Forest Service Handbook
National Headquarters - Washington Office
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Forest Service Handbook 7709.56 – Road Preconstruction Handbook
Chapter 40 - Design

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Approved by: Gregory C. Smith, Acting Associate Deputy Chief, NFS

Date approved: June 27, 2014

Responsible Staff:

Explanation of changes: Following is an explanation of the changes throughout the directive by section.

40: Revises, updates, and sets forth new direction throughout the entire chapter.

Table of Contents

This chapter provides guidance for design of roads. Design implies the concept of alternative solutions. It is the responsibility of the designer to apply engineering judgment to develop and evaluate alternatives that best fit project objectives.

40.2 - Objective

The objective of this chapter is to provide guidance for the selection of design elements and standards in order to meet design criteria and resource management prescriptions as set forth in the road management objectives (RMOs) (FSM 7714). Meeting RMOs involves collaboration with engineering peers, other Forest Service specialists, such as realty specialists, landscape architects, hydrologists, and fisheries biologists, and relevant State and Federal agencies.

40.3 - Policy

The geometric design of National Forest System (NFS) roads, managed as public roads, is subject to this chapter. Additional guidance for roads at level of service F and above is contained in the "Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT<400)" and "A Policy on Geometric Design of Highways and Streets," issued by the American Association of State Highway and Transportation Officials (AASHTO), hereinafter referred to as the "AASHTO Guidelines".

40.5 - Definitions

See FSM 7721.05 for additional definitions pertaining to development of roads. Forest Service definitions for local, collector, and arterial roads are found in FSM 7705 and differ from the definitions of those terms in the AASHTO Guidelines. Most NFS roads fit the definition of a local or minor collector road in the AASHTO Guidelines.

Administrative National Forest System Road. Any National Forest System road that is not a public road.

Average Daily Traffic (ADT). The daily number of vehicles on a route, determined by dividing the annual number of vehicles on the route by 365.

Clearance. The distance from the edges of the traveled way to vertical and horizontal obstructions.

Critical Vehicle. A vehicle type, typically the largest on a road by weight, size, or unique configuration, whose limited use on the road is necessary to fulfill the RMOs.

Design Criterion. A requirement derived from management area direction, such as safety requirements, level of service, traffic types and volumes, the environmental considerations, and the economic constraints that governs the selection of design elements and design standards.

Design Element. A physical characteristic of a road (such as traveled way width, shoulder, slope, curve widening, and pavement structure) that is considered in its design.

Design Exception. A proposed variation in design that would employ a less restrictive standard than the AASHTO Guidelines.

Design Speed. The maximum speed that the design vehicle can safely maintain along a road or road segment when the design features of the road, rather than the operational limitations of the design vehicle, are taken into account. (The design speed is used to determine the design elements and design standards of a road.)

Design Standard. The definitive length, width, depth, slope, or grade of a design element.

Design Vehicle. A vehicle type that frequently travels a road, that is not subject to restrictions on use of that road, and that travels at the road's design speed and that determines the design standards for a particular design element for the road.

Forest Road. A road wholly or partly within or adjacent to and serving the NFS that the Forest Service determines is necessary for the protection, administration, and utilization of the NFS and the use and development of its resources (36 CFR 212.1).

Highway-Legal Vehicle. Any motor vehicle that is licensed or certified under State law for general operation on all public roads in the state. Operators of highway-legal vehicles are subject to State traffic law, including requirements for operator licensing.

Level of Service. A road's significant traffic characteristics and operating conditions.

National Forest System Road. A forest road other than a road which has been authorized by a legally documented right-of-way held by a State, county, or local public road authority (36 CFR 212.1).

Passing Sight Distance. The distance required to enable the driver of one vehicle to pass another vehicle safely and comfortably.

Public Road. A road that is:

1. Available, except during scheduled periods, extreme weather, or emergency conditions;

2. Passable by four-wheel standard passenger cars; and

3. Open to the general public for use without restrictive gates, prohibitive signs, or regulation other than restrictions based on size, weight, or class of registration. (23 U.S.C. 101(a)(27); 23 CFR 460.2(c) and 660.103).

Seasonal Average Daily Traffic (SADT). The daily number of vehicles on a route intended for seasonal use determined by dividing the number of vehicles using the route during the season of use by the number of days in the season of use.

Travel way. Synonymous with the term "Traveled Way," (sec. 42.4, ex 01).

40.7 - References

The following publications are referenced throughout this chapter.

1. AASHTO. Guide for Design of Pavement Structures. 1993. 700p.

2. AASHTO. A Policy on Geometric Design of Highways and Streets. 5th ed. 2004. 872p.

3. AASHTO. Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT<400). 1st ed. 2001. 94p.

4. AASHTO. Roadside Design Guide. 3rd ed. 2002. 44p.

5. Glennon, J. Design and Traffic Control Guidelines for Low-Volume Rural Roads. National Cooperative Highway Research Program (NCHRP) Report 214. TRB, National Research Council, Washington, D.C., Oct. 1979, Appendix F.

6. Mohney, J., *et al*. 1994. Retaining Wall Design Guide. EM-7170-14. Washington, D.C. U.S. Department of Agriculture, Forest Service. 542p.

7. Steward, J., Williamson, R., and Mohney, J., 1977. Guidelines For Use of Fabrics in Construction and Maintenance of Low-Volume Roads. FHWA-TS-78-205. FHWA, Washington, D.C.

8. U.S. Department of Agriculture, Forest Service. 1999. Dust Palliative Selection and Application Guide. 9977 1207-SDTDC. San Dimas Technology Development Center, San Dimas, CA.

9. U.S. Department of Agriculture, Forest Service. 1997. Relief Culverts. 9777 1812-SDTDC. San Dimas Technology Development Center, San Dimas, CA.

10. U.S. Department of Agriculture, Forest Service. 1997. Traveled Way Surface Shape. 9777 1808-SDTDC. San Dimas Technology Development Center, San Dimas, CA.

