepness of the topography. When the rock surface is known, developing the design of compound slopes is recommended.

9.5.2.5.2 Rockfall Considerations

As applicable for design of rock excavation or rockfall mitigation, provide design details that describe techniques for slope scaling of existing rock cut slopes using machine scaling and hand scaling techniques, and scaling of excavated rock slopes after blasting. Coordinate closely with the geotechnical discipline to develop techniques for rock bolting, netting, etc., and how to present these in the PS&E.

Refer to Chapter 6 for guidance for designing rock cuts and fallout ditches. Rely on the recommendations in the Geotechnical Report. Typical sections for rock cuts should be shown on the plans.

Rock slopes higher than 30 ft [10 m] from shoulder grade may require wider fallout ditches and the geotechnical staff should be consulted. Cuts less than 20 ft [6 m] in height generally do not require a fallout ditch.

Special rock protection features may be applicable on higher volume highways experiencing falling rock. The Geotechnical Unit should recommend or approve these features before inclusion into a project.

9.5.2.6 Slides and Slope Stabilization

When the Geotechnical Report identifies potential areas for slides, the earthwork excavation quantities may require adjustment to cover potential slide removal. Provide for the removal and disposal of excess slide material, if necessary.

Coordinate closely with the Geotechnical Unit to develop techniques for rock buttresses, drainage layers and similar techniques for stabilizing cut and fill slopes and how to present these in the PS&E. Refer to Chapter 6 for additional guidance.

9.5.2.7 Slope Protection

Coordinate closely with the Hydraulics Unit to develop techniques for embankment slope protection for erosion, stream impingements, etc., and how to present these in the PS&E. Refer to Section 7.4.4 for additional guidance on such details.

9.5.3 EARTH RETAINING STRUCTURES

Information on retaining wall design may be found in Section 10.4.12 and Section 6.4.4.

9.5.3.1 Determination of Need

The determination that a retaining wall may be needed should be made early in the conceptual studies and preliminary design phase. Refer to Section 4.8.4.

9.5.3.2 Alternative Wall Systems

When it is determined that a retaining wall is needed, identify and determine the retaining wall system alternatives that are technically suitable to the site, and aesthetically acceptable to the highway facility owner and the land-owning agency.

Determine which alternative wall system(s) will be designed and included in the PS&E, and which wall systems will be designated as alternative contractor designs. Determine the alternatives permitted for design by the contractor that are technically suitable, cost-effective and aesthetically acceptable to the highway facility owner and the land-owning agency.

Avoid designating only one retaining wall system, if the system is proprietary. Contracts specifying a proprietary wall system must have at least one other reasonably competitive proprietary or non-proprietary wall system permitted as an alternative.

9.5.3.3 Selection of a Retaining Wall System

Unless alternative wall systems are applicable, determine the retaining wall system or type that will be designated. Coordinate this decision with the project manager, geotechnical, highway design, structural design, environmental specialists, highway facility owner and land-owning agency. Evaluation factors to consider in the selection include:

- Terrain,
- Soil conditions,
- Constructability,
- Demonstrated performance and durability,
- Estimated cost,
- Aesthetics,
- Environmental compatibility,
- Geotechnical considerations, and
- Maintenance.

Document the selection process. The designated wall system or type should be based upon an analysis of the specific constraints and conditions. The analysis must consider the suitability or compatibility of various wall systems to the site.

9.5.3.4 Retaining Wall Systems

When applicable, the roadway design should include the general layout of the retaining wall systems including the geometry, location, offset from the roadway, length, batter or slope, foundation embedment, excavation and backfill requirements, and the coordination with other roadway design elements. Incorporate the design considerations of the wall type into the general layout of the retaining wall system and coordinate the layout with the overall highway design. Refer to Chapter 6 and Chapter 10 for design guidelines applicable to the specific retaining wall systems.

Consider the following in the layout, overall design and construction of a retaining wall system:

- Highway geometry,
- Topography,
- Subsurface conditions and soil parameters,
- Loading conditions,
- Length and height of wall required,
- Material to be retained,
- Presence of ground water,
- Scour protection if adjacent to surface waters,
- Future planned improvements that may affect design of the wall, and
- Appearance and aesthetics of the completed structure.

Walls installed near the roadway can also serve as traffic barriers if they have an approved traffic barrier design incorporated into the wall details.

Whenever practical, design the retaining walls to allow usage of native soil conserved from the roadway or wall excavation for the backfill, if it meets the requirements for the particular wall system. Coordinate the estimated volume of wall excavation and backfill with the roadway earthwork design.

All retaining walls require a geotechnical investigation and report of the underlying foundation soils. Refer to Section 6.3 for guidance on the investigation of foundation soils and native soils that may be used for backfill.

Design retaining walls, as applicable, with an aesthetically pleasing appearance compatible with other structures in the area and with the surrounding terrain. Although economics generally dictate wall selection, an aesthetic wall facing treatment could be an overriding selection factor. Consistent architectural treatment and economy of scale will frequently result in the same wall type being used throughout any given project. Aesthetic requirements may include the wall's material, top profile, terminal transitions and the surface finish for texture, color and pattern. Short sections of walls should be avoided if possible.

9.5.3.5 Geometric Information for Design of Retaining Wall Systems

The following lists the minimum geometric information to be developed and included for the design of retaining wall systems:

- Beginning and ending wall stations;
- Horizontal alignment;
- Offset from the roadway to the face of the wall;
- Profile elevation of top of wall;
- Typical cross-sections of the wall geometry and required elements;
- Representative existing ground topography, or cross sections, or both, in relation to the wall geometry;
- Estimated foundation elevations;
- Estimated wall face area;
- Wall base width;
- Layout of appurtenances in the area (e.g., culverts, guardrail);

- Proposed construction limits;
- Right-of-way limits;
- Locations designated for removal of unsuitable foundation materials; and
- Construction sequence or staging for traffic control needs.

9.5.4 LANDSCAPING AND RESTORATION OF VEGETATION

As applicable, retain, restore, or include landscaping and vegetation to provide the following operational, environmental, and visual benefits:

- Prevent soil erosion,
- Enhance water quality,
- Provide runoff storage,
- Provide slope stabilization,
- Preserve and provide wildlife habitat,
- Preserve scenic views, and
- Serve as a buffer and glare screen.

Whenever practical, incorporate the following landscaping and vegetation treatments to restore, enhance and emphasize the natural beauty of the roadside. Consult with a professional landscape architect (e.g., the Federal land management agency landscape architect) or include a landscape architect in the project design team to identify opportunities and provide specific recommendations regarding enhancements or modifications of the slope design and grading, for design of landscaping treatments, and for restoration of vegetation.

For additional guidance refer to *A Guide for Highway Landscape and Environmental Design*, AASHTO, 1990.

9.5.4.1 Enhanced Clearing Techniques

When applicable, incorporate enhancements to the clearing techniques described in Section 9.5.1.1.

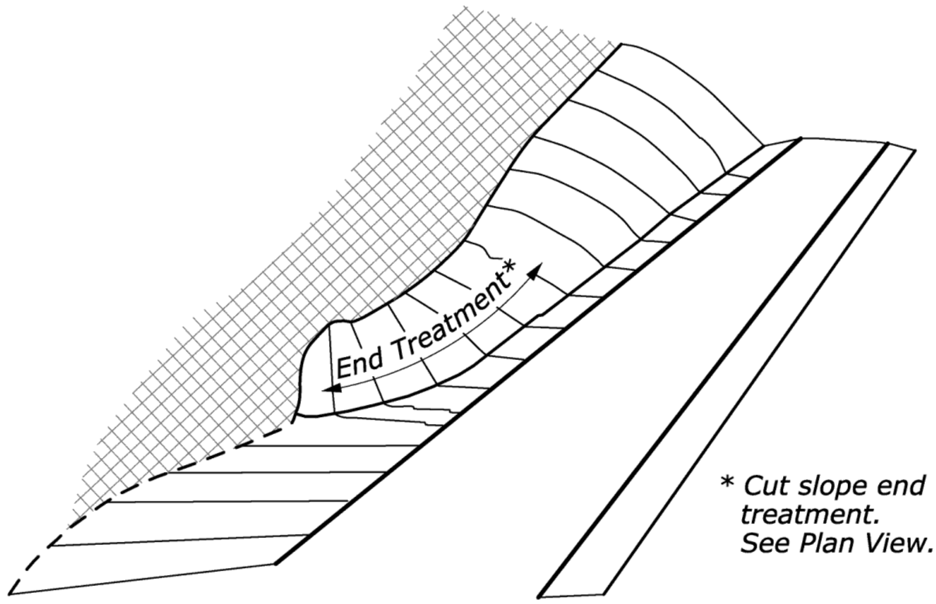
9.5.4.2 Enhanced Grading Techniques

When applicable, incorporate enhancements to the grading techniques described in Section 9.5.2 and as described in the following sections.

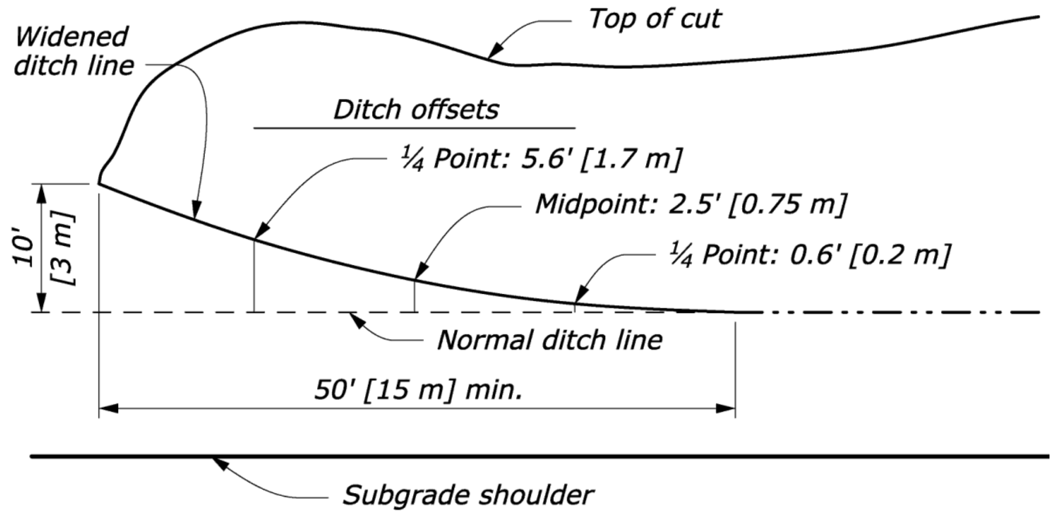
9.5.4.2.1 Cut Slope End Treatment

As applicable, transition cut slopes from the cut into the fill section with varying slope ratios. Flare the ends of cuts and blend the ends of fills into the cut slopes. Refer to Exhibit 9.5-B. Using a special ditch grade or widening the ditch can accomplish this objective.

Exhibit 9.5-B ENHANCED CUT SLOPE END TREATMENT



OVERHEAD PERSPECTIVE



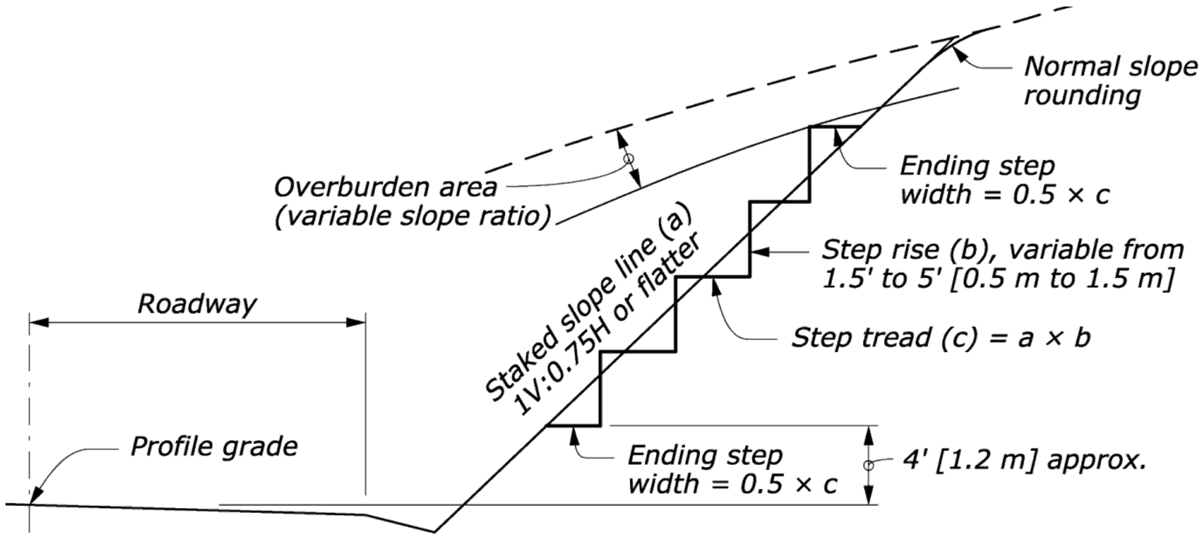
PLAN VIEW

9.5.4.2.2 Serrated Slopes

As applicable, consider design of serrated (stepped) slopes, which are a series of small steps, in soft rippable rock cuts having slope ratios between 1.3V:1H and 1V:2H. Exhibit 9.5-C shows a typical section of a serrated slope.

If used, include a drawing in the plans showing step tread and rise dimensions. Generally, the step rise varies from 1.7 ft [0.5 m] for easily ripped rock to 5.0 ft [1.5 m] for harder rippable rock. If the slope contains nonrippable rock outcrops, design the steps to blend into the rock. The step tread width is equal to the rise multiplied by the cut slope ratio.

Exhibit 9.5-C SERRATED SLOPES



At the ends of the cut slopes blend the steps smoothly into the natural ground.

Where the series of steps in the slope is a concern from a visual or aesthetic standpoint, serrated slopes may not be appropriate.

9.5.4.3 Enhanced Rock Work

Incorporate enhancements to the rock slope techniques described in Section 9.5.2.5. Where practical, design planting pockets or benches in the slopes for the introduction of plant material. It is desirable to spread topsoil on all rock benches to encourage grass growth and minimize the visual scar through restoration of vegetation. Consider planting seedlings of trees and shrubs.

9.5.4.4 Topsoil Placement

Where practical, design the project to conserve topsoil from within the project limits and replace it on the finished slopes, within the same growing season. The topsoil provides needed chemical and organic materials for the vegetation, and it contains an abundance of native seeds. Native forbs and grasses present in conserved and topsoil usually grow quickly, dense and blend with the existing undisturbed vegetation, which most effectively restores the indigenous vegetation onto the new slopes.

Coordinate closely with the Geotechnical Unit to determine the locations, depth, quality and other information about factors that may influence special contract requirements, such as for the potential need for special equipment or construction methods to salvage, stockpile and place the topsoil.

Where existing topsoil from the project is limited, consider designing the slopes for placement of furnished topsoil, or topsoil manufactured on the project site from a well-blended mixture of the limited existing topsoil combined with finely chipped clearing slash, conserved fine-grained soil excavation and furnished compost.