11. U.S. Department of Agriculture, Forest Service. 1997. Water/Road Interaction Technology Series. 9777 1806-SDTDC. San Dimas Technology Development Center, San Dimas, CA.

12. U.S. Department of Agriculture, Forest Service. 1977. National Forest Landscape Management, Volume 2, Chapter 4, “Roads.” Agriculture Handbook 483. Washington, D.C. 62p.

13. U.S. Department of Agriculture, Forest Service. 1994. Slope Stability Reference Guide for National Forests in the United States, Volume II. Forest Service Engineering Staff, Washington, D.C. EM 7170-13. 359p.

14. U.S. Department of Agriculture, Forest Service. 1996. Earth and Aggregate Surfacing Design Guide for Low-Volume Roads. FHWA-FLP-96,001. Washington, D.C. EM-7170-16. 302 p.

15. U.S. Department of Defense, U.S. Army Corps of Engineers. 1983. Revised Procedures for Pavement Design Under Seasonal Frost Conditions. Cold Regions Research and Engineering Laboratory, Office of the Chief of Engineers, Washington, D.C. Special Report 83-27.

16. U.S. Department of Transportation, Federal Highway Administration (FHWA). 1992. Soil and Base Stabilization and Associated Drainage Considerations, Volumes I and II. FHWA-SA-93-004.

17. U.S. Department of Agriculture, Forest Service. 2012. National Best Management Practices for Water Quality Management on National Forest Lands, Volume 1, "Road Management Activities." Washington, D.C.: U. S. Department of Agriculture, Forest Service . FS-990a. 104p.

41 - Design Criteria

This section discusses design criteria and explains how it serves as a basis for selection and application of design elements and design standards. Design criteria are outputs of travel planning (FSH 7709.55, ch. 10).

1. Environmental and Resource Considerations. Environmental and resource considerations include factors such as topography, climate, and soils that affect road alignment, gradients, sight distance, quantities of cut and fill, slope selection, drainage, and pavement structure. Forest Service environmental requirements usually result in more restrictive design elements than the AASHTO Guidelines. Recreational uses, such as hiking, riding, and over-snow vehicle use, may require restricting use of roads by highway-legal vehicles.

2. Safety Considerations. Safety considerations include factors such as possible hazards and corresponding corrective action and the need for traffic control devices and maintenance. Safety considerations affect the selection of geometric elements and standards, such as design speed. Direction on safety requirements for National Forest System (NFS) roads is found in FSM 7733.

3. Traffic Requirements. Traffic requirements include volume, composition, distribution, and whether the route is a public road. Traffic requirements are used in the design of turnouts, road widths, surfacing, safety features, and traffic control devices.

4. Levels of Service. Levels of service A through F in the AASHTO Guidelines are for roads with average daily traffic (ADT) greater than 400. Section 41, exhibit 01, adds levels of service G through J which uses the design guidance of this chapter. The exhibit provides expected traffic characteristics and operating conditions of the road. Use this information in making design element decisions such as:

a. Number of lanes.

b. Turnout spacing.

c. Lane widths.

d. Type of driving surface.

e. Sight distances.

f. Design speed.

g. Clearance.

h. Horizontal and vertical alignment.

i. Curve widening.

j. Turnarounds.

41 – Exhibit 01

Levels of Service G Through J for ADT Less Than 400*

	G	H	I	J
Flow	Free flow with adequate parking facilities.	Periodically congested, such as during peak logging or recreational periods.	Interrupted by limited passing opportunities or slowed by road condition.	Slow or blocked flow. Two-way traffic is difficult and may require backing to pass.
Volume	Uncontrolled; will accommodate expected traffic volume.	Occasionally controlled during heavy use periods.	Erratic; frequently controlled as capacity is reached.	Intermittent, usually controlled, and limited to a single purpose.
Vehicle Types	Mix of vehicles normally found on public roads.	Mix of vehicles normally found on public roads.	Controlled mix: accommodate all vehicle types normally found on NFS roads. Some use may be controlled by vehicle type.	Single use; not designed for mixed traffic. Some vehicles may not be able to negotiate the road.
Critical Vehicles	Clearances are adequate to allow free travel. Overload permits are required.	Traffic controls needed where clearances are marginal. Overload permits are required.	Special provisions may be needed. Some vehicles will have difficulty negotiating some road segments.	May require special temporary road treatments, such as filling of ditches or water bar removal. Loads may have to be removed and walked in.
Safety	Safety features are part of the design.	Safety is a high priority in design. Some protection is accomplished by traffic management.	Protection may be provided by traffic management and restrictions rather than by road design.	The need for protection is minimized by low speeds and traffic management restrictions.
Traffic Management	Normally limited to regulatory, warning, and guide signs and permits.	Employed to reduce traffic volume and conflicts.	Traffic restrictions are frequently needed during periods of high volume for the primary use.	Used to discourage or prohibit traffic other than for a single purpose.
User Efficiency	Important and high.	Generally less important and may be somewhat lower than for level of service G.	Not important; may be traded for lower construction costs.	Not a consideration.
Alignment	Design speed is the predominant factor within feasible topographical limitations.	Influenced more strongly by topography than by speed and efficiency.	Generally dictated by topographical features and environmental factors. Design speeds are generally low.	Dictated by topography, environmental factors, and design and critical vehicle limitations. Speed is not important.
Road Surface	Stable and smooth, with little or no dust during the normal season of use.	Stable for the predominant traffic during the normal season of use. Periodic dust control for heavy use or environmental reasons. Smoothness is commensurate with the design speed.	May not be stable under all traffic or weather conditions during the normal season of use. Surface rutting, roughness, and dust may be present, but are controlled for environmental or investment protection.	Rough and irregular. Travel with low-clearance vehicles is difficult. Stable during dry conditions. Rutting and dusting controlled for vehicle safety, driver visibility, and soil and water protection.

* For roads with greater than 400 ADT, refer to AASHTO Guidelines Levels of Service A Through F.

5. Vehicle Characteristics. Vehicle characteristics describe the types of vehicles using a road.

a. Design Vehicle. Design vehicles determine the design standards for each design element, from the types and configuration of vehicles using the road. Analyze each design element for its design vehicle and check for passage for the critical vehicle. A single design vehicle type rarely controls the design standards for all design elements of a road.

Section 41, exhibit 02 displays examples of typical relationships between design elements and design vehicles.

41 - Exhibit 02

Typical Relationships Between Design Elements and Design Vehicles

Design Element	Design Vehicle
Horizontal alignment.	Large recreational vehicle (such as a motor home, tour bus, or pick-up and trailer combination) or logging truck.
Thickness of pavement structure: • Campground or picnic area. • Road with heavy commercial traffic.	• Garbage or other service truck, large recreational vehicle, or bus. • Log truck, dump truck, or belly dump.
Curve widening: • Lateral clearance.	• Large recreational vehicle with trailer or log truck. • Articulated truck or fifth wheel truck.
Gradient	Large recreational vehicle.

b. Critical Vehicles. A critical vehicle's convenience and/or speed of travel are not considerations in road design. The use of a critical vehicle may require a permit, a pilot car, temporary traffic control, and restrictions on other traffic. Examples of critical vehicles include:

(1) A log yarder on a timber access road.

(2) A truck with a lowboy trailer carrying an oversized load of construction or mining equipment.

(3) Wheel or track-mounted equipment using the road for construction and maintenance purposes.

(4) A motor coach bus used to bring large groups to a recreation site.

Special design features, operating considerations, or a combination of both may be required to accommodate critical vehicles according to a road's level of service. Consider both the equipment needed to construct and maintain the road, and the traffic it will carry when designing a road for critical vehicles.

6. Road Users. The selection of design elements and design standards should be based on a road user who is considered to be a safe and prudent driver. A prudent driver is a person operating within their physical and mental limitation, with a properly equipped and maintained vehicle, and who always exercises due care for the road, traffic, lighting, and weather conditions (AASHTO's "Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT<400)").

7. Economics. Design NFS roads to serve the projected traffic and to meet RMOs at the lowest overall cost, consistent with environmental protection and safety considerations. Economics are a primary consideration in the determination and selection of design standards. Economic analysis of design alternatives should balance risk to the investment against risks to the environment from the selected design; this will include and is not limited to life cycle costs, including costs of initial construction, operation, maintenance, environmental mitigation, and closure or decommissioning. Road maintenance projections, performed with appropriated funds, should be based on expenditures made on similar roads with similar traffic within current annual road maintenance appropriations.

8. Other Considerations. Follow applicable best management practices (BMPs) established for compliance with the non-point source provisions of the Clean Water Act, other applicable laws, and their implementing regulations.

42 - Design Elements and Design Standards

National Forest System (NFS) roads with an objective road maintenance level of 3, 4, or 5 meet the definition of a public road and are subject to Federal safety requirements for public roads. These NFS roads are also subject to the requirements in FSM 7705, FSM 7731, FSM 7733, and FSH 7709.59. Users can expect to drive these roads in any typical design vehicle type, including standard passenger cars. They can expect some degree of consideration regarding comfort, convenience, and speed of travel.

NFS roads, with an objective maintenance level of 1 or 2, meet the definition of an administrative NFS road. User comfort, convenience, and speed of travel are not management considerations for these roads, and no provision is made to warn users regarding hazards on the road. The design of administrative NFS roads should reflect that users of these roads assume risks associated with using roads where hazards like pot holes, washouts, and fallen trees may be present and do so knowing no warning is provided.

Commercial users may temporarily improve some design elements of objective maintenance during periods of heavy commercial use. For example, levels 1 and 2 roads may improve to

standards normally associated with levels 3 to 5 roads, such as providing for a smooth and dust free road surfaces. These roads are not suitable for use as public roads unless the need for signs and traffic control devices has been assessed by a qualified engineer and any signs and devices identified by the engineer are in place and functional.

Roadside features and other design considerations, depending upon the traffic type and volume, are the determining factor as to whether NFS roads are single-lane or double-lane. The AASHTO Guidelines are primarily oriented towards double-lane roads. This chapter provides more specific information on single lane roads then the AASHTO Guidelines.

Consider the range of values associated with each design element, and select the value appropriate for the road segment. The AASHTO Guidelines and this chapter establish minimum standards for each design element. Any exception to a requirement for a design standard or design element, in the AASHTO Guidelines, must have prior written approval from the regional director of Engineering.

Proficient designs are the result of engineering judgment, rather than rigid application of techniques or automated systems. Appropriate techniques and systems include use of computers, hand designs, field designs, and flag lines. Use the technique or system most suited to a particular project. Decisions about which technique or system to use for a project depend upon many factors, including cost, user safety, and impacts on NFS resources. A combination of approaches may be appropriate for a single project.

42.1 - Application of Design Standards

Standards for certain design elements can be found in matrix form or graphics in this chapter, such as lane width, stopping site distance, or curve widening. Other standards can be found within the text under topic headings, such as number of lanes, or within the general body of the text, such as maximum design speed. Exceptions to design standards should be handled on a case-by-case basis with application of engineering judgment and appropriate approvals.

42.2 - Coordination of Design Elements

Do not consider or select a single design element independent of the others. Coordinated design elements will meet RMOs and generally result in the least resource impacts and costs.

Improved safety occurs with coordinated design elements. Consider surfacing for improving traction coefficient around curves or for stopping sight distance. Consider longer stopping sight distances than required in some areas based on other elements and local conditions, as well as turnouts on double lane roads or adjusting cut slopes for additional visibility. Avoid, to the extent practicable, combinations such as designing short stopping sight distances on horizontal or vertical curves; or designing sharp curves at the end of long tangents. A coordinated road design alleviates the extensive use of traffic warning signs due to changing and unexpected road conditions.