9.5.4.5 Restoration of Vegetation

Include treatments for restoration of roadside vegetation using appropriate planting to pro-actively improve the quality of the highway and its surrounding ecosystem. Refer to *Roadside Revegetation*, FHWA-WFL/TD-07-005.

Coordinate with botanists or specialists in restoration of vegetation to select species and application rates of grasses and other plant seed that is native to or compatible with the area. The Federal land management agency will typically have expertise and local knowledge of native and compatible vegetation species. The seed mixture should be diverse to establish growth in the differing soils, slopes, moistures, elevations, aspects and solar exposures present along the project, and different seed mixtures may be needed on a relatively long project. Use soil mulches and mulch blankets as appropriate to protect the disturbed soil and stabilize soil moisture until vegetation becomes established.

When appropriate, include planting containerized native plants, shrubs and trees, or seedlings, to restore the disturbed roadside slopes and blend them with the adjacent undisturbed landscape. If plant materials are limited, prioritize the location and density of plant groupings in those areas most visible to the user, and most beneficial to mitigate visual or environmental impacts.

As applicable, include design specifications for monitoring and control of noxious weeds prior to, during, and for a period subsequent to construction operations.

To assure successful growth, the design specifications should provide for a period of monitoring the viability of the restored vegetation and establishment of new vegetation.

9.5.4.6 Landscape Planting

Landscape and planting treatments should blend and transition with existing features, to simulate natural forms and landscapes.

In a rural environment, design treatments to emulate the existing landscape elements. Consider that a motorist traveling at higher speeds (i.e., at 50 mph [80 km/h]) is less able to recognize detailed landscape patterns. In areas of slower travel speeds (e.g., parking areas, overlooks, vistas), a more detailed landscape planting approach is appropriate to present landscape plantings to the highway user.

Vary the intensity of landscape treatment to be consistent with to the extent of landscape changes and visibility. The most visible and noticeable areas should receive the greatest attention. Recommended treatments for the highest priority locations are plantings, site-specific slope molding, rock cut sculpturing, etc., where less visible locations may receive typical grading techniques and more general vegetation restoration methods.

To blend the new construction with the existing landscape, emphasize landscaping efforts near the base of fill slopes and along the top of cut slopes. Locate larger diameter tree plantings near the top of cut slopes or near the toe of fills. Locate tree species that mature to 4 in

[100 mm] or larger trunk diameter beyond the clear zone and, when applicable, beyond the snow storage area in snow plowing areas.

On higher speed rural roadways, consider individual groupings of one or two native tree species may provide an effective treatment. Greater species diversity together with an appropriate mix of groundcover and shrubbery is recommended in urban situations.

9.5.4.7 Slope Enhancements

As applicable, consider design of embedding boulders, stumps and old logs on cut and fill slopes, outside of the clear zone, to represent natural conditions that exist beyond the clearing limits, using materials that are generally available on the project. Logs and stumps should be randomly located and established to approximate the natural scattering of such material on adjacent undisturbed slopes. Boulders may be embedded individually or in naturally appearing clusters. Boulders should be buried from 1/3 to 2/3 of the diameter into ground to appear as natural rock outcroppings.

9.5.4.8 Ornamental Landscapes

An ornamental landscape is one that is intended to showcase the various plant species and which is typically irrigated, mulched, routinely weeded, organized with shrub or flowerbeds and with delineated grass areas that are routinely mowed. Coordinate with a landscape architect or other landscaping specialists in this field for the design of such areas, as applicable.

9.5.5 DRAINAGE DESIGN

Refer to Section 7.3 for standards, references and guidance for designing roadway drainage facilities. Also refer to *Green Book* Section 4.8.2.

Existing culverts should be inspected and evaluated to determine their performance and remaining service life, both in hydraulic capacity and durability of materials.

Incorporate the design of drainage facilities, and provide design data and coordinate any needed information and reports with the Hydraulic, Structural Design, and the Geotechnical Units regarding drainage features. Design minor drainage structures and appurtenances (e.g., small culverts 48 in [1200 mm] and smaller, end sections, catch basins, inlets) as well as minor drainage channels and ditches using standard methodology as described in Section 7.3.

Large (over 4 ft [1.2 m] diameter) culverts and channels are normally sized by the hydraulic engineer or may be sized by the designer using methodology and oversight provided by the hydraulic engineer. For large culverts and channels, the hydraulic engineer may develop a conceptual or preliminary design with the final design and detailing performed by the roadway designer.

Coordinate the roadway design with the bridge and hydraulic design features and elements.

Coordinate the roadway design and adjust the alignment, grades and slopes to accommodate the natural flow lines of streams and channels, to provide adequate cover for culverts and other drainage considerations, as well as to accommodate drainage facility designs performed by others.

Early in the design process, consult with the hydraulic, structural design and geotechnical disciplines when special drainage design needs are anticipated. Also, discuss the need for various Federal, State and local water quality permits and approvals with the hydraulic discipline early in the design process.

Review and incorporate commitments from the environmental documents and correspondence with fish and wildlife agencies, and review all permit requirements to ensure that all drainage requirements and water quality considerations are incorporated in the roadway design and in the PS&E.

The hydraulic or the structural design discipline specialists provide the technical recommendations or the designs for the larger and more complicated drainage facilities. Coordinate the roadway design and supply adequate information so others can design these facilities. Obtain the existing vertical clearance dimensions of overpass structures to adjust the highway grade, and consider alternative drainage designs that may affect the alignment and grade of the highway.

For every new or existing drainage facility, determine the quantity of flow that the facility must pass. Various methods are described in Section 7.2 to accomplish this.

Consult with the Hydraulics Unit for guidance on the design of ditch relief cross-drains and downdrains that are proposed near retaining walls. Verify the ditch capacity and do not rely on a set interval for cross drains where structures are potentially at risk from water escaping the ditch and flowing across the roadway.

9.5.5.1 Safety Considerations

Design drainage features, including channels, inlets, grates, etc., to provide a safe environment for all users including drivers, pedestrians, bicyclists and other users. Refer to Section 8.1.4 for general roadside safety design guidelines as applicable to drainage features. Also see the AASHTO *Roadside Design Guide* for information on roadside safety in the design of drainage structures.

9.5.5.2 Roadway Ditches and Channels

Design roadway ditches and channels to:

- Intercept and drain surface runoff and small streams away from the roadway into culverts and cross drains, and
- Drain and lower the ground water level below the subgrade.

See Section 7.3.2 for applicable hydraulic standards and guidance.

9.5.5.2.1 Shape and Depth

Design ditch cross sections to accommodate drainage of the roadway and the drainage that flows directly into the roadway ditch from uphill areas. Design the depth of the ditch to meet hydraulic needs and groundwater control needs. Design roadway cut ditches to meet AASHTO, State or county minimum standards for depth and foreslope shape. The minimum depth should be 6 in [150 mm], and preferably 1 ft [300 mm] below the subgrade shoulder for drainage and maintenance purposes.

Ditches should preferably have a smooth and rounded cross section for safety (see the AASHTO *Roadside Design Guide*) and ease of maintenance. Wide ditch bottoms are used in rock fallout areas as well as in projects designed with side borrow.

When hydraulic needs dictate ditches of greater capacity, a flat bottom ditch should be used versus deepening the v-ditch. For additional groundwater control purposes, a deeper “V” shape ditch is preferred.

Drainage channels may require a design by the hydraulic engineer when the accumulated discharge is greater than the capacity of the normal roadway ditch. When applicable, furnish the alignment, grades, cross sections and pertinent information about the existing site conditions to hydraulic discipline for the channel design. As applicable, include provisions for fish habitat and aesthetics in the channel design. Fish habitat includes pools, riffles, boulders, logs and gravels in the streambed and brush and shade on the stream banks. For design of channel changes, obtain guidance and direction regarding specific habitat features to include. If used, include the design of drainage channels and channel changes in the roadway design, and provide typical sections and detailed drawings in the design plans. See Section 7.3.2 for guidance on hydraulic design of open channels.

9.5.5.2.2 Lining Materials

In soils subject to erosion, consider lining the ditches with rock or some other suitable material especially on grades steeper than the natural channels. Refer to *HEC 15, Design of Roadside Channels with Flexible Linings* for additional guidance. Consultant the hydraulics engineer when ditch erosion is a concern and the suitable ditch lining cannot be identified (See Section 7.3.2.5).

9.5.5.2.3 Ditch Grades and Transitions

Design ditch gradients at a minimum of 0.5 percent, with 1 percent being the desired minimum ditch grade where practical. Transition the depth and gradient of ditches at transitions from cuts to fills. Where applicable, design special ditch gradients to provide a gradual depth transition and a uniform gradient from the normal ditch flow line to the inlet of culverts, to convey drainage from cut slope waterways into culvert inlets, in areas of flat roadway or ditch grades and at other locations as needed.

Also consider the need for special gradients for ditches on long crest and sag vertical curves and in superelevation transition areas where ditch grades may be flat for substantial lengths. Evaluate the roadway ditch profile to identify any sags in the ditch line or in shallow fills, and identify and locations where culverts or special ditch grades should be provided to ensure drainage.

9.5.5.3 Culverts

Design culverts to carry the flow of ditches, natural drainages, streams and surface runoffs. Design culverts with consideration for minimum size requirements, minimum and maximum gradients, sediment and debris transport, materials and other factors as described in the following sections. See Section 7.3.2 for hydraulic standards and guidance.

When applicable, include provisions for fish habitat or special aesthetic considerations in the design. Fish habitat features may include baffles, energy dissipation structures within the culvert or at the inlet or outlet, inlet or outlet pools, riffles, boulders, logs and gravels within the culvert and the adjacent streambed, and restoration of vegetation, brush and trees for cover and shade on the adjacent slopes and stream banks.

9.5.5.3.1 Locations

Locate the culverts on the detail topographic map or plan sheets based on the location of natural drainages, streams, swales, low points in the terrain, ditch relief or other drainage considerations. Consider the location of cut and fill slopes, natural drainage flow lines and design cross sections to determine the length of culvert invert, inlet and outlet elevations and available depth for headwater.

Evaluate the ditch profile, transitions from cut to fill, low areas of fill slopes and other aspects of the cross sections and roadway plans and profiles. Streams crossing the alignment, draws and low spots in fills and ditch lines are the obvious sites for culverts. In long cut sections between the obvious culvert locations, space the cross drains such that water does not build up in the ditch line and infiltrates the subgrade or cause erosion problems. There is no set rule for minimum spacing between cross drains because of various soil types encountered and the wide differences in rainfall in different geographical areas. Consult with the hydraulic engineer on a project-by-project basis for recommended minimum and maximum culvert spacing.

9.5.5.3.2 Cover and Roadway Grade

After locating the culverts on plotted cross sections, verify that the roadway grade is sufficient to accommodate the design headwater and minimum cover requirements. Determine the culvert slope, maximum cover and prepare a drainage summary sheet for the plans. See Section 7.3.1 and Section 7.3.6 for more information on culverts.

9.5.5.3.3 Inlet Considerations

Design grated drop inlets, as applicable, to intercept all ditch flow or as a safety measure in roadway ditch lines. In this case, maintain the normal ditch depth at a culvert inlet and provide a traversable grate at the top of the catch basin or inlet.

Design inlets to intercept all runoff and ditch flow to prevent bypass flow from running across the roadway or onto an embankment slope, retaining wall, bridge deck or other structure.

9.5.5.3.4 Outlet Considerations

Locate culvert outlets to closely match natural drainage channels and to minimize erosion at the outlet. Design outlet channels, as applicable, for culvert outlets that are located in cut sections. Design outlet ditches at a gradient sufficient to ensure drainage and sediment conveyance and with configurations that facilitate future maintenance, safety, aesthetics, water quality and restoration of vegetation. When applicable, design outlet sediment detention structures and energy dissipation devices in consideration of the culvert outlet velocity and discharge volume. See Section 9.5.5.9. Include the volume of excavation for outlet ditches in the earthwork design.

9.5.5.4 Pavement Drainage

Design pavement drainage, as applicable, for curb and gutter sections, storm drains, embankment protection curbs, paved ditches, depressed medians and bridge ends. Evaluate pavement drainage using the hydrology and hydraulic standards, references, and guidance described in Section 7.3.3.

In curb and gutter or embankment curb sections, space the catch basins and inlets close enough together so water spread on the traveled way is within the allowable criteria. Spacing will depend on the gutter grade, cross slope and width of the road or gutter. Consult with the hydraulic engineer on spacing design requirements.

At the lower ends of bridges, design catch basins or inlets to prevent runoff from the bridge gutters eroding the fill slopes at the corners of a bridge.

At culvert inlets, determine the need for catch basins and the type of inlet and grates on an individual basis. Consider the amount of runoff to be collected, the capacity of the inlet under various slope and gradient conditions, and the amount and type of anticipated debris; slide material and sedimentation that may plug them. Determine the need for culvert inlets at the upstream approach end of bridges, and where there are curbs or guard walls. In all cases, drainage grates and drop inlets should be designed so that they do not encroach into the traveled way. Drainage grates adjacent the roadway should always be designed bicycle-safe. Where shoulder width, or a bike lane, adjacent to a curb is less than 5 feet [1.5 m], recessed drainage inlets or curb inlets should be used.

9.5.5.5 Downdrains and Pipe Anchors

Downdrains or chutes are generally used to convey the discharge water from the inlets to the embankment toe. Buried pipe downdrains are preferable because the flow is confined, erosion along the embankment slope is minimized, interference with maintenance functions is reduced and they are aesthetically pleasing. Downdrains may be used to convey drainage down high or steep embankments. Downdrain culverts may be used to reduce excessive excavation required to install a new culvert at the bottom of an existing fill. Also, consider downdrains where the culvert outlets on erodible soils. Do not use downdrains for culverts larger than 48 in [1.2 m].

Design the outlets of downdrains to control or minimize scour and erosion.

Pipe anchors should be specified for all above ground downdrain installations. Buried downdrains may require an anchoring system depending on specific site and slope conditions.

9.5.5.6 Storm Drains

Storm drain systems and urban drainage systems require design by or in consultation with the hydraulic engineer. Furnish layouts, lines and grades and topographic mapping and land features for each drainage area. Include detailed storm drain system drawings in the plans.

For further information, see Section 7.3.4.

9.5.5.7 Underdrains and Horizontal Drains

Coordinate with the Geotechnical Unit for design recommendations or conceptual designs for underdrain systems and horizontal drains based on field observations and exploration of subsurface conditions. Incorporate the recommendations in the detailed roadway design and provide detailed drawings as part of the PS&E.

9.5.5.8 Riprap Slope Protection

Obtain recommendations from the hydraulic discipline for the class, thickness and cross section of riprap for slope protection along streams and lakes, and for ditch and channel lining. Incorporate these recommendations and data in the roadway design and PS&E preparation. The location, quantity, surface dimensions, class, thickness and typical section of riprap slope protection should be shown in the plans and specifications. Refer to FLH standard drawings for typical outlet protection details. See Section 7.3.2 for more information on channel stabilization.

Place riprap around culvert inlets and outlets, as necessary, to prevent erosion and undercutting.

9.5.5.9 Energy Dissipators and Outlet Detention Basins

In areas of erodible soils, consider energy dissipators at the outlet of downdrains and culverts with high outlet velocities and in channels at points where the grade flattens. Energy dissipators may be in the form of riprap outlet basins, stilling wells, weirs or concrete structures. These features may be needed for temporary or permanent stormwater management. For more information, see Section 7.3.5.