42.3 - Number of Lanes

Where the estimated seasonal ADT for the design life is 100 to 250, a double-lane road should be considered. Where the estimated ADT for the design life is over 250, a double-lane road generally is the minimum design standard. Where the estimated ADT for the design life is less than 100, a single-lane road is generally preferable. Single-lane roads may have economic and environmental advantages. Decisions regarding the number of lanes may depend largely on environmental factors and costs.

Design and construct NFS roads as single-lane or double-lane. Design widths will be established in accordance with the AASHTO Guidelines for double-lane roads or this chapter for single-lane roads. Bicycle lanes and pedestrian walkways should meet the AASHTO Guidelines.

The decision to construct or reconstruct a road as single-lane or double-lane should be made and documented during travel planning. Additional information obtained during the design process may necessitate reevaluation of the planning decision. Modifications of planning decisions should be documented as amendments to the planning documents. Construction and reconstruction decisions may depend largely on environmental factors and costs.

42.4 - Road Structure

The following relates to design of various elements of a roadway. Road structure terminology is found in section 42.4, exhibit 01.

42.41 - Traveled Way

For double-lane roads, provide sufficient lane width for vehicles traveling in opposite directions to pass each other. The types of vehicles, users, and the volume of traffic determine whether to construct or reconstruct a single-lane or double-lane road. The primary consideration for determining the width of the traveled way is the types of vehicles that will use the road. Secondary considerations are the design speed, traffic volume, anticipated driver skill, and the presence or absence of shoulders and ditches.

Use the minimum traveled way widths for the conditions shown in exhibit 02 of this section. Do not construct or reconstruct a traveled way that is less than 10 feet wide for a single-lane road.

Each region should evaluate local conditions where off-highway haul is a factor and should establish regional standards for traveled way width where necessary (FSM 7731.04a).

a. Single-Lane Roads. For minimum widths, see section 42.4, exhibit 02 of this section and for additional information, see AASHTO's "A Policy on Geometric Design of Highways and Streets," chapter 5, "Special Purpose Roads."

A ditch may permit a narrower traveled way width because a ditch provides the necessary lateral clearance on one side.

In the absence of a ditch, a reduction below the minimum traveled way width shown in section 42.4, exhibit 02 should only occur in unusual circumstances with the understanding that such widths will probably result in higher construction costs, higher maintenance costs, and significantly reduced road utility. Use of widths which are less than those shown in section 42.4, exhibit 02 should be approved by the Regional Director of Engineering.

Traveled way widths should not exceed 14 feet, plus curve widening, unless wider lane widths are needed to accommodate off-highway haul and have been approved in a regional handbook supplement.

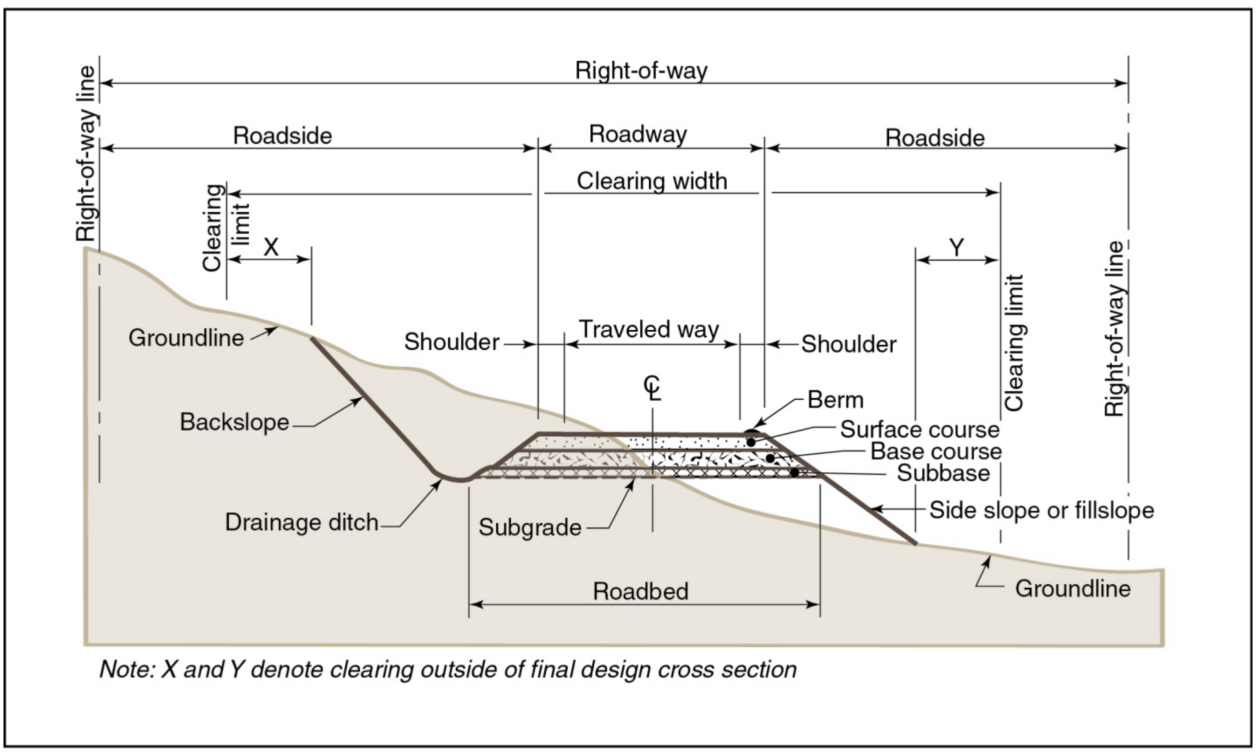
Limit design speed on single-lane roads to a maximum of 40 miles per hour.

b. Double-Lane Roads. See AASHTO's "A Policy on Geometric Design of Highways and Streets" or AASHTO's "Guidelines of Geometric Design of Very Low-Volume Local Roads (ADT<400)" for appropriate widths for double-lane roads.

c. Critical Vehicles. Check traveled way and shoulder widths to ensure that critical vehicles can traverse the road. Critical vehicles do not have to traverse the road at or even approaching the speeds of design vehicles. On roads with an asphalt or concrete surface, it is often appropriate to design widening to accommodate critical vehicles that are managed as an unpaved shoulder.

42.4 - Exhibit 01

Road Structure Terms



42.4 - Exhibit 02

Traveled Way Widths for Single-Lane Roads

<table>
<tr><th colspan="2" rowspan="3">Type and Size of Vehicle</th><th colspan="3">Design Speed (in miles per hour)</th></tr>
<tr><th>20 or Less</th><th>20 - 30</th><th>30 or More</th></tr>
<tr><th colspan="3">Minimum Traveled Way Width (in feet)</th></tr>
<tr><td colspan="2">Recreational, administrative, and service vehicles, 6.5 to 8.0 feet wide.</td><td>10</td><td>12</td><td>14</td></tr>
<tr><td rowspan="2">Commercial hauling and commercial passenger vehicles, including buses, at least 8 feet wide.</td><td>Roads with ditch and roads without ditch where ground cross slope is less than 25 percent.</td><td>12</td><td>12</td><td>14</td></tr>
<tr><td>Road without ditch with ground cross slope greater than 25 percent.</td><td>12</td><td>14</td><td>14</td></tr>
</table>

42.42 - Shoulder Width

Shoulders may be necessary to provide:

a. Lateral support for the outside edge of asphalt or concrete pavement. The minimum shoulder width that can be economically constructed, generally 1 to 2 feet on each side, is adequate.

b. Parking areas when needed for specific activities or attractions along a road. The need for parking areas may be determined during travel planning or project planning. Provide a minimum usable width of 8 to 10 feet for parallel parking areas. Normally, parking areas are not provided along NFS roads for stalled or disabled vehicles.

c. Space for installations such as drainage structures, berms, guardrails, signs, and roadside utilities. The design of these devices or facilities determines the required width.

d. An increase in roadway width on the approach to a bridge or other structure so as to match the traveled way width of the structure.

e. A recovery zone for vehicles straying from the traveled way on roads designed under AASHTO's "Guidelines of Geometric Design of Very Low-Volume Local Roads (ADT<400)," where a risk analysis indicates the costs are justified.

f. Additional width to provide for passage by a critical vehicle.

42.43 - Turnouts

The purpose of turnouts on a single-lane road is to provide for safe passing of vehicles.

a. Turnout Spacing. Intervisible turnouts (where a motorist at a turnout can see the next turnout) should be provided on public roads. In situations where intervisible turnouts cannot be provided, signing should be used to advise motorists of the situation.

Turnout spacing is determined by applying engineering judgment to information derived from exhibit 03, exhibit 04, and the Turnout Spacing Equation, all of which are shown below.

Exhibit 03 displays the increased vehicle travel times that result from passing oncoming vehicles at turnouts for four different turnout spacing as a function of the number of vehicles passing over a road per hour. (When converting ADT to VPH, use a 10-hour day.)

42.4 – Exhibit 03

Increased Travel Time for Various Turnout Spacings

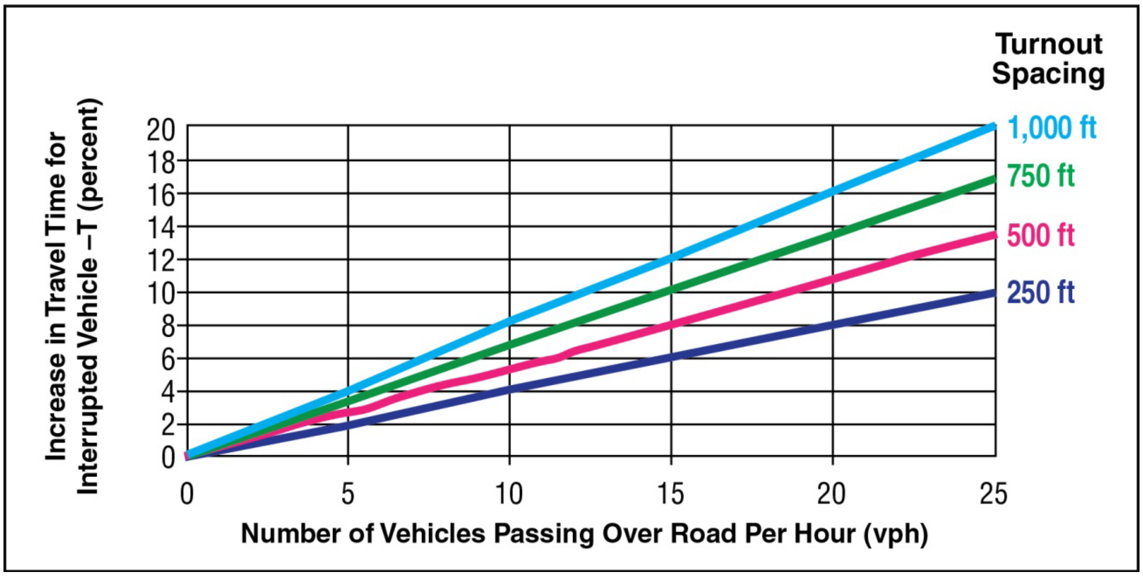


Exhibit 04 contains turnout spacing requirements and operational constraints for levels of service G through J.