9.5.6 SOIL EROSION AND SEDIMENT CONTROL

Erosion and sediment control are important considerations in the development of the design of a highway facility. **It is the policy of FLH that highways be designed and constructed to standards that will minimize erosion and sediment damage to the highway and adjacent properties.** See *Green Book* Section 3.6.1.

It is FLH standard practice to determine the need for various types of soil erosion and sediment control features, develop their proposed design, and include the appropriate items of work in the contract. Refer to 23 CFR 650 Subpart B. Also refer to Section 7.5.4 for stormwater management guidance. Roadway construction projects with soil disturbance exceeding 1 acre [0.4 hectare] requires filing a Notice of Intent (NOI) with the U.S. Environmental Protection Agency (EPA) and preparation of a Storm Water Pollution Prevention Plan (SWPPP) including erosion and sediment controls. The type and extent of erosion and sediment control measures will depend on the soils, proximity of adjacent streams or lakes, cut and fill slope magnitudes, topography, hydrology and other factors. Coordinate the design of soil erosion and sediment control features and incorporate input from hydrology and hydraulics, geotechnical, construction and environmental discipline specialists. The techniques for addressing temporary soil erosion and sediment control are commonly described as Best Management Practices (BMP's). Sources of BMPs are:

- *Best Management Practices for Erosion and Sediment Control*, FHWA (Report No. FHWA-FLP-94-005), 1995.
- US Environmental Protection Agency, National Menu of Stormwater BMPs, *Construction Site Stormwater Runoff Control*,
- AASHTO Center for Environmental Excellence (CEE), Construction Practices for Environmental Stewardship, *Erosion and Sedimentation Control*, and
- NCHRP Synthesis 430, Cost-Effective and Sustainable Road Slope Stabilization and Erosion Control, TRB, 2012.
- NCHRP Synthesis Report 70, Design of Sedimentation Basins, TRB, 1980.

Additional references are State regulatory agencies BMPs and State DOT stormwater and erosion and sediment control manuals; refer to the CEE reference above for links to a number of such manuals.

9.5.6.1 Developing Erosion and Sediment Control Plans

The erosion control plans describe the location and type of controls to be implemented temporarily during construction and at the completion of earthwork and drainage construction. The controls should address erosion from the initial clearing stage to the final site stabilization.

The plans should reference FLH *Standard Drawings* and Division Details detailing the construction and installation of the particular control. Special resources (e.g., wetlands, surface waters) must be clearly identified on the plan along with protection measures. Any known problems including highly erodible soils, unstable slopes, etc., should also be identified while developing the plans. In addition, the plans should typically include basic drainage information (e.g., drainage patterns, drainage areas) and the size and location of drainage structures.

As appropriate, include a narrative in the PS&E or supporting documents to assist in plan implementation. The narrative should address issues that may not be clearly conveyed with a drawing. This may relate to construction sequences, maintenance on the controls, stabilization timing or other critical factors. The narrative may consist of brief notes and comments while an in-depth discussion may be provided in the Storm Water Pollution Prevention Plan (SWPPP).

9.5.6.2 Erosion and Sediment Control Phases

Erosion control plans should address the different stages of construction:

- Initial clearing and grubbing,
- Intermediate grading and drainage, and
- Final stabilization of the site.

The initial phase should address the perimeter controls required during the initial clearing and grubbing stage to prevent sediment from leaving the site. The intermediate grading and drainage phase should reflect the controls required during earthwork construction. This includes the point from grubbing operations until final grade is reached. The third phase of erosion control is the final stabilization of the site and installation of the permanent controls.

Consider the need for initial perimeter controls such as:

- Filter barriers,
- Diversion structures, and
- Settling structures.

Consider the need for intermediate controls such as:

- Temporary slope drains,
- Temporary channel linings,
- Mulching,
- Temporary and permanent turf establishment,
- Check dams,
- Settling and detention structures, and
- Inlet and outlet protection.

Consider that turf establishment or stabilization may be performed in incremental stages on cut and fill slopes, and may need additional quantity for multiple applications.

The last phase of erosion control consists of final site stabilization. This includes final stabilization of the slopes and waterways, stabilization of outfalls and other disturbed areas. Consider the need for final controls such as:

- Permanent turf establishment,
- Channel linings,
- Temporary slope drains,
- Check dams, and
- Outlet and inlet protection.

Both temporary and permanent erosion control measures must be considered during the design and all necessary features incorporated into the contract plans and specifications.

Temporary control measures are those features temporarily installed for use during construction activities. Upon project completion they are generally removed and disposed. The design for temporary control measures (e.g., silt fences, brush barriers, diversion channels, sediment traps, check dams, slope drains, berms) are contained in the *Best Management Practices for Erosion and Sediment Control Manual*, FHWA-FLP-94-005.

Division Standard Details detailing the more common temporary control devices are available and should be included in every project plans set containing construction activities that could possibly affect soil degradation or water quality.

Permanent control measures are those features installed as part of the highway to minimize scour, sedimentation, erosion, etc., during the facility life. Refer to the roadway drainage features described elsewhere in this chapter.

See HEC 22 for details and information relative to permanent inlets, downdrains, grates, curbs, gutters and other similar roadway drainage designs useful in controlling erosion. Chapter 7 lists additional information sources applicable to the design of debris control structures, riprap or slope protection installations, energy dissipator systems, ditch, channel linings, and similar structures.

9.5.7 PARKING AND REST AREAS

On FLH projects, parking and rest areas are typically constructed for the scenic, recreational and cultural enhancement of the highway facility. Coordinate the parking area design with the partner agency and if appropriate with local officials and business owners to identify acceptable locations for parking and to determine the geometry, capacity, design vehicle type and other related requirements. Information on rest area design is provided in the *Guide for Development of Rest Areas on Major Arterials and Freeways*, AASHTO, 2001.

Design parking and rest areas to accommodate persons with disabilities. Refer to the *Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities (ADAAG)* for the applicable standards. The *Green Book* contains information on sidewalk curb ramps in Section 4.17.3. Refer to Section 9.3.16.3 for accessibility requirements applicable to the design of parking areas and passenger loading zones.

Refer to Section 9.3.9.3 for design of parking lanes, and Section 9.3.9.9 for parking pullouts.

Determine the appropriate design vehicle and design parking areas to accommodate all circulation and parking maneuvers. Design intersections within the parking area to provide safe traffic movement. See Section 9.3.19 for parking lot layout considerations.

9.5.8 ROADWAY APPURTENANCES

Refer to Section 8.5 for design of traffic barriers and end treatments, and to Section 8.7 for design of signs, traffic signal installations and traffic control devices.

9.5.8.1 Highway Lighting Systems

As applicable, consider providing illumination to facilitate traffic operations and to improve traffic safety during nighttime hours. Where used, design highway lighting to enable the driver or pedestrian to better recognize important details in the roadway or parking area quickly, accurately and confidently. Coordinate the selection of lighting hardware and components with the maintaining agency to ensure compatibility. An engineer with expertise in this specialty should design highway lighting systems.

Refer to Section 8.7.3 for warrants and design of highway lighting systems. Also, refer to the *Roadway Lighting Design Guide*, AASHTO, 2005.

9.5.8.2 Fencing

Design fencing to separate highway users from livestock encroachment, and to separate pedestrian activity from vehicular travel where applicable. Coordinate the needs for wildlife passage or restriction in the fencing design. Generally, fencing is designed to replace an existing fence and is usually constructed on the right-of-way line through private lands. Some States have laws requiring fence for all State highway right of way. Check the applicable State or local regulations during the design process. Coordinate with the Right of Way unit to address fencing in the right-of-way negotiations and documents. Fencing type and location must agree with the right-of-way documents, or otherwise be agreed by the property owner as a right-of-way consideration for the project.

When the right-of-way line has many abrupt irregularities over short distances, fencing runs should have continuous alignment, but should never encroach upon private land. Minimize the number of different fence types on a particular project.

Fence type selection depends on the character and density of adjacent development and cost of installation and maintenance. In general, chain link fence should be installed in urban and suburban areas, and woven wire or high-tensile fence in rural areas. Consider chain-link fence where the following situations exist adjacent the highway:

- Along steep embankments or drop-offs such as a box culvert headwall, that are adjacent to a pedestrian facility or sidewalk or bicycle path,

- Industrial areas,
- Residential developments or where development is expected to occur,
- Military reservations,
- Schools and colleges,
- Recreational and athletic areas, playgrounds, and
- Other locations where a high level of protection to prevent encroachment on the right-of-way is necessary, or is requested by the maintaining agency.

Chain link fence should not be located where it restricts sight distance, particularly on curves. Also consider that chain link fence may increase snow drifting in some areas, and may collect waste paper and trash.

Generally, provide a 6 ft [1.8 m] high chain link fence if needed to prevent encroachments in urban or suburban areas, and to discourage climbing over the fence. A 4 ft [1.2 m] height may be used if conditions are less critical or if a lower height is needed to allow sight distance, or to meet right-of-way agreement considerations. In some locations it may be appropriate to consider improving the aesthetics of chain link fence by adding a colored epoxy coating or privacy slat inserts.

Wire fencing types apply in all rural areas and in some suburban and urban areas where developments along the right of way are infrequent and future development is not anticipated. The fencing may consist of barbed wire, woven wire and other metal fabric types. Woven wire and high tensile wire fence may not be adequate to retain livestock, and such applications should be specifically designed and coordinated with the property owner and addressed during right-of-way negotiations.

Determine the fence height and wire spacing, which may vary depending on the primary purpose of the fence (e.g., controlling cattle, sheep, or wildlife). Wire fencing may need to be as much as 10 ft [3.0 m] high if necessary to control elk and deer. In some western States, the special design of the wire spacing and height is important to minimize potential hazard for deer, elk or antelope crossings.

Metal right-of-way fencing can interfere with airport traffic control radar. When fencing in the vicinity of an airport, review the FAA permit to determine if the fencing will create radar interference. An alternate type of fencing may be appropriate in this case.

Provide gates, where required, and at the locations stated in the right-of-way agreements or as agreed to during the development of the project. Also provide gates, and locks if required, where needed for access by maintenance personnel. Designate the type, size and location of gates on the plans.

9.5.8.3 Cattle Guards

The design of cattle guard substructures must be concrete, timber or steel. The width and type may need to be documented in a right-of-way agreement or be agreed to during the project plan-in-hand review.

At a minimum, cattle guard widths should be shoulder-to-shoulder, or traveled way widths plus 8 ft [2.4 m] whichever is greater.

Cattle guard wing guards are usually not crashworthy and should be placed outside the clear zone, or treated as an exception to the roadside design.

9.5.9 RIGHT-OF-WAY AND UTILITY CONSIDERATIONS

Refer to Chapter 12 for Right-of-Way and Utility guidance. Also see *Green Book* Section 3.6.4.

The existing right-of-way should be considered and evaluated as a design constraint and should act as a design control similarly to all other environmental, social, economic, aesthetic and cost control factors. There may be certain projects where property values or the land's intrinsic values are so high or that its acquisition is so contentious that designing within either the existing right of way or a specified right of way limit may be necessary.

Right-of-way limits may be established following the completion of the highway design and determination of construction limits, including all earthwork, drainage, approach roads, walls, structures, and all other features affecting physical disturbances are determined.

The minimum right-of-way width is the horizontal distance from the centerline to the edge of construction limits for clearing. It is always desirable to provide some additional area to accommodate minor changes during construction and to provide space for normal construction and maintenance operations.

Refer to Chapter 12 for the standard minimum widths and the desirable distance from the clearing limit to the right-of-way line.

The clear zone recovery area should receive consideration when establishing new right-of-way limits. Good engineering judgment is essential in this area to determine when taking a prudent right of way equals the need for a portion of the theoretical recovery area.

The right-of-way should provide for maintenance, control of access, utilities, and future widening, control of adjacent drainage and vegetation for ensuring sight distance and aesthetics. The same land is often desirable for dwellings, farming, commercial or recreational purposes. Hence, right-of-way is seldom ideal but is usually a compromise.

It is not mandatory to provide right-of-way for new utilities. However, it is the usual practice to accommodate them when they do not conflict with the primary function of the roadway. Construction often causes the relocation of utilities located with the existing right-of-way. It is a requirement that the new right-of-way must provide areas for their relocation or the development of easements specifically to accommodate the utility.

Poles or other surface utility relocations should be beyond the clear zone area or behind guardrail. Design underground utilities such they are placed outside of the roadway, either in the foreslope, ditch, backslope, between the construction limits and right-of-way, or preferably outside the right-of-way line within a utility easement. Easements for pole lines usually require a minimum of 16 ft [5 m] of width to accommodate the cross arm and anchor systems and to provide for control of vegetation under the wires.

Right-of-way limits should be outside drainage control structures, channel changes, riprap, stilling pools, etc., constructed above or below the roadway allowing space to maintain or repair them. The right-of-way should extend at least 10 ft [3.0 m] beyond these facilities. It is preferable to obtain right-of-way (fee title) to cover these installations but in some cases a permanent maintenance easement may suffice. A permanent maintenance agreement will often cost nearly the same to acquire and administer as to acquire the right-of-way outright, but may be advantageous to the acquiring and highway-owning agency if the right-of-way acquisition is very contentious.

States, counties and other cooperating agencies generally have established standard widths for highway right-of-way. Contact the highway-operating agency to determine the standard minimum widths and any other applicable criteria.

9.5.10 ENVIRONMENTAL PROTECTION AND ENHANCEMENTS

Coordinate with the environmental discipline for the design of environmental protection and enhancements that are included in commitments made as part of the environmental document. Such enhancements may also be requested and appropriately added as part of the final design process, in addition to commitments included in the environmental document. Enhancements may include special features and details for wildlife connectivity, fish passage and accommodations for wildlife crossings, adjustment of horizontal and vertical alignment to avoid sensitive areas, to fit topographical features, and to protect scenic and visual quality. Enhancements to the roadway cross section may include:

- Adjustment of the typical slope ratio to enhance new slopes or protect existing ones;
- Use of curb and closed drainage systems to minimize the width of roadside ditches;
- Use of retaining walls;
- Riparian enhancements and wetland or wetland buffer restoration or creation;
- Slope design for viewshed and scenic enhancement and vegetation management;
- Selection of aesthetic traffic barriers and to allow visibility of the roadside;
- Preservation of significant roadside features such as rock outcrops and vegetation;
- Use of landscaping for screening or earth berm buffers;
- Preservation and retrofitting of historical features such as culverts, walls, curbs;
- Incorporation of historical features at interpretive facilities, rest areas, overlooks; and

- Use of architectural landscape design details.

Refer to the FHWA "Critter Crossings" and the Forest Service "Wildlife Crossings Toolkit" for wildlife crossings guidance and design references. Refer to the FWS "FishXing" for fish passage through culverts guidance and design references. Also refer to *Management and Techniques for Riparian Restorations: Roads Field Guide. Vol. I and II*, FS, 2002.

9.5.11 CONSTRUCTION CONSIDERATIONS

Construction considerations include work sequencing and constructability. If a route is to be constructed in phases due to programming of funds or other considerations, coordinate closely with the Planning and Programming Unit to develop the highway design and PS&E for implementing the most effective strategy and sequence of projects to deliver the overall route.

9.5.11.1 Construction Sequencing

Consider construction sequencing in the design of features that may need to be constructed in a specific order to enable traffic management through the work zone, utility accommodation, environmental restrictions, earthwork, drainage, structural considerations or other factors. At a minimum, the design must reflect an orderly sequence of construction such that all design and environmental commitments can be efficiently accomplished. Preferably, the design should demonstrate a comprehensive analysis and design details for a fully optimized construction sequence that appropriately balances the overall cost, time, resources, quality, stakeholder and public concerns and environmental protection.

As applicable, provide construction sequencing details, or applicable special contract requirements, or both, in the design and PS&E documents that depict the intended construction sequencing.

9.5.11.2 Constructability

Constructability refers to the practicality of the design to be bid, built and administered during construction. In order to receive fair and competitive bids the prospective bidders must clearly understand the design and the construction requirements. Avoid using unclear design requirements or nebulous notes, descriptions and requirements than cannot be readily quantified for basis of bidding and contract administration purposes.

Constructability also includes the consideration in the design for earthwork balance, availability of the materials and equipment needed to perform the work, construction access, ability to comply with any restrictions while performing the work, etc. Coordinate closely with the Construction Unit throughout the design process to include input for developing the design and contract provisions and to facilitate a thorough review of the design and PS&E.

9.6 PLANS SPECIFICATIONS AND ESTIMATE (PS&E) DEVELOPMENT

This section prescribes procedures and policies for the preparation of the plans, specifications and cost estimate (PS&E) and supporting design documentation for performing the work to construct a highway facility. The following addresses the PS&E format and decisions made for PS&E preparation, within the constraints imposed by earlier environmental and engineering studies and decisions.

Coordinate with other technical disciplines and cooperating agencies as applicable to obtain specific information, input, design data and other contributing portions of the design documents for inclusion in the completed PS&E.

Also, refer to the FHWA FAPG 23 CFR 630B, *Guidelines for Preparation of Plans, Specifications and Estimates*.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.1 PS&E PACKAGE

Provide the following items for a standard PS&E assembly:

- Plans,
- Specifications including the Standard Specifications (FP-XX) and the Special Contract Requirements (SCRs),
- An engineer's estimate and unit cost analysis to perform the construction,
- An estimated construction schedule and contract time analysis,
- Design data that is made available to the bidders (e.g., GEOPAK output reports, hydraulic data, geotechnical data, cross sections), and
- Supporting information for the geometric design and PS&E, construction stakeout and control, and engineering data for construction management.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.2 ALTERNATIVE PS&E DEVELOPMENT AND CONTRACTING OPTIONS

When applicable, provide the following design and PS&E development options:

1. **Design-build.** Design-build is a project delivery method that combines the final design and construction together under the same contract. Normally, the decision to select a project for design-build will be made during the planning and programming phase. For design-build, typically develop the highway design and PS&E to no more than a preliminary (30 percent) level for contracting. Refer to Chapter 4 for guidance on requirements for development of the preliminary design package. Coordinate closely with the Acquisitions Unit for special guidance on the development of the design and PS&E documentation for design-build projects. For additional information on design-

build refer the AASHTO *Guide for Design-Build Procurement*, 2008 and "Public-Private Partnerships" from FHWA.

2. **Alternative Bid Schedule Packages.** Alternative bid schedules provide several increments of the design and PS&E package within the same solicitation documents. Include all necessary details, quantities, specifications and cost estimates for the entire project package as well as for one or more lesser increment packages, such that any one of the alternative bid packages may be awarded depending on the funding available and the amount of the bids received. The design of the lesser packages must be fully compatible and able to be constructed within their lesser scope, such that the alignment, earthwork balance, roadway geometry including connections with the existing roadways, environmental commitments and other design requirements are fully provided for within each of the alternative bid schedules. Provide alternative bid schedules for design package increments that are estimated to cost:

    a. Approximately 10 to 15 percent below the program amount,

    b. At the program amount, and

    c. Approximately 10 to 15 percent above the program amount.

3. **Options.** When applicable, provide a base design and PS&E package, with provision for additional work to be included in the project either at the time of award, or possibly at some later time, depending on the funding available at these respective times and the amount of the bids received. Options may be developed for increasingly additive work, or for one or more additional project features that are independent of each other, within the contract. The PS&E must be very clear regarding what is included within each option, to avoid potential contract administration conflicts if a particular option is exercised or not.

9.6.3 PS&E DEVELOPMENT AT VARIOUS STAGES OF DESIGN

Develop the PS&E to an increasing level of detail during each stage in a project's iterative design process. The following are the PS&E development requirements for each major point in the design process.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.3.1 Conceptual Studies and Preliminary Design

Refer to Chapter 4 for the design development activities at the conceptual and preliminary design phase. The plans and cost estimate are typically developed to the 30 percent level for preliminary design.

9.6.3.2 Intermediate Design

During the intermediate design phase, the PS&E package should be developed to the 50 percent level. The intermediate design PS&E package should include cross-sections, major pay items with their associated quantities, major design details (e.g., intersections, turnouts, large culverts, guardrail, walls), and any items affecting permits and right-of-way (ROW) acquisition (e.g., erosion control plan). The completed intermediate design, with review comments incorporated and revisions, should enable the development of final right-of-way plans and descriptions, final structural designs, final retaining wall designs, final hydraulic and geotechnical designs and for all major elements that other technical disciplines will develop or finalize as applicable for later inclusion in the PS&E.

Consider the following information to develop the intermediate design PS&E package:

- Summary of comments provided at the preliminary design (30 percent) review,
- Preliminary Engineering Study Report, and
- Preliminary design plan and estimate.

Activities required to develop the intermediate design PS&E package include:

- Document the resolutions to the preliminary field review comments and revise the PS&E package accordingly.
- Update the design exception portion of the Highway Design Standards Form (see Section 9.1.3).
- Incorporate interdisciplinary, cross-functional team (CFT) (e.g., hydraulic, geotechnical) and cooperating agency recommendations into the plans.
- Develop design drawings and quantities required for environmental permitting.
- As needed, provide design information to the Right-of-Way Specialist for the development of the draft right-of-way plans and easement plats.
- As applicable, for projects exceeding $5 million in construction costs, perform a Value Engineering (VE) study. Incorporate any approved VE recommendations into the PS&E package.
- Refine the preliminary cost estimate (from the preliminary design) to reflect all intermediate design changes.
- Prepare a draft set of special contract requirements, as needed. This is recommended, but not required, at this point.

Following completion of the intermediate design PS&E package, perform an intermediate design (i.e., 50 percent) review as described in Section 9.6.4.2.

9.6.3.3 Intermediate Design Revisions

During this phase, revise the PS&E package to sufficient detail to apply for applicable permits, to allow for preliminary roadway staking and to prepare final right-of-way and utility plans, as applicable.

Consider the following information to perform the intermediate design revisions:

- NEPA document,

- The summary of comments provided at the intermediate (i.e., 50 percent) design external review, and
- The intermediate design PS&E package.

Activities required for the intermediate design revisions include:

- Document the resolutions to the intermediate external review comments and revise the PS&E package accordingly,
- Incorporate any environmental commitments from the NEPA document,
- Update the Highway Design Standards Form and document any design exceptions (see Section 9.1.3.4), if not completed previously.
- Finalize construction limits,
- Prepare draft environmental permit applications as needed. Develop the plans to sufficient detail to enable preparation of applications for permits,
- Provide revised cross-sections and staking data (e.g., slope stakes, centerline) to the survey discipline, if staking for Plan-in-Hand (PIH) review will be required, and
- Provide the revised intermediate PS&E package to the right-of-way specialist, as applicable, for development of final right-of-way and utility plans. See Chapter 12, Right-of-Way and Utilities.

9.6.3.4 Plan-in-Hand (PIH) PS&E

During this phase, develop the PS&E package to the 70 percent level. The Plan-In-Hand (PIH) PS&E should include semi-final plans representing a draft of each plan sheet, except certain special plan sheets (e.g., structural design details) to be included in the final plans. Develop all major design elements (e.g., grading, detail sheets of parking areas and road intersections, drainage, structures, erosion control, traffic control, cross-sections) a draft set of special contract requirements and a complete construction estimate including all pay items that are shown on the plans with their associated quantities. Verify that the proposed right-of-way and utility plans provide for all the final design and construction requirements so that acquisition of the right-of-way and utility adjustments, as applicable, may be expediently accomplished.

Information used to develop the PIH PS&E includes the revised intermediate PS&E package (revised in accordance with Section 9.6.3.3).

Activities required to develop the PIH PS&E package include:

- Develop a proposed set of special contract requirements,
- Determine all pay items to be used in the contract and calculate the associated quantities,
- Provide quantity tables and a summary of quantities in the PS&E package,
- Further develop the plan sheets to adequately support the work items called out in the plans,

- Compile a complete engineer's estimate for all work items called out in the plans, and
- Update the Highway Design Standards Form and document any design exceptions (see Section 9.1.3.4), if not completed previously.

Following development of the PIH PS&E package, perform a PIH (i.e., 70 percent) design review according to Section 9.6.4.3.

9.6.3.5 Final Design

During this phase, revise the PIH PS&E package according to the PIH field review comments and develop the PS&E package to the 95 percent level.

Consider the following information to develop the final (i.e., 95 percent) PS&E package:

- The summary of comments provided at the PIH field review.
- The Plan-in-Hand (PIH) PS&E package.

Activities required for development of the PS&E package include:

- Document the resolutions to the PIH field review comments and revise the PS&E package accordingly.
- Provide documented comments resolutions to the attendees of the PIH field review.
- Incorporate all final design details into the plan sheets.
- Finalize the special contract requirements.
- Finalize the proposed construction schedule to determine the contract time or anticipated construction completion date.

Following completion of the final (i.e., 95 percent) design PS&E package, perform a final PS&E review according to Section 9.6.4.4. Following that review, advance the package to 100 percent and prepare all documentation to submit to the Acquisitions Unit as described in Section 9.6.4.5.

9.6.4 REVIEWS

Perform office reviews or on-site field reviews at milestone phases applicable to the specific project to ensure that the design and PS&E reflect and are consistent with contextual values and with Federal, State and local stakeholder's goals, objectives and standards. As appropriate, conduct multi-disciplinary and multi-agency inspections, as well as specialized meetings with a single discipline to resolve a specific problem. Include all cooperating agencies and appropriate FLH Division staff, and other appropriate stakeholders in each milestone review.

Before reviews, perform a check of the highway design and PS&E, using the applicable quality control process and design file documentation. Check the overall technical soundness of the work and appropriate application of design and PS&E standards. When applicable, after revisions from the initial check are completed a senior highway designer or Highway Design Manager (HDM) should perform a secondary review using the applicable quality control process and design file documentation. After revisions from the quality control checks are completed, the interdisciplinary project team and partner agency reviews the PS&E with the intent to:

- Evaluate how all work products of each function fit within the design and PS&E as a whole,
- Ensure that the design and PS&E conforms to the overall project scope, and
- Ensure that the design and PS&E incorporates commitments made to partners and regulatory agencies.

Prior to conducting field reviews, provide the participants with the appropriate information (e.g., plans, specifications, cost estimate, exhibits, visualizations) sufficiently in advance for them to schedule their time to perform a comprehensive review of the information and to formulate their input or questions, prior to the onsite meeting. To expedite the field review, arrange in advance to provide an appropriate level of stakeout (e.g., marking or flagging the centerline, proposed slope stakes, structural foundations), as applicable.

During reviews communicate the proposed design to the cooperating agencies and other stakeholders, and solicit comments from all participants to ensure that the design is being developed with regard to its context, and in compliance with the intended scope and social and environmental commitments. Provide an opportunity for free and open discussion that encourages early and amicable resolution of controversial issues that may arise during the development of the design and PS&E package, among the interdisciplinary project team, cooperating agencies, and other stakeholders.

During field reviews verify data and check the design as developed in the office against field conditions to identify any discrepancies and minimize conflicts and changes during construction.

In all cases, document the conclusions reached at the field reviews and distribute to the interested parties.

The following sections describe reviews for various phases of the design development.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.4.1 Preliminary Design (15 or 30 Percent) Review

The preliminary design review covers the preliminary design and results in evaluation and resolution of the major design features for a project (e.g., horizontal and vertical alignments, typical section, and access control). It typically represents a level of design detail sufficient to support the environmental analysis, documentation and decisions, which is typically some level within the 15 to 30 percent range of development. The preliminary design review typically includes both an internal review and an external (i.e., partner agencies and stakeholders) review, and will typically include an on-site field review. These may be held separately or concurrently.

The purpose of the review is to evaluate and resolve the roadway geometry, safety considerations, and environmental impact mitigation and cost effectiveness of the proposed improvement, to support completion of the environmental document and decision-making process. The review should also identify the revisions needed to bring the roadway design, plans and estimate to a full 30 percent stage. The field review should also include verifying the mapped features and spot-checking the topography, particularly in areas of narrow roadbed bench width or constrained right of way.

The level of detail for the preliminary design review depends on the scale of proposed improvements and may be different for RRR projects than for reconstruction or new construction projects. The information available for the review (deliverables) includes detail maps or plans and profiles showing preliminary alignments and plotted cross sections of the mainline and major intersecting roadways for all alternatives being considered and preliminary construction cost estimate. Provide exhibits and visualizations of the project alternatives, if available. The plans and cost estimate are typically developed to the 15 percent level for an initial line and grade review, if applicable, and to 30 percent level for preliminary design.

As part of the review, it is essential to identify and document any exceptions to standards, along with any associated hazards or risks so that all parties are aware of the potential consequences of the decisions. See Section 9.1.3.

9.6.4.2 Intermediate Design (50 Percent) Review

The result of the intermediate design review is the determination of the design features affecting the limits of disturbance for a project (e.g., horizontal and vertical alignments, cross sections, major approach roads, intersections, parking areas, earthwork, and type, size location of structures and retaining walls). On some projects, an intermediate design review may not be necessary to complete the design.

The information provided for the review includes:

- The 50 percent plans containing detail plans and profiles showing alignments, grades, construction limits,
- The plotted cross sections,
- Draft Special Contract Requirements, and
- The engineer's cost estimate.

The level of detail of the review depends on the scale of construction proposed (e.g., RRR to new construction).

The purpose of the review is to resolve all aspects of the roadway geometry and design features that affect the physical disturbances, safety considerations, environmental impact mitigation and cost of the proposed improvement, to ensure that the design and PS&E:

- Is context sensitive,
- Minimizes or avoids resource impacts,
- Mitigates environmental impacts (wetlands, etc.),
- Addresses safety,
- Has correct roadway geometrics,

- Is cost-effective and constructible,
- Integrates into the design the environmental mitigation and stipulations, and
- The PS&E package is being developed with appropriate design and drafting standards.

The extent of all proposed construction limits for the roadway footprint is typically a key issue for most Federal land management agencies that requires resolution at this stage.

For the review, identify and document any exceptions to standards and the associated safety risks so that all parties are aware of the ramifications of the decisions.