42.4 - Exhibit 04

<u>Turnout Spacing</u>

Level of Service	Turnout Spacing	Operational Constraints
G	Turnouts are intervisible, unless compliance with cost or environmental criteria would be prohibitive. Closer spacing may contribute to efficiency and convenience. Maximum spacing is 1,000 feet.	Traffic: mixed Capacity: up to 25 VPH Design Speed: up to 40 MPH Delays: 20 sec./mile or less
H	Intervisible turnouts are highly desirable, but may be precluded by excessive cost or environmental constraints. Maximum spacing is 1,000 feet.	Traffic: mixed Capacity: up to 25 VPH Design Speed: up to 25 MPH Delays: should be 30 sec./mile or less Use signs to warn noncommercial users of commercial traffic. Road segments without intervisible turnouts should be signed.
I	When the environmental impact is low and the investment is economically justifiable, additional turnouts may be constructed. Maximum spacing is 1,000 feet.	Traffic: some mixed Capacity: up to 20 VPH Design Speed: up to 20 MPH Delays: up to 60 sec./mile Road should be managed to minimize conflicts between commercial and noncommercial users.
J	Generally, only naturally occurring turnouts, such as additional width on ridges or other available areas on flat terrain, are provided.	Traffic: not intended for mixed use Capacity: generally 10 VPH or less Design Speed: 15 MPH or less Delays: at least 60 sec./mile expected Road should be managed to restrict concurrent use by commercial and non-commercial users.

<u>Turnout Spacing Equation</u>:

T=DS/36, where:

T = increase in travel time for the interrupted vehicle as a percentage
D = delay time per mile for the interrupted vehicle in seconds (sec. 42.4,ex. 04)
S = design speed in miles per hour

Process for determining turnout spacing:

1. Begin by solving the Turnout Spacing Equation for T.

2. Use the graph in exhibit 03 of this section to determine the turnout spacing required to accommodate the number of vehicles passing over the road per hour (VPH).

3. Then use engineering judgment to apply the turnout spacing considerations for levels of service displayed in exhibit 04 of this section.

a. The variables of spacing, VPH, delay time, and design speed should each be analyzed based on their relative importance. Different combinations should be investigated to determine their effect on safety, cost, and the environment. The objective is to provide turnout spacing to attain the appropriate traffic flow for the intended level of service.

b. In locating turnouts, consider the types of road users, safety, and cost. Desirable physical locations of turnouts are:

1. On the outside of cuts, such as the outside of a curve around a point of a ridge;

2. On the low side of fills, such as the upper side of curves across ravines;

3. At the runout point between through cuts and fills; and

4. On roads intended for logging traffic, so that empty haul vehicles or other traffic can use the turnouts while a loaded vehicle maintains speed and course.

c. Turnouts should not be included in designs solely to provide for waste or storage of excavated material. Turnouts may be used to provide openings for scenic vistas.

d. Standards for minimum turnout widths and lengths are shown in exhibit 05 of this section. When turnouts are located on curves, provide curve widening in addition to the turnout width (42.45).

e. When the design alignment and grade require numerous turnouts, consider constructing a two-lane road, if practicable based on cost and safety considerations.

42.4 – Exhibit 05

Turnout Widths and Lengths

Level of Service	Turnout Width	Turnout and Transition Lengths
G	10 feet	Design vehicle length or at least 75 feet, whichever is greater; at least 50-foot transitions at each end.
H	10 feet	Design vehicle length; at least 50-foot transitions at each end.
I	Minimum total width of the traveled way and turnout equals the width of two design vehicles plus 4 feet.	Design vehicle length; at least 30-foot transitions at each end.
J	Minimum total width of the traveled way and turnout equals the width of two design vehicles plus 4 feet.	Empty truck length; at least 30-foot transitions at each end.

For tangent and curved section turnouts, measurement of the length and transition starts at the centerline of the road. For additional information on these turnouts, see AASHTO's "A Policy on Geometric Design of Highways and Streets," chapter 5, "Special Purpose Roads," especially exhibits 5-17 and 5-18.

42.44 - Turnarounds

Turnaround designs should consider both critical and design vehicles. Turnarounds should be provided at or near the end of roads, at points where the level of service or road standards change, and at closure points such as gates and barricades. Normally, when the need for turnarounds has been considered in project planning, meeting that need will not require additional extensive construction. A terminal facility can often be used as a turnaround with minor alterations.

Intermediate turnarounds are usually not necessary on most roads and should be provided only when existing facilities, such as turnouts, do not provide adequate room for users to turn around.

Consider placing signs if intermediate turnarounds create a hazard to other users. Design turnarounds to allow design vehicles to turn reasonably safely. To the extent practicable, design turnarounds to allow design vehicles to reverse direction in one backing and turning maneuver.

RMOs may require additional turnarounds for fire staging, maintenance, or other access needs. Additional turnarounds for construction purposes may be cost-effective.

42.45 - Curve Widening

Widening of the traveled way is required on some curves to provide for off-tracking of tractor trailers and for some light vehicle-trailer combinations. Curve widening to accommodate the design vehicle is considered a part of the traveled way.

In most cases, the design should consider several types of vehicles, most commonly:

a. Tractor trailer combinations where the fifth wheel is located directly over the drive wheels, such as a lowboy or a gravel truck.

b. Tractor trailer combinations with the towing pivot point offset to the rear of the drive wheels, such as logging trucks with a stinger to facilitate making short radius turns.

c. Tractor trailer combinations that have two fifth wheels and accessory axles.

d. Special configurations for other commercial vehicles such as tractors with double or triple trailers.

e. Large recreational vehicles such as motor homes, tour buses, and pick-up and trailer combinations.

f. Log yarding and construction equipment vehicles arranged in operational mode or travel configuration.

Curve widening is affected by the type of vehicle, radius of curvature, and the central or delta angle.

Generally, the need for curve widening increases as the radius decreases. Shorter curves require less curve widening than longer curves.

The following discussion outlines the relationship of curve widening to the level of service (sec. 41, ex. 01).