The review may consist of an office review, or a field review at the project site, or both. The external review should preferably occur after an internal review is performed, and preferably after the PS&E package has been revised as necessary based on comments from the internal review. Provide copies of the plans, cross-sections and Special Contract Requirements to the external agencies sufficiently prior to performing the external review. For Forest Highway projects, the external review will typically include interdisciplinary project team members and cooperating agency representatives. For Park Roads projects, the attendees will typically include interdisciplinary project team members, Park representatives and Denver Service Center representatives, as requested. Prepare additional presentation materials and visualizations as necessary to convey design information at the external review. Following completion of the external review, prepare a report summarizing accomplishments and decisions made during the review.

9.6.4.3 Plan-In-Hand Design (70 Percent) Review

The PIH design review consists of a review of the 70 percent (semi-final) plans and specifications for the proposed project. The primary purpose of this review is to resolve all the design elements and other special conditions for finalization and inclusion in the PS&E package. The information required for the review is:

- Semi-final plans (all anticipated plan sheets, completed to 70 percent stage)
- Plotted proposed cross sections,
- The draft Special Contract Requirements, and
- The current engineer’s cost estimate.

Since the line and grade, construction limits, drainage features and other roadway design geometry has been reviewed and presumably resolved at earlier stages, this review is primarily focused on final design and specification details, finalization of minor roadway appurtenances and construction sequencing details.

At this stage, the design should conform with all of the governing criteria, including input from geotechnical and hydraulic reports, environmental documents, safety requirements and other matters pertinent to the project. Resolve those items affecting the plans or Special Contract Requirements, or make arrangements for obtaining the necessary data and decisions for their resolution.

For the review, identify and document any exceptions to the standards, and the associated safety risks, so that all parties are aware of the ramifications of the decisions.

The review normally consists of a field review at the project site. The external review should preferably occur after an internal review is performed, and preferably after the PS&E package has been revised as necessary based on comments from the internal review. Provide copies of the plans, cross-sections and Special Contract Requirements to the external agencies sufficiently prior to the external review. Typically, the review includes similar participants as the Intermediate Design (i.e., 50 percent). Review described in Section 9.6.4.2. Prepare additional presentation materials and visualizations as necessary to convey design information at the external review. Following completion of the external review, prepare a report summarizing accomplishments and decisions made during the review.

After the review has been completed, revise the PS&E package to resolve the comments of the participants. Document resolutions and provide to the attendees of the field review. If necessary, update the Highway Design Standards Form and document the approval of any design exceptions.

Following the review, the designer should have all input necessary to prepare the final plans, Special Contract Requirements and complete the engineer's estimate for the project.

9.6.4.4 Final PS&E (95 Percent) Review

This consists of the final PS&E review phase, both internally and externally. In some cases, the internal and external reviews described below are combined and done simultaneously. After revising the plans and Special Contract Requirements to show changes from the previous reviews, the PS&E package is typically distributed internally for a final review by Division staff specialists to ensure consistency with programming, environmental, geotechnical, hydraulics, bridge or other project requirements. A 95 percent PS&E Review comment resolution meeting should be held, if comments need to be discussed and reconciled. After the PS&E is reviewed internally and the comments addressed, or concurrently if necessary, the PS&E package should be distributed externally to the highway facility owner and Federal land management agency for review and concurrence, and may also be distributed to other stakeholders and interested agencies for their review and comment. Depending on the thoroughness of the previous reviews, an on-site inspection may or may not be required. In either case, resolve all comments received concerning the proposal so that the project may proceed to solicitation for construction.

Incorporate the recommendations from any final geotechnical reports and permit requirements, and stipulations from right-of-way and utility agreements. Ensure that all necessary permits, agreements and other requirements for advertisement of the project are completed and are addressed in the PS&E. Provide the title sheet of the plans to the agency and individuals listed in the signature block for signature, or obtain a letter of approval for the signature.

9.6.4.5 PS&E Approval and Authorization (100 Percent)

This consists of final approval, sign-off of the PS&E and authorization for solicitation of the contract package. The purpose of this activity is to advance the PS&E package to the 100 percent level so that the PS&E is ready for advertisement, and to deliver the PS&E and associated documents and necessary data to the Acquisitions Unit. During this activity the plans are signed and all specifications, estimates, certifications and other documentation are approved. The funding authorization and obligation documents are also approved. The completion of this activity allows the solicitation of the contract package.

Information needed to perform the PS&E approval and authorization (100 percent) includes:

- The summary of comments provided from the final PS&E (i.e., 95 percent) review.
- The final design PS&E package.

Activities required for the PS&E approval and authorization include:

- Document the resolutions to final (i.e., 95 percent) PS&E review comments and revise the PS&E package accordingly.
- Finalize any remaining details necessary to complete the PS&E package and compile supporting documentation for approval.
- Perform a final QC/QA review. This review typically evaluates the completeness of the documentation, forms and PS&E package before submittal to Acquisitions. Revise the documentation, forms and PS&E package as necessary.
- Obtain all required signatures and approvals of the PS&E, funding authorization and obligation documents. Minor design revisions may be necessary to resolve any final comments or conditions from the approving officials.
- Deliver the final PS&E package and supporting documentation to the Acquisitions Unit.

9.6.4.6 Value Engineering

FHWA Order 1311.1A, *Value Engineering*, describes policy relating to value engineering in design and construction and the review of designs and standards. **It is FLH policy to employ VE when there is a reasonable potential for a significant ratio of savings to the cost of the VE analysis.** A VE study should be considered on all projects where there is a reasonable potential for a ratio over 5:1 of implemented savings to VE cost, or with an estimated construction cost over $10 million, or are complex, or include major structures.

As applicable, perform a VE study and apply recognized value engineering techniques by a multi-disciplined team to:

- Identify the functions of the designed products or services,
- Establish a worth for those functions,
- Generate alternatives through the use of creative thinking, and
- Provide the needed functions to accomplish the original purpose of the project, reliably and at the lowest life-cycle cost without sacrificing safety, quality and environmental attributes of the project.

VE is typically applied at the intermediate stage of design; however, studies are applicable as early in the design process as feasible.

Prepare a report of the study findings and recommendations. Document the VE results and probable cost savings, if any, from implementation of the VE study recommendations into the highway design.

For guidance on VE practices refer to Value Engineering from FHWA. Also, refer to AASHTO *Guidelines for Value Engineering*, 2nd Edition, 2001.

For Park Roads and Parkways projects a value analysis may be required. Refer to the NPS Value Analysis Report Template for performing these analyses.

9.6.5 PLANS

Provide plans consisting of an organized series of drawings containing the necessary engineering data about the location, character and dimensions of the work, including layouts, roadway geometry, cross sections, structures and related details. The plans should not encompass material that is more appropriately included in the specifications. The plans, together with the specifications, should contain all of the data required for the contractor to submit a bid, stake and construct the project.

Project plans should be prepared using the guidance provided in the following sections and the Division Supplements.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.5.1 Format

It is FLH standard practice to prepare all plan sheets using an approved CADD system. MicroStation from Bentley Systems, Inc. is the current FLH standard CADD system. Rare exceptions (e.g., conceptual drawing, architectural renditions, emergency projects) may be necessary to accommodate special needs of internal sections or cooperating agencies. When manual drafting becomes necessary, it should be accomplished in a manner that duplicates the appearance of CADD drafting to the extent possible.

The standard size of plan sheets should be approximately 11 in by 17 in [279 mm by 432 mm]. The standard size plan sheets should provide approximately a 1.4 in [35 mm] margin for the binding on the left edge, a 0.3 in [7 mm] margin on the right edge and a 0.3 in [7 mm] margin on the top and the bottom. This accommodates an effective sheet size of approximately 10.4 in by 15.3 in [265 mm by 390 mm]. For plotting purposes, the useable sheet dimensions may be slightly reduced (e.g., 10.7 in by 16.7 in [271 mm by 423 mm] with 1.1 in [27 mm] left margin and 0.2 in [5 mm] margins on the right, top and bottom). Margins may be reversed for double-sided (duplex) printing.

When applicable, provide abbreviated “book size” plan sheets, which may be as small as 8.5 in by 11 in [216 mm by 279 mm], and may be used provided they give sufficient information to describe and construct the project. Consider abbreviated plans for very low complexity projects such as minor emergency relief, safety improvements, and RRR.

Refer to Division Supplements for CADD plan sheets format and for the organization of plans. Consider the complexity of the work and provide the format accordingly.

9.6.5.2 Drafting Standards

Refer to Division Supplements for drafting standards applicable to each Division.

The following primary drafting requirements apply:

- Adhere to the applicable drafting standards for uniformity and quality,
- Use care in laying out details and locating text on plans to clearly relate the text to the applicable details,
- Provide sufficient notes on plan drawings to clarify the drawing and provide necessary information for a complete understanding of the work,
- Notes must be clear, concise, descriptive and as brief as possible to convey the message,
- Do not duplicate instructions or requirements covered in the Specifications on the plans,
- Use the correct text font, style and size, with proper spacing between figures, symbols and words, and
- Use the correct line level, line style, color, and weight and in the correct relationship to other lines on the plans.

The following general drafting guidelines apply to all plans:

- Do not use “Station” or “Sta” as a prefix to station numbers. Any numbering including a plus sign (e.g., 92+95) is understood to be a station number;
- Use a Note for general information that is relevant to the entire sheet. Do not use the term “General Notes.” When possible, place Notes on the right hand side of the sheet;
- When placing text on plan sheets, do not crowd other information. Carefully choose a place for the notes that is as close as possible to the point of application;
- Use standard cross-section indicators;
- Do not use the letters “I,” “O,” “N” or “Z” as cross-section indicators. “I” and “O” resemble symbols shown on drawings and “N” and “Z” are the same shape, but oriented 90 degrees. When at the end of the alphabet, use AA, BB, etc.;
- Write numbers with commas separating millions or thousands (i.e. 99,999 rather than 99999 or 99 999);
- Do not draw hidden contours under a structure with long dashes. Make dashes 0.12 in [3 mm] long with 0.06 in [1.5 mm] spaces between. Show hidden lines of structures with the same symbol;
- Avoid running hatching, lines or patterning through words or figures. Do not use the border lines of the sheets as a basis for establishing angle of parallel hatching lines. It is

desired to gradually change the direction of hatching at angle points in the section to maintain a 45-degree angle with the neat line of the structure;

- Use abbreviations on plan and profile sheets only where there is not enough space to spell out the word. In instances where the meaning of abbreviation appears doubtful, the word should be spelled out;
- Do not capitalize abbreviations unless the word or words represented are ordinarily capitalized, or unless the abbreviation itself has become established as a capital letter, such as N for north; and
- Use a period following each part of an abbreviation that represents a single word. This aids in quick interpretation of an abbreviation (e.g., "a.m.", not "am"). The exception to a period following an abbreviation is with units of measure where periods are not used.

Minor deviations from the guidelines for the plans may be acceptable provided the primary requirements above are followed.

9.6.5.3 Organization of Plans

The *Guidelines for Preparation of Plans, Specifications and Estimates*, FAPG 23 CFR 630B, provides guidelines in the preparation of plans, specifications and estimates. The guidelines are presented in a non-regulatory supplement attachment to FAPG, Subchapter G, Part 630, Subpart B.

As applicable, follow the guidelines in the *FAPG* for the following subject areas in the organization of plan sheets:

1. Title Sheet,
2. Typical Sections,
3. Summary of Quantities,
4. Tabulation of Quantities,
5. Plan and Profile,
6. Bridges,
7. Drainage Facilities,
8. Traffic Control Plan,
9. Standard Drawings, Division Standard Details, and Special Details,
10. Environmental mitigation,
11. Cross Sections,
12. Contiguous projects, and
13. Right-of-Way Plans (if not provided separately).

The *FAPG* guidelines permit latitude in the arrangement of plan sheets provided the intent of the plans is clear. Determine an arrangement that best fits the needs within the *FAPG*.

Refer to the Division Supplements for arrangement and organization of plan sheets and for example sample plan sheets. The following sections provide guidelines for the plans.

9.6.5.3.1 Title Sheet

The Title Sheet serves to identify the location and limits of the project so bidders can find it in the field. Descriptive terms appearing on the Title Sheet should be readily identifiable by the topography or culture or by using State highway maps.

Details that help to clarify the limits of the work or provide data needed to conveniently bid the work are encouraged. Additional details that may help the bidders include:

- Locations of material sources described in Section 105;
- Locations of disposal areas, staging areas, stockpile sites; and
- Off-project mitigation work.

The *Guidelines for Preparation of Plans, Specifications and Estimates*, FAPG 23 CFR 630B, recommends that the scales used on the plans show on the Title Sheet. Considering the number of scale variations found in a typical project, a scale legend could be confusing and difficult to cross-check. Therefore, the Title Sheet exhibits show a bar scale only for the map appearing on that sheet.

A completed Title Sheet should contain the following data:

- Proper title and project designation.
- Statement of the project length.
- The State, county, city or town (and, where applicable, the National Forest, National Park, etc.).
- Key map of the State with designator showing project location.
- The location or route map showing project location with beginning and ending stations or termini, and the corresponding mileposts consistent with program's road inventory data for the route.
- Index of sheets comprising the plans.
- Design classifications (e.g., the current average daily traffic (ADT), design year ADT, design hourly volume (DHV), directional distribution (D), percent of trucks (T), design speed (V) and maximum superelevation rate (e)).
- Distance from the project to nearest city, town, etc.
- Provisions for dates and signatures of the approving officials.
- Standard Specifications applicable to the project.
- Units of measurement applicable to the project (i.e. US Survey Foot, International Foot, or meter; see Section 5.3.2.5)

The location or route map should be prepared using a scale ratio of 1:100 000 or larger and show the project area, the nearest towns appearing on a State highway map, other roads, railroads, major streams, etc. In instances where sufficient information cannot be placed on the route map to adequately identify the project work, additional vicinity maps should be prepared on separate sheets and placed following the Title Sheet.

The large number of symbols and abbreviations used within FLH precludes placing the information on the Title Sheet. Therefore, a separate Plan Symbols and Abbreviations Sheet should be used and typically follows the Title Sheet in a set of plans.

When a special symbol is required that is not included, show it in a legend on either the first plan sheet where the symbol appears or on the left side of the first Plan and Profile Sheet. Abbreviations not shown may be placed on the plans similar to the way symbols are placed, or may be added to the contract as a Special Contract Requirement under Subsection 101.03 of the Specifications.

The symbols and abbreviations should not be changed on a project-to-project basis, but if necessary may be supplemented with additional project-specific items. When a change is required for a Division's needs, change the master file so all future projects will have the same symbols and abbreviations. This prevents the need to check all the symbology on the sheet for every project.

For complex projects consider providing a supplemental sheet showing the overall total project site plan, including contractor staging areas, material stockpile or storage areas, construction access, water or material sources, disposal sites, and other locations of interest to the contractor.

9.6.5.3.2 Typical Sections

The Typical Section Sheet shows the shape of the finished surface and shoulders, and represents the appearance of the completed project. It must be specific enough to describe the proposed work, its location and the material needed. Ensure that all references to materials, bid item names and numbers are consistent with the summary of quantities and bid schedule.

For combined roadway and bridge projects, the typical section for the bridge may be shown with other bridge design information. All plans should show typical sections for the project including those for bridges only and those where abbreviated plans are used. On projects requiring more than one Typical Section, the limiting stations for each section should show. This may require additional plan sheets for clarification of the work.