42.4 – Exhibit 06

Relationship to Level of Service

Level of Service	Curve Widening
G	Provided to accommodate the design vehicle at the design speed for each curve. Curve widening for design vehicles should be provided in each lane of double-lane roads. Curve widening for highway-legal critical vehicles should be provided by the use of other design elements, if planned, such as turnouts and shoulders. Curve widening for non-highway legal critical vehicles should be provided only to the extent necessary for them to traverse the road safely with operational controls, such as permit-required pilot cars, in effect.
H	Same as for level of service G.
I	Same as for level of service G, except curve widening for highway legal critical vehicles may be reduced to only what is necessary to traverse the road safely with operational controls.
J	Generally provided only for the design vehicle. Loads carried by critical vehicles may be off-loaded and walked to the project or transferred to vehicles capable of traversing the road. Temporary widening to permit the passage of critical vehicles, such as temporary filling of the ditch at narrow sections, may also be used.

On the level of service I and J roads, it may be desirable to design turnouts where significant curve widening would otherwise be required, such as on short-radius curves. In these situations, the minimum lane width should be the greater of the:

1. Single-lane width, plus design vehicle curve widening, plus turnout width.

2. Single-lane width plus critical vehicle curve widening.

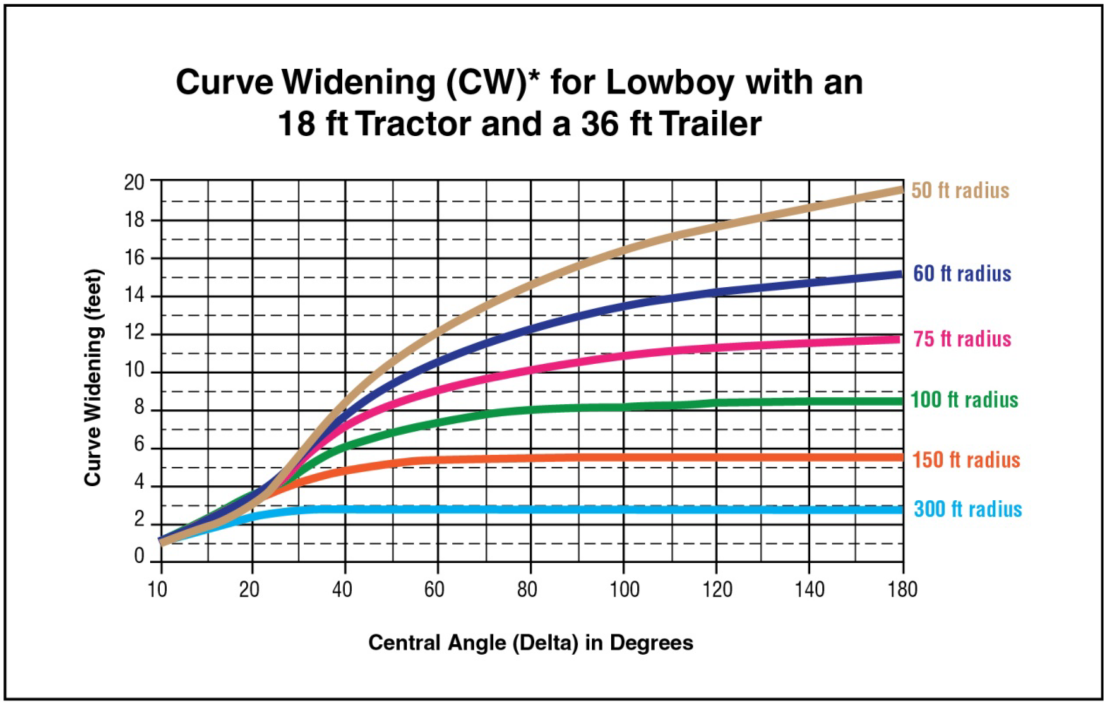
The turnout should extend from the point of curvature (PC) to the point of tangency (PT), with tapering provided as appropriate for the design vehicle.

Use section 42.4, exhibits 06, 07 and 08 and the following equations (sec 42.4, ex. 09), as appropriate, to determine curve widening. The curves in the graphs were developed from the central and delta angle variations of vehicles using off-tracking equations. Exhibit 07 applies to lowboy configurations, and exhibit 08 applies to logging truck configurations.

For other configurations, see AASHTO's "A Policy on Geometric Design of Highways and Streets."