Identify all functional elements of the typical section to a relative scale. Show widths in feet [meters] and show thickness or depth in inches [millimeters]. Show the thickness of each element in the pavement structure in inches [millimeters].

Use notes or tables on the Typical Section Sheet to describe varying pavement structure thicknesses. These may occur due to differing soil conditions, traffic volumes or other roadway characteristics.

For stage construction projects, identify the ultimate typical section. Clearly distinguish the work to be performed under the contract and the future stage construction work.

Include tables or notes to illustrate curve widening, relationship of slope ratios to cut and fill heights, slope rounding and other special treatments.

Identify the profile grade on the Typical Section Sheet at the point where it is carried relative to superelevation.

Use supplemental typical sections to show variations in special ditches, clearing widths, rock cuts, etc. Also use supplemental typical sections to detail curbs, median treatments, slope protection, channel changes, etc. Place these supplemental typical sections on the Typical Section Sheet or on a following sheet. List the stations where the typical sections apply. Place a note on the Plan and Profile Sheet describing the site-specific work and referencing the appropriate typical section. On abbreviated plans, supplemental typical sections may be placed on the plan sheet at the locations where the work is proposed.

9.6.5.3.3 Summary of Quantities

The Summary of Quantities tabulates, combines, and summarizes quantities of the various construction items. This summary informs prospective bidders where to locate work within the plan sheets, the basis of plan and bid schedule quantities, and expands on contract bid schedule information. It also serves as a checklist to the designer to ensure that all elements of the design receive consideration.

This is generally one of the last plan sheets prepared in final form. All the pay items are listed in numerical order and identified by appropriate descriptions using the engineer's estimate program. The bid schedule quantities duplicate those in the contract. Items of work paid for under the contract quantity provision of Section 109 should be identified when preparing the engineer's estimate.

In the preparation of the Summary of Quantities Sheet or the Tabulation of Quantities Sheets, always spell out the pay unit the way it is shown in the FLH master pay item list. Symbols for pay units are expressed without periods (e.g., ft [m], sqft [m2], cuyd [m3], lb [kg], etc). Conform with the information shown on the Plan Symbols and Abbreviations Sheet for consistency of plans.

9.6.5.3.4 Tabulation of Quantities

A Tabulation of Quantities Sheet consists of a detailed summary of an item of work or several items of work usually presented in a tabular or table format. It provides bidders with more detailed information on the location and extent of the work required than can be shown on the Summary of Quantities Sheet. Ensure that all references to quantities, bid item names and numbers are consistent with the summary of quantities and bid schedule. The following provides a description of typical Tabulation of Quantities Sheets:

1. **Drainage Tabulation**. The Tabulation of Drainage Quantities Sheet lists all culvert and related drainage data. Show the location of the drainage installation under the station heading. Show related data in the row across the sheet under an appropriate column heading. Total the figures in the various columns to obtain the quantities shown on the Summary of Quantities Sheet for the appropriate culvert item.

The Tabulation of Drainage Quantities Sheet may be developed using a spreadsheet format. The designer may modify the sheet layout to address specific project requirements.

Where maximum cover is the controlling factor in acceptable culvert pipe selection, provide this information on the plans. Where environmental factors control acceptable culvert pipe selection, provide this information. The primary purpose of the Summary of Drainage Quantities Sheet is to present all available options for potential bidders to evaluate in preparing their estimate for the project.

Where maximum cover is the controlling factor on acceptable culvert pipe, the designer has the option of specifying the thickness, class or type of culvert on the summary or simply tabulating the controlling information and having the contractor or supplier determine the thickness, class or type.

2. **Other Tabulations**. A Tabulation of Quantities Sheet should be referenced to the location or description of the work in the plans. Use a separate plan sheet for the tables or place the tables on the same sheet as the details for the work. Separate sheets are required when the tabulation is supported by work detailed on FLH standards or Division standard details.

   Consider placing a tabulation of pavement structure quantities table referenced to the Typical Section Sheet in groups of the required work that is easy to comprehend and check.

   Tabulation of quantity tables referenced to the Plan and Profile Sheets for items of work (e.g., removal of individual trees, roadway obliteration, roadway excavation, turf establishment) aids the bidders in precisely locating the work areas and determining the effort required to perform the work. Tabulations for items of work (e.g., guardrail, fences) may be referenced to the Plan and Profile Sheets or the Special and *Standard Drawings* detailing the installation of those work items.

   A sheet tabulating all the items required, that can be referenced to the detail sheets for a major parking area, a roadside development area, a scenic overlook or other special work may assist bidders as well as internal checking. This also applies to traffic control plans, signing plans, landscaping plans and other work.

9.6.5.3.5 Plan and Profile

Prepare plan and profile sheets at a scale that is adequate to show the necessary details as governed by the topography and the complexity of the work. Profiles have the same horizontal scale as the plan, but the vertical scale should have an exaggeration of 5 or 10 times the horizontal scale.

Plans should have a horizontal scale of 1:600, 1:1200 or 1:2400 [1:500, 1:1000 or 1:2000] when prepared on the standard sheet size. Larger or smaller scales can be used depending on the amount of detail to be shown.

When laying out Plan and Profile Sheets, avoid dividing major structures, highway intersections, interchanges or grade separations between sheets. Increasing stationing should run from left to right. Typically roadway stationing increases from south to north and from west to east. If the direction of mileposts or road inventory data conflict with this, use the milepost or road inventory direction.

Leave about 10 in [250 mm] or more of blank space before the beginning of the project on the first Plan and Profile Sheet and a similar blank space after the end of project on the final Plan and Profile Sheet. Except for the first and last sheet, attempt to place a consistent station range on each sheet and always break sheets at even station numbers.

Show a prominent North arrow for orientation on each sheet.

Show all boundary lines, State, county, city, township and section lines. Show ties to section corners that fall off the sheet by breaking the line and showing the corner with the tie distance. Describe found corners and show their coordinates. At the bottom of the plan portion of the sheet, show township, range and meridian. Streams, lakes, swamps, estuaries, etc., must also be shown.

Show the station and coordinates of the beginning of the project and the end of the project on the first and final Plan and Profile Sheets, as appropriate. Identify them as State grid or other system.

On the plans, show the elevation datum used for the project.

Show the designed centerline prominently and comply with the following, as applicable:

- If the designed line (L line) is not staked, and a preliminary control line (P line) is staked, show as a light line. Label the P line as “P Line as staked” and the L line as “Line to be constructed.” Where the preliminary control line consists of a series of survey control points to be used by the contractor during the construction staking operation, label the control points by number and show the coordinates and elevation either on the plans or on a separate tabulation sheet.
- If the L line is staked, do not show a P line on the Plan and Profile Sheets. Where control points are provided for the contractor’s staking operation, label the control points by number and list the coordinates and elevations either on the plans or on a separate tabulation sheet.
- If an L line is visibly staked at the time of bidding, but another line is designated in the plans for construction, make the staked line dashed and label it as “Line as staked” and make the other line solid and label it as “Line to be constructed.”

On all sheets, show the cut and fill slope limits, construction limits (when applicable), access control lines, easements and right-of-way lines. Within the right-of-way, show all cultural features affecting construction or requiring relocation (e.g., utilities, fences). Identify all ownerships for right-of-way purposes. Show all existing and proposed drainage structures. Show any cultural features adjacent to the right-of-way that may be affected by the project.

Curve data consisting of delta angle, radius of curve, tangent length, length of curve and superelevation should be shown. Curve widening may also be shown at this location. For spiral transitions, the spiral angle and length of spiral should be shown. Identify every 100 ft [100 m] station along the centerline. Bearings or azimuths of all tangents should be shown.

Show the location of borings, test pits or other sites where subsurface investigations have been made on the plan portion of the Plan and Profile Sheet, or on special plan detail sheets, as applicable. Do not show actual boring log or test results on the plan-profile. Use separate plan sheets for this data, if applicable, or reference the materials investigation reports.

On the profile portion of the Plan and Profile Sheets show the profile grade and existing ground lines. Show gradients on the profile to at least three, preferably four decimal places, grade elevations to three decimal places and natural ground points to two decimal places.

Show vertical and horizontal clearances for railroads, highways and streambeds under proposed and existing structures.

Identify and show type and clearance, if known, under and over utility lines within the right-of-way.

In addition to profile data, the quantity and limits of the following items may be shown by arrow diagram at the bottom of the Plan and Profile Sheet.

- Turf establishment;
- Clearing and grubbing;
- Embankment, where it occurs;
- Roadway excavation, where it occurs; and
- Earthwork balance points.

At the top of the profile portion of the sheet, the designer may show information (e.g., curbs, fences, guardrail) at the proper stations and identify them appropriately. These items may show instead on separate sheets using tables, tabulations or other appropriate formats.

Show profiles of connecting roads, waterlines, road approaches, etc., on the Plan and Profile Sheet. Offset their location on the plan if they obscure the main profile or show them on a separate plan sheet.

Show bridges and major structures to be constructed on the Plan and Profile Sheet in outline only, with a note to see the appropriate drawings.

Show irrigation facilities requiring minimum service interruptions during construction of the project.

Show all culverts on the Plan and Profile Sheets.

Abbreviated plans are acceptable on rehabilitation type work, emergency relief work or other types of work where Plan and Profile Sheets would not clarify the required construction.

The work areas can be identified along the route by stations, mile [km] posts, and etc., with a written description of the work to be performed at each site.

The description is used to identify work details, specify quantities, and reference applicable Special Details, Standard Drawings, or Division Standard Details elsewhere in the plans. The information may be placed in a tabular format or may be included as descriptive text at the specific work locations as shown on a straight-line diagram or graph. Any plan format that is clear, concise and adequately details the work is generally acceptable.

9.6.5.3.6 Bridge Plans

The Structural Design Unit designs most bridges and other large structures. The designer will usually receive a complete set of bridge plans and accompanying draft Special Contract Requirements for insertion into the PS&E assembly. The bridge plans and roadway plan-profile sheets, and other plan sheets, must be crosschecked for compatibility and to ensure that stationing, gradients, elevations and other geometric details are identical. The notes on the bridge plans and the draft Special Contract Requirements must be reviewed and checked to eliminate any potential conflict with other provisions of the contract. Transfer quantities on the bridge plans to the summary sheet and assign item numbers as appropriate. Resolve any differences found during the review and number the bridge plans for insertion into the final package.

9.6.5.3.7 Cross Section Plans

When cross section plans are included in the contract plan assembly, show sufficient information on each of the sections to accurately determine the extent of the proposed work. Use a scale that is appropriate for the work.

9.6.5.3.8 Temporary Traffic Control Plans

A Temporary Traffic Control Plan is required for all projects. Also refer to Section 9.6.6.2.4 for development of a Transportation Management Plan.

The plan sheets for the Temporary Traffic Control Plan are applicable FLH Standard Drawings, or Division Standard Details, or project-specific Special Details, or combination thereof, that graphically portray all temporary traffic controls required to assure safe travel through the project construction zone. Such temporary traffic controls include provisions for pedestrians (including those with disabilities), bicyclists, and motor vehicles. All pay items related to temporary traffic control may be tabulated on this Sheet or have a separate tabulation sheet.

Temporary Traffic Control Plans may range from simple line diagrams for low-volume rural roads to complex plan sheets detailing every stage of the project work on high-volume urban highways. Guidance on Temporary Traffic Control Plans is provided in the *MUTCD*. Also refer to *Green Book* Section 3.6.6.

9.6.5.3.9 Permanent Signing and Marking Plans

When applicable, show permanent signing, pavement markings, delineation and other permanent traffic control devices on separate plan sheet details for clarity and ease of use. Refer to Section 8.7.1 for additional guidance on preparation of signing and marking plans. Adhere to guidance on permanent signing and marking that is provided in the *MUTCD*.

9.6.5.3.10 Erosion and Sediment Control Plans

The plan sheets for the erosion and sediment control plan may include Special Drawings, or Division Details, or both, that detail the measures required to protect resources and to comply with permit stipulations. The plan sheet details should reflect Best Management Practices (BMP); comply with *Erosion and Sediment Control on Highway Construction Projects*, 23 CFR 650 Subpart B; and be in agreement with the stipulations in the National Pollutant Discharge Elimination System (NPDES) permit.

9.6.5.3.11 Landscaping and Revegetation Plans

When applicable, show permanent landscaping features on separate plan sheet details for clarity and ease of use. As applicable, include the following details:

- Removal or salvage of plan materials,
- Site plan and layout of landscaping and vegetative items, plant list with quantities and symbology,
- Grading plan showing existing and proposed contours, applicable spot elevations,
- Special grading details and typical slope treatments, and
- Planting details showing typical plant installation details, irrigation details, etc.

9.6.5.3.12 Environmental Mitigation

Commitments for environmental mitigation features that are contained in the environmental documentation should be detailed as necessary and included in the project plans as Special Details, or Division Details, or both.

Plan sheets for wetland replacement or mitigation are Special Drawings that detail all work required to ensure successful mitigation. These may range from simple sketches to elaborate contour grading and planting plans to conform to the commitments in the environmental document. Pay items may be tabulated on these sheets or on separate sheets.

9.6.5.3.13 Major Drainage Facilities Plans

Plan sheets under this subject area would include details of large culvert installations conforming to the requirements listed in Section 7.3.1. Headwalls, inlet and outlet treatments, fish passage requirements, energy dissipators, catch basins, manholes and other drainage installation can also be detailed under this subject area. The drainage plan sheets should be numbered and placed in the plans in logical order as appropriate.

9.6.5.3.14 Material Source Reclamation Plans

FLH standard practice is that government designated material sources require rehabilitation under an approved reclamation plan, and applicable environmental documentation as described in Section 3.5.

The reclamation plan must set forth measures to return the land to the most appropriate function following use of the source. The site may be reclaimed in a series of stage reclamation efforts when several projects designate the same source. Side borrow sites within the right-of-way do not require a reclamation plan.

The reclamation plan provides that reclamation measures, particularly those relating to control of erosion, be conducted simultaneously with surface mining. When this is not possible, initiate reclamation measures at the earliest possible time after completion or abandonment of mining on any segment of the site area.

As applicable, the reclamation plan should include the following:

- A vicinity map describing site boundaries as shown on the right-of-way or sundry site boundaries and enough information to locate the site on quadrangle or county maps.
- Existing water forms and ground contours. Existing contours are optional unless the design or permit process requires them.
- Proposed finished ground contours and cross sections needed to show finished slopes.
- Statement of the proposed subsequent use of the land. Include any local zoning and planning requirements, any indications of whether the site is intended for use by other contractors or maintenance forces in the future and whether or not stage reclamation applies. For stage plans, provide interim reclamation measures that ensure an orderly depletion and restoration of the site. Scheduled staged use to reclaim the largest possible surface area under the final reclamation plan.
- Manner and type of revegetation and other surface treatment of disturbed areas.
- Preservation or establishment of visual screening and vegetative cover to screen the view of the operation from public highways, public parks and residential areas.
- Proposed practices to protect adjacent surface resources. This includes prevention of slumping or landslides on adjacent lands.
- Slopes that are blended with adjacent terrain to meet future use requirements. In all cases, provide for adequate safety.
- Method of preventing or eliminating conditions that create a public nuisance, endanger public safety, damage property or are hazardous to vegetative, animal, fish or human life in or adjacent to the area.
- Method of controlling contaminants and disposing of surface mining refuse.

- Method of diverting surface waters around the disturbed areas.
- Method of restoring stream channels and stream banks to a condition minimizing erosion, siltation and other pollution.
- Planned lakes, ponds or other bodies of water that would be beneficial for residential, recreational, game or wildlife purposes.
- Restoration of any borrow, quarry or pit site. Sites resulting in a lake or wetland involve careful planning and must take into consideration all factors impacting the fauna and flora.
- Proposed stockpiles of 11,000 tons [10,000 metric tons] or more.
- Permanent buildings and any protective stipulations required.
- Photographs whenever possible.

The FLH Division will cooperate with other governmental and private agencies to provide land reclamation of the sites used for the described purposes.

Reclamation plans for sources located on Federal Lands require coordination with and approval by the agency responsible for administration of the land in accordance with the appropriate Memorandum of Understanding.

Reclamation plans for sources on private lands usually require coordination and approval by a State agency, or local agency if applicable, with responsibility for issuing and administering material removal operating permits.

9.6.5.3.15 Right-of-Way and Utility Plans

On occasion, right-of-way plans or utility plans may be too complicated to incorporate on the Plan and Profile Sheets, and may be prepared as a separate plans set with only the pertinent information (e.g., ownerships, existing and proposed right-of-way lines) shown on the roadway plans. Refer to Chapter 12 for guidance on preparation of right-of-way plans.

9.6.5.3.16 Contiguous Projects

A general plan or layout of contiguous construction projects may be beneficial to potential bidders in determining the cost of work on FLH projects. This is particularly true where another agency is constructing a project that will affect FLH contractors. It is essential that the relationship between the projects be well detailed on the plans.

There are instances where as-built plans should be included in the contract plan package. If a bridge or other structure is scheduled for salvage, a set of the as-built plans will greatly assist a contractor in determining the most effective method to disassemble the structure.

9.6.5.4 FLH Standard Drawings, Division Standard Details and Special Details

Arrange the FLH Standard Drawings, Division Details and project-specific Special Details in an order that best clarifies the work to be accomplished.

9.6.5.4.1 FLH Standard Drawings

The Office of Federal Lands Highway (FLHO) issues Standard Drawings for use in the Federal Lands Highway programs. Standard Drawings, together with the Specifications, contain all appropriate information that is necessary to describe the details of the proposed work. The FLHO maintains the Standard Drawings and supersedes or withdraws those drawings that become obsolete or ineffective.

FLH Standard Drawings cover various design elements that have been approved by FLHO for use on a nationwide basis. FLH Standard Drawings have a fixed format and each drawing has its own unique identification number. FLH Standard Drawings are usually incorporated into the contract plan assembly and not issued as a separate booklet.

The Functional Discipline Teams periodically review FLH Standard Drawings and Division Standard Details for consistency with FLH Standard Specifications and with FLH policies, and industry best practices.

A FLH Functional Discipline Team or FLHO may propose new FLH Standard Drawings or revisions to existing FLH Standard Drawings at any time. Functional Discipline Teams submit their proposals for consideration as summarized below. When it is determined that FLH Standard Drawings should be developed, adopted or revised, the FLHO or Functional Discipline Teams will agree upon a responsible Functional Discipline Team to perform the preparatory work.

The responsible Functional Discipline Team will develop or modify FLH Standard Drawings on the CADD system. The responsible Functional Discipline Team will then submit proposed new or revised FLH Standard Drawings to the FLHO. Any Special Contract Requirements for the FLH Standard Drawings should accompany the distribution. Normally, the submission to the FLHO should be in electronic format. The responsible Functional Discipline Team will coordinate the review and comment of proposed FLH Standard Drawings with the other Functional Discipline Teams and the FLH Divisions.

The following process shall be used for approval of proposed new FLH Standard Drawings and revisions to approved FLH Standard Drawings:

- On behalf of the FLHO the responsible Functional Discipline Team will make distribution of the proposed new or revised FLH Standard Drawings to the Headquarters and Division offices and others as appropriate, with a request for comments.
- The responsible Functional Discipline Team will consolidate and review the comments received and make the appropriate revisions, with coordination of the other Functional Discipline Teams and the FLH Divisions.

Upon disposition of comments, the responsible Functional Discipline Team will resubmit the Standard Drawings to the FLHO. The submissions should include a summary of the disposition of comments. If needed, additional distributions will be made by the FLHO in accordance with these procedures. If additional distributions are not required, approval will be given to the responsible Functional Discipline Team to finalize and date the title block of the FLH Standard Drawings. The approval date or revision date to be included on FLH Standard Drawings will be provided with FLHO approval.

The responsible Functional Discipline Team will distribute electronic versions of the CADD files to each Division. The files will also be posted in a centralized location for use by all offices and industry.

The FHLO will distribute a complete list of the FLH Standard Drawings with the latest approval or revision dates with the approval memorandum noted above. Each Division shall ensure that links to the latest approved FLH Standard Drawings are provided in their CADD files.

In FLH Standard Drawings, the lettering will be sentence-case italicized True Type Verdana excluding titles and subtitles that will be vertical. Standard letter size will be 0.08 in [2 mm]. Minimum letter size will be 0.05 in [1.25 mm]. Use minimum letter size sparingly to ensure clear and readable plans at the scales proposed for standard size plans and letter sized abbreviated plans. Additional information is available in Division Supplements.

9.6.5.4.2 Division Standard Details

These drawings are used on a repetitive basis within each Division. They should be placed in the plans as applicable to clarify the work required.

Each Division will provide links to their current Standard Details in their CADD files.

9.6.5.4.3 Special Details

Special Details are project specific details necessary to properly describe the work. Special Details include plan sheets detailing grade crossings, turnouts, retaining walls, dikes and ponds, waste or borrow areas, stage construction plans, permanent striping and signing plans, road approaches, material source locations and other work.

When a Division office must modify Standard Drawings or Division Standard Details for specific projects, they become special details and they no longer have typical standard drawing title blocks. To prevent confusion, title blocks for special details must be clearly distinguishable from the Standard Drawing title blocks.

Standard plans prepared by a State DOT or other outside agencies that are incorporated into the contract should be treated as Special Details for insertion into the plans package.

A FLH Special Details Database is maintained, which may be helpful for development and sharing of project-specific special plan details and the associated specifications and unit costs.

9.6.6 SUPPORTING INFORMATION

Supporting information includes all information that documents the development of the geometric design, the preparation of the PS&E, and design information needed for layout and control of the construction work, and to support the construction management.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.6.1 Computation of Quantities

Determine the contract items and appropriate pay units needed for the work. All computations for estimating quantities are a part of the supporting data. Keep the computations in support of a contract item together and the items listed in numerical sequence.

Clearly distinguish and define any estimated quantities that are computed and shown for information only, to be included in other items of work and not measured or paid for separately.

Some work may not be paid for directly, e.g., small quantities that would be difficult or uneconomical to measure. Limit the no-payment work to types of work that can be clearly differentiated from pay items, or that can be clearly described and are not ambiguous for inclusion under the contract as incidental to the bid items, and clearly define it on the plans and in the Special Contract Requirements (SCRs) so that bidders can adequately include it in their cost estimates under other contract items.

A lump-sum item can is used where the work required consists of a number of inter-related, small quantity items to obtain a specified end result or the work can be described in complete detail in the SCRs. Identify the breakdown of the work required when a number of items are included in the lump-sum item.

When several methods may be used to measure the work, coordinate early with the Construction Unit to verify the most appropriate method to estimate, measure and pay for the work.

Follow the requirements of the Standard Specifications, *FP-XX*, as amended by the project SCRs, for the method of measurement and basis of payment used in the computation of design quantities. Coordinate with the Materials Unit and the Construction Unit for guidance in selecting the appropriate pay items, application rates, unit weights, and other design assumptions for quantity computations.

9.6.6.2 Design Documentation

In addition to the PS&E preparation, provide all required additional information supporting the development of the geometric design and PS&E. The following sections provide applicable guidance for the design documentation.

9.6.6.2.1 Design Files

As applicable, provide the following general information that should be contained in the project design files, which may not be described specifically in the other sections below:

- Pertinent correspondence, reports, memoranda, project agreement, emails, etc., relating to the development of the design and related design considerations;
- Design technical information regarding design criteria and design decisions;
- Highway Design Standards Form (Section 9.1.3);
- Environmental document and commitments pertaining to the highway design;
- Pertinent right-of-way documentation, agreements, certification;
- Utility agreements;
- Pertinent technical reports and recommendations from other disciplines;
- CADD files and summary documentation for archival and retrieval;
- Calculations for design quantities, properly organized and checked; and
- Review comments and documentation regarding their disposition.

9.6.6.2.2 Design Exhibits

As applicable, develop exhibits for use at design reviews, stakeholder meetings, public meetings, etc. Such exhibits should be designed and formatted for presentation to a non-technical audience, and should enable clear understanding of the design concepts and features and should foster interactive communication and constructive feedback from those viewing the exhibits.

For additional guidance on developing and utilizing design exhibits refer to the FHWA report: *Public Involvement Techniques for Transportation Decision-Making*.

9.6.6.2.3 Visualization and 3D Modeling

As applicable, the latest visualization technology should be used to facilitate communication and understanding of project design goals and solutions with stakeholders and the general public. Computer three-dimensional (3D) modeling and imaging should be used to depict and evaluate the design aspects in addition to the traditional orthogonal views of plan, profile and cross-sections. Visualization and electronic media and graphics presentations should be used to assist designers, as well as the interdisciplinary project team, stakeholders and the public to better comprehend, evaluate and communicate complex roadway design features than by using traditional two-dimensional (2D) roadway drawings.

In addition to using modeling and imaging presentations that depict how the proposed facility will appear within the existing conditions, consider using dynamic, real-time techniques to simulate and analyze the operational characteristics of the facility.

The FHWA Visualization in Planning site and TRB Visualization in Transportation Site provides information on visualization techniques and their applications for highway projects. Also refer to the FLH Visualization Guide.

9.6.6.2.4 Transportation Management Plan

The Work Zone Safety and Mobility Rule requires consideration of the safety and mobility impacts of work zones during project development, and the implementation of a Transportation Management Plan (TMP) to manage these impacts during project delivery. The TMP includes development of a plan for Temporary Traffic Control (TTC) measures and devices, applicable public information and outreach, and operational strategies. The scope, content, and level of detail of the TMP varies based on the anticipated work zone impacts of the project. Refer to Section 9.6.5.3.8 for preparation of TTC plans.

As applicable, prepare transportation management plans and reports that are required and the responsibility of the FLH or the client agency. The transportation management plans and reports may precede or may be in addition to the PS&E, and may be required for submittal to State DOTs or local governments, community relations, public information efforts, etc.

9.6.6.3 Permits

As applicable, include all permit requirements into the design and PS&E documents. The specific permits and their requirements may be included within the special contract requirements for direct incorporation within the contract documents, as applicable. Refer to Section 3.3.3 for guidance on commonly required permits.

9.6.6.4 Design Data for Construction Engineering

Document and provide all necessary design and related information that will be made available to the prospective bidders during the advertisement period, and to the contractor after award. Such information may include materials reports, geotechnical reports, earthwork reports, permits, specifications that are referenced but not directly shown within the solicitation documents, and traffic management plans.

For projects with retaining wall systems that require engineering by the construction contractor, the information that may be needed by prospective bidders or the construction contractor includes the subsurface investigation, structural requirements and geotechnical design data. The data should include:

- Shear strength and consolidation properties of foundations materials,
- Shear strength and unit weight of backfill,
- Design life (minimum service life) – typically 75 years,
- Safety factors for overturning, sliding and stability of temporary slopes,
- Allowable foundation bearing pressure and minimum embedment depths,
- Maximum tolerable differential settlement,
- MSE internal design requirements,
- External loads,

- Drainage requirements,
- Backfill requirements, and
- Facing requirements.

9.6.6.5 Stakeout Data and Construction Controls

As applicable, provide information necessary for survey, stakeout and field control of construction work. This may include supplemental engineering data not provided on the plans such as survey data, coordinate geometry data, structural data, slope stake and grade finishing notes, clearing and seeding reports, superelevation reports, design cross section data, and other design information. Provide sufficient copies for the design file, the construction project management engineer, and the construction contractor both in hard copy and electronic format, as applicable.

When converting cross-section based roadway designs to 3D design surface models for construction control, provide the intended level of precision. The model precision is affected by the length of chords (breaklines) connecting like points between cross sections, and the resultant offset from the chords to curved design elements. Deviations to the chord offsets should be well within the staking tolerances for construction survey listed in Table 152-1 of the FP, such that any deformations in the 3D surface model are negligible and have no discernable effect on the intended roadway geometry. For construction control, the 3D design surface model should use sections (pattern lines) spaced at 10 ft [2.5 m] maximum intervals, and at superelevation transitions, roadway widening, special ditch transitions, and inlet catch basins where culverts are designed in cuts. In sharp horizontal or vertical curves, closer spaced sections should be used. A 3D design surface model should be prepared for major public road approaches similar as for the mainline. Minor road approaches and other minor features built with standard drawings or typical details need not be modeled. All limitations in the 3D design model data should be described in the special contract requirements.

9.6.6.6 Information for the Construction Branch

As applicable, provide pertinent design information to the construction project engineer, including the following:

- Design special considerations narrative;
- PE package and hold file;
- Quantity support calculations and related drawings;
- Environmental commitments, including those that are not performed by or the responsibility of the contractor;
- Agreements;
- Permits;
- Pertinent correspondence and reports;
- Pertinent meeting minutes and design field trip reports;

- Technical discipline reports applicable to construction; and
- Survey and stakeout information.

9.6.7 CONSTRUCTION SCHEDULE AND CONTRACT TIME

Determine the anticipated construction schedule including reasonable times for completion of construction activities and total contract time. Factors that determine contract time include materials, equipment, manpower, costs and constraints (i.e., weather, regulations, traffic, utilities, user convenience).

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.8 ENGINEER'S ESTIMATE

Prepare an engineer's estimate of cost for each project as part of the PS&E development associated with each stage of the project's design process. The estimate should become more detailed and complete at each subsequent stage. For each estimate type, document the estimate basis, assumptions, calculations, and uncertainties, as described in the following sections. In addition to the estimated unit costs and total cost for construction, the engineer's estimate includes, as separate line items, the estimated costs for preliminary engineering, construction engineering, right-of-way acquisition, utility relocation and other anticipated contingencies.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.8.1 Preliminary Engineering Cost Estimate

Design engineering costs can be based on a percentage of the construction cost estimate, for various types of projects and design activities. More detailed cost estimates are based on the estimated labor hours and direct costs to perform each activity of the preliminary engineering work, or may be based roughly on the estimated number of plan sheets.

9.6.8.2 Construction Engineering Cost Estimate

Construction engineering (inspection and construction management) costs can be based on a percentage of the construction cost estimate, for various types of projects and construction activities. More detailed cost estimates are based on estimated equipment (office trailer, laboratory trailer, vehicles, inspection equipment, etc.) and labor hours and direct costs to perform the construction engineering work.

9.6.8.3 Right-of-way Acquisition and Utility Relocation Cost Estimate

Estimated costs can be based on consideration of the number of parcels, acreages, appraisal costs, right-of-way considerations, and the type and extent of individual utility adjustments. Refer to Chapter 12 for guidance and detail on estimating these costs.

9.6.8.4 Construction Cost Estimates

For each type of construction cost estimate, document the supporting calculations thoroughly and appropriately, as described in the following sections.

9.6.8.4.1 Class C Construction Cost Estimate

A Class C construction cost estimate is based on cost per mile of similar scope construction work, and adjusted for estimated rate of inflation and local conditions. It is normally developed for planning, programming, and conceptual studies.

9.6.8.4.2 Class B Construction Cost Estimate

A Class B construction estimate is based on the estimated quantities and unit costs for the major high cost categories of work, and either cost per mile or percentage of total construction costs for minor categories of work. It should be developed in the preliminary design (15 and 30 percent) phase and updated at the intermediate design (50 percent) phase of design detail. Consider the following major items for development of estimated quantities and unit costs:

- Clearing and grubbing per acre [hectare],
- Roadway excavation per cubic yard [cubic meter],
- Minor drainage per mile [kilometer],
- Aggregate base, subbase or surfacing per ton [metric ton],
- Asphalt or concrete paving items (type) per ton [metric ton],
- Major structures, including any bridges and retaining walls, per square yard [square meter], and
- Large culverts per each.

Miscellaneous minor items may be grouped into categories as a lump sum or percentage of the total construction (include mobilization, construction survey and staking, temporary traffic control, guardrail, signing, striping, erosion and sediment control, fences, revegetation, landscaping, etc.) based on historical data of similar projects.

9.6.8.4.3 Class A Construction Cost Estimate

The Class A construction cost estimate (Engineer's Estimate) is a listing of all items of work in the contract, showing quantity, unit of measurement, unit cost and total cost of each. The total amount of all items of work, including appropriate incentive payments, makes up the construction estimate. Contingencies, construction engineering, project agreement costs and other costs added to the construction estimate makes up the program amount. A Class A construction cost estimate should be provided for the plan-in-hand (70 percent) design phase, and the unit prices verified and updated for the final (95 percent) design phase.

When a contract is financed by multiple funds, and expenditure of a fund is limited to a particular section, a separate estimate, summary sheet and bid schedule are necessary for each section. When a contract is financed by more than one type of fund, but expenditures are not limited to a particular section, only one bid schedule is necessary, supported by a combined estimate and summary sheet.

For the plan-in-hand (70 percent) phase of development, typically a 5 percent contingency should be added to the overall construction cost estimate. For final (95 percent) phase of development all pay items, quantities, and any pay items incentives should be known and specified, and no separate contingency amount is included for the final estimate. An allowance may be included within the tabulations of individual bid item quantities listed on the plans to address approximated quantities potentially needed to fit the project site conditions.

Retain confidentiality of the unit price analysis and construction cost estimate at all times to maintain the integrity of the bidding and procurement process.

9.6.8.5 Development and Update of Prices

FLH standard practice for developing and updating estimated prices for construction includes the following:

- Develop unit prices that consider the location, timing and characteristics of the work to be performed.
- Estimated unit prices may be based on historical data (i.e., bid prices for previous contracts), or on actual costs, or both.
- For major items of work identify and analyze the primary factors and risks affecting the cost of the work (e.g., local labor rates, equipment rates, unusually small or large quantities, transportation distances, interest rates, time allowance, competition levels, material shortages).
- Document the methods and assumptions used to establish each unit price, including the primary unknowns and risks that are taken into consideration.
- Perform periodic reviews of the unit prices and construction cost estimate during the design process, at each major project development phase, to confirm it is accurate and fully reflects the project scope and current market conditions.
- Before communicating unit prices or a construction cost estimate to program partners, confirm that the unit price analysis is current, and update if necessary.

Unit prices for the engineer's estimate should reflect the actual cost to the contractor of doing business, including a reasonable profit. Consider the two common methods to determine this cost; historical costs (bid-based estimating) and actual costs (cost-based estimating). With either method, the designer should strive to predict the expected overall low bid, and develop unit prices that will at least equal, or slightly exceed this amount. Develop unit prices for each defined pay item using either historic bid data that is factored for the project conditions, or cost-based pricing (using costs for equipment, labor, material, and production rates applicable for the project conditions), or use both methods for comparison, as appropriate for each pay item.

1. **Bid-Based Estimating**. Use historical bid data as a basis for estimating current costs. Consider the bids received for like items on recent (within the past two to five years), representative projects built under similar conditions that fairly represent the contractor's cost plus a reasonable profit. Consider the average of the low bids received on previous projects in similar locations, factored for project conditions and cost indices, as a basis for the anticipated minimum overall cost for current projects. However, do not use solely the lowest bids for analysis of historic unit prices, due to the variability in bids and costs for the individual bid items.

   Consider that the lowest bid for a project may not represent a consistent distribution of costs among the bid items, and that the low-bidder's prices on each individual item may not represent the lowest or most reasonable cost for every item. Therefore, it is recommended to use the average of the unit prices from the lowest three bidders to verify that the low-bid unit price is reasonable and consistent. Use the lowest three bidder's prices from representative past projects, and modify them to fit the conditions on the project, and adjust for increases in the overall cost of construction over time using an inflation index. Consider factors that may have a direct bearing on the historical bid prices in relation to the current project, including the following:

   - Availability of construction material,
   - Proximity of access roads and railroads,
   - Distance from towns and travel speed,
   - Timing of construction,
   - Inflation indices, and
   - Amounts of quantities.

   The historical bid price approach, tempered with engineering judgment, is recommended for estimating the minor items of work on a project. For major items of work, it is recommended to also consider the cost-based estimating approach, in addition to the bid-based estimating approach, to verify the unit price analysis is reasonable.

2. **Cost-Based Estimating**. Consider the cost-based approach for some items of work, especially major items such as roadway excavation, base and plant mix material, bridge material, etc. The actual costs to construct these items should be analyzed to ensure that all factors that bear on the cost of the item receive consideration. Use current labor, equipment and materials costs, production rates, as well as overhead and profit to develop cost-based unit prices.

When updating costs used in the engineer's estimates, consider the effects of inflation on pay items, wage rates, equipment rates and material costs. Use current inflation trends in highway construction prices. Several cost inflation indexes are available to track short and long-term construction pricing trends, including:

- FHWA *Price Trends in Federal-Aid Highway Construction Projects*
- American Road and Transportation Builders Association (ARTBA) Price Index
- State DOT Price Indices

When updating historic bid prices or other cost data, use an inflation time period that begins at the year and month the historic bid or cost data originates from, and ends in the year and month of the proposed project's anticipated construction completion.

9.6.8.6 Assessment of Cost Estimate Uncertainties and Risks

For each estimate type, identify and assess the potential price uncertainties and risk factors associated with the estimate. Use an interdisciplinary approach to identify project cost risks and uncertainties early, and evaluate these identified risks to establish cost ranges and appropriate contingencies. Anticipate potential external cost influences and incorporate them into the overall assessment.

After the proposed quantities, unit prices and estimated costs are determined; determine a project cost range and probability. Evaluate the potential risks for deviations in the construction quantities, as well as their unit costs. Consider cost impacts of potential project risks such as:

- Limited number of available or qualified contractors to perform the type of work,
- Changes in construction market conditions or competing work opportunities,
- Changes in labor or materials availability,
- Uncertainties in costs for construction materials supplied to the project,
- Uncertainties in site conditions, in-situ materials, utilities, weather, stream flows,
- Changes in traffic conditions and traffic maintenance requirements,
- Changes in construction time restrictions, access, or hauling limitations,
- Delays in construction permitting,
- Delays in funding availability,
- Delays in right-of-way acquisition, PS&E completion, or contract award.

Describe the type of estimate, its key assumptions, and its uncertainties, whenever a cost estimate is communicated. When communicating prices or a construction cost estimate for programming purposes, also convey the extent of cost unknowns, risks and variability that should be considered with the estimate amount.

9.6.9 SPECIFICATIONS

Prepare all necessary Special Contract Requirements relating to an individual project to describe the work with clarity and precision in a clear logical format. FLH standard practice is to follow the format and guidelines described in the FLH *Specification Writer's Guide*.

The *FLH Specifications Procedures* provides information primarily for FLH internal use in developing new specifications and coordinating them with the plans and estimate; and FLH procedures for specification review and evaluation.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.10 CONTRACT ASSEMBLY

A standard contract assembly or solicitation package consists of several main parts:

1. **Solicitation, Offer and Award (SF 1442)**. This contract form, after being signed by the contractor and contracting officer, consummates the contract and makes it legal and binding on all parties.
2. **Solicitation Provisions**. The *Federal Acquisition Regulations* (FAR) define the scope of the contract and sets forth bidding requirements.
3. **Bid Schedule**. A list of all pay items in the contract to be completed by bidders with their offered bid prices for the work. The bid schedule is prepared from data obtained from the engineer's estimate.
4. **Contract Construction Clauses**. FAR clauses regulating and controlling contractor construction activities.
5. **Labor Standard Clauses**. All laborers and mechanics working on the project are covered by Federal regulations (i.e., *Davis-Bacon Act*), that includes a minimum wage schedule.
6. **Special Contract Requirements**. The amendments and supplements to the Standard Specifications necessary for the construction of the project.
7. **Plans and Drawings**. The plans and drawings necessary to detail and identify the work. These also include FLH Standard Drawings, Division Standard Details, and Special Details that may be applicable.

The Federal Lands Highway offices use these seven subdivisions in their contract solicitations (advertised or negotiated). The solicitation generally contains all the necessary forms and contract documents that a bidder needs to make the Government an offer for the construction of the highway facility.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.11 QUALITY CONTROL AND QUALITY ASSURANCE

Ensure that all design work is performed in accordance with an approved quality control and quality assurance (QA/QC) plan, and provide documentation of the completed QA/QC activities related to design. Refer to Division Supplements for specific FLH Division requirements. The established QA/QC process may be supplemented by a project-specific quality plan described in Section 9.6.11.1, as applicable. For design work performed by A/E consultant, the A/E firm should have an established process for the formulation, implementation, and administration of their firm's QA/QC program, but which may need to be supplemented to meet the FLH quality requirements of the project.

The design QA/QC plan should include the following general components:

- A project-specific quality plan that designates individual responsibilities;
- Comprehensive quality control (QC) during the design and PS&E production;
- Independent quality assurance (QA) monitoring; and

- Evaluation and feedback of the QA/QC procedures.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

9.6.11.1 Project-specific Quality Plan

As may be applicable for each project, provide a project-specific QA/QC plan to supplement the standard, established QA/QC process. The project-specific quality plan should identify any special QA/QC activities, and individual roles and responsibilities for preparation, performance, and maintenance of applicable quality activities. The project-specific quality plan together with the established QA/QC process should address all quality expectations and applicable quality requirements for design of the particular project. The plan should:

- Reference standard, established QA/QC procedures applicable to design of the project, including applicable quality requirements;
- Reference special technical aspects and level of effort vital to the quality of the project,
- Identify a schedule of milestones for significant quality control (QC) activities, including;
  - ◊ QC activities, description and when in the design process they occur;
  - ◊ Checks, back checks, and any anticipated QC audits, if applicable
  - ◊ Approximate duration and anticipated level of effort for each QC activity;
- Identification of the responsible individual(s);
- Identify those individuals responsible for performance of the quality assurance (QA) activities sufficient to verify and ensure adherence with applicable QC requirements;
- Analyze the level of risk associated with above efforts, and assess the potential impacts for each activity identified as having a high level of risk, obtain applicable approval or endorsement of risks, and incorporate applicable measures to mitigate the risks; and
- Provide for periodic review and updating, if necessary, of the design QA/QC activities and those responsible during the life of the project.

9.6.11.2 Quality Control

Quality control (QC) applies to internal design work as well as externally outsourced A/E consultant or sub-consultant work. Perform quality control using an established QC plan during the design and production of:

- Highway geometric design,
- Manual and computer-generated design calculations,
- Engineering drawings,
- Specifications,
- Quantities calculations,
- Construction cost estimate and unit price analysis,
- Technical documents, studies and reports,
- Incorporation of environmental commitments and technical discipline recommendations,
- Permit applications, permitting requirements and their incorporation, and
- Construction stakeout data and reports.

The established QC plan should include the following essential elements:

- Guidelines are provided for using a standard checking and back-checking markup system, review checklists, and other QC control tools and documents;
- All design work is checked by the originator before completion of a task to provide continuous QC during the design and PS&E production work;
- All documents and supporting calculations developed for each stage of design development and review are fully checked by a qualified individual other than the originator before being issued. The QC checker should ensure each document meets an established level of quality, typically identified through using a checklist;
- QC checks identify, incorporate, track and verify the markups and review comments;
- Back checking of review markups to assure that the completed design reflects input received during checks and various iterative reviews used to control the work and evolution of the design, and reflects the intent of the review recommendations;
- QC checks involve subject matter experts for the specific technical discipline;
- QC checks involve the project manager in overall quality control overlapping multiple disciplines;
- QC checks ensure that the design and PS&E products conform to applicable policies and design standards, FLH standard practices, and are accurate and of high quality;
- The QC checks made and their date and responsible person(s) performing the check are recorded; and
- Documentation of the quality control checks made by the originator, reviewer(s), project manager, and others, as applicable is maintained during the life of the project. Refer to Section 9.6.11.4.

9.6.11.3 Quality Assurance

Perform independent quality assurance (QA) checks of the design and PS&E as necessary to:

- Verify that the established quality control (QC) checks have been performed;
- Assure that the completed work conforms with the established QC procedures;
- Ensure that the design and PS&E conform to applicable policies, standards, FLH standard practices, and are accurate and of high quality;
- Verify that design solutions and products meet the overall expectations of FLH, and the FLH Division, and the needs of the partner agency and project stakeholders;
- Comply with legal, regulatory and contractual requirements;
- Assure technical features are consistent with the project scope and intent, and each individual feature is properly integrated into the overall project; and
- Appropriately balance risk between various project constraints, using professional engineering judgment and endorsement of FLH management and partner agency as applicable.

9.6.11.4 Documentation of QA/QC Activities

Throughout the highway design and PS&E development, maintain evidence that applicable QA/QC procedures have been performed. Documentation of QA/QC activities should include notes from reviews, checked plans, specifications, and estimates showing review markup, checked computations showing review markup, and updated CAD files and design notes demonstrating conformance with the applicable QA/QC procedures.

The design QA/QC documentation should address:

- The documents, tracking, file management and retention of QA/QC checks and records;
- Designation of the line of design engineering responsibility;
- Certification of QC checking performed in accordance with an established plan;
- For A/E consultants, sealing and signing of A/E consultant-prepared documents such as:
    - ◊ Engineering drawings,
    - ◊ Specifications,
    - ◊ Construction cost estimate,
    - ◊ Engineering reports and formal technical memorandums,
    - ◊ Construction staking data and reports, and
    - ◊ Other formal technical recommendations or deliverables.

9.6.11.5 Evaluation of QA/QC Procedures

At the conclusion of each project, conduct an evaluation of the QA/QC procedures that were used, to identify and document any significant design problems encountered, areas for process improvement, lessons learned, outstanding quality issues, and to identify any deficiencies in the established QA/QC plan that was used. Refer to Chapter 13 for design feedback processes.