42.4 – Exhibit 07

Lowboy Configurations

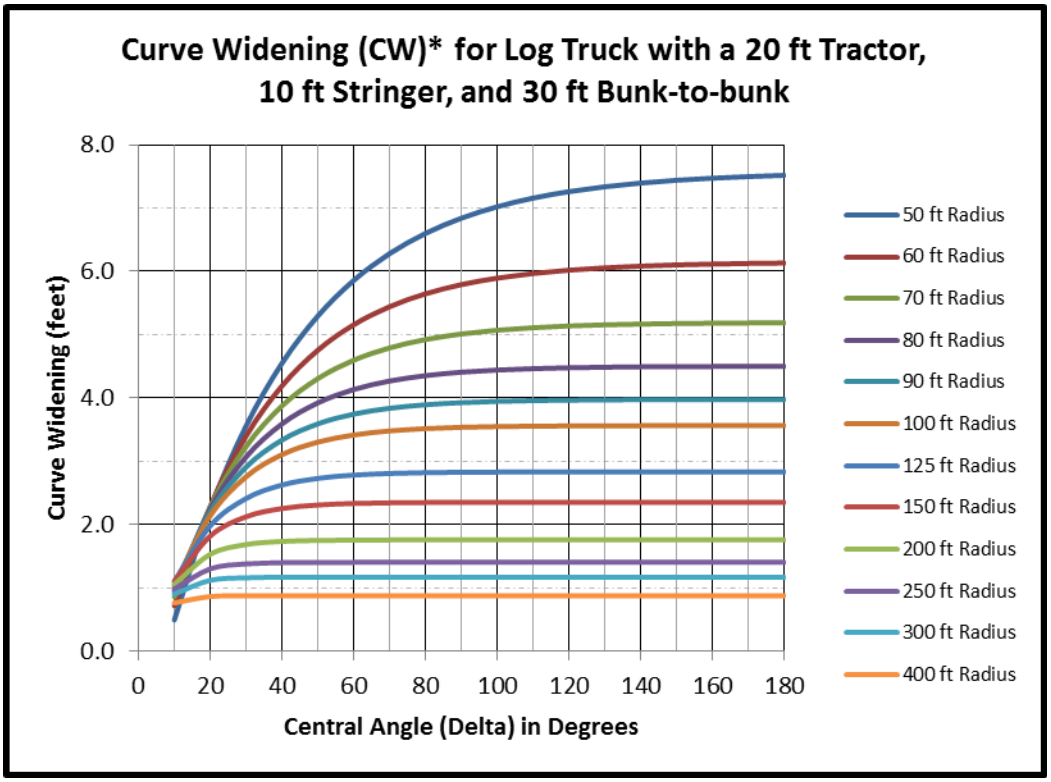


* *Add curve widening (CW) to lane width*

It is not necessary to widen all curves. If the minimum width as determined by the equation below is equal to or less than the traveled way width, no curve widening is required.

42.4 – Exhibit 08

<u>Logging Truck Configuration</u>



Add curve widening (CW) to lane width.

The following field-checked equation, which is reasonably accurate for a radius of 50 feet or more, yields the minimum lane width (MLW), which includes 2 feet for off-tracking corrections.

MLW = 14 feet + curve widening (CW), where CW is determined using the equation below.

MLW may be reduced to 14 feet plus curve widening for level of service I roads open to commercial hauling or commercial passenger vehicles (sec. 42.4, ex. 02) and to 12 feet plus CW on other level of service I roads where analysis indicates that adequate user safety and utility can be maintained at the reduced width.

42.4 – Exhibit 09

Equation to Determine Curve Widening

$$CW = \left[\left(R - \sqrt{R^2 - L^2} \right) \left(1 - e^{\left\{ \frac{-0.015\Delta R}{L} + 0.216 \right\}} \right) \right],$$ where:

R = centerline radius in feet,
e = base for natural logarithms,
Δ = central angle in degrees, and
L = the value computed below.

For a lowboy or standard tractor trailer, $L = \sqrt{L_1^2 + L_2^2 + L_3^2}$, where:

L_1 = the wheel base of the tractor in feet,
L_2 = the distance from the fifth wheel to the middle of the rear duals for the first trailer in feet, and
L_3 = the distance from the fifth wheel to the middle of the rear duals for the second trailer in feet.

For a logging truck with a stinger, $L = \sqrt{L_1^2 - L_2^2 + L_3^2}$, where:

L_1 = the wheel base of the tractor in feet,
L_2 = the length of the stinger measured from the middle of the tractor rear, duals to the end of the stinger in feet, and
L_3 = the bunk-to-bunk distance, minus the length of the stinger in feet.

Curve widening should be uniformly tapered before the PC and after the PT for the following lengths:

Curve Widening Taper Lengths	
Radius (in feet)	***Taper Length (in feet)***
<70	60
70-85	50
86-100	40
>100	30

Carefully consider the adequacy of curve widening when designing roads with reverse or compound curves or curves separated by tangents shorter than the curve widening transition length.

Limited initial studies on reverse curves indicate that minimum lane width at the point of reverse curvature should be:

1. Fourteen feet for level of service I roads open to commercial hauling or commercial passenger vehicles.

2. Twelve feet for other level of service I roads + 2/3 (curve widening for the first curve) + 2/3 (curve widening for the second curve).

Curve widening for compound curves should be calculated using the total of the deflection angles of both curves. Use the greater of the individually calculated curve widening for adjacent curves, as the curve widening at the point of compound curvature (PCC).

For more information on vehicle tracking, refer to AASHTO's "A Policy on Geometric Design of Highways and Streets," chapter 2.

42.46 - Clearance

The desirable minimum horizontal clearance is 4 feet for level of service G and H roads. The desirable minimum horizontal clearance varies from 0 to 4 feet on level of service I and J roads, based on local factors determined during road planning and design. The minimum vertical clearance on level of service G, H, and J roads is 14 feet. At higher speeds, consider increasing horizontal and vertical clearances.

Critical vehicles, with unique features, such as a spar on a log yarder or construction equipment vehicle usually require special clearances. The completed design should accommodate critical and design vehicles or include provisions for operational controls to accommodate them.

42.47 - Fill Widening

Depending on the construction technique specified, some shoulder material settling can be expected. Fill widening may be used to provide additional width during construction so that the intended traveled way width remains stable.

Engineering judgment should be employed to determine whether to use fill widening. Consider the requirements of BMPs for compliance with non-point source pollution potential in such judgments. The engineer should also consider other measures besides fill widening to achieve stable roadways, such as flattening constructed slopes, compacting soils, using "select" borrow instead of "common" material; contractual requirements to revegetate slopes should be kept current as excavation progresses. Fill widening over 2 feet should not be used.
Do not use fill widening in place of widening the shoulders, the traveled way, curves, or other parts of the road structure that require stability.

42.48 - Clearing Widths

Provide the minimum clearing widths consistent with RMOs. To minimize costs, especially on short-term level of service J roads, consider the reduction of clearing widths through the:

1. Design of fills to encroach on live trees to an acceptable height depending on species and size.

2. Reduction or elimination of clearings above the cut slope, where cut slope stability and road operation and maintenance allow.

42.49 - Daylighting

When the road design provides for a through cut with a low cut bank on the downhill side, it is often desirable to "daylight" the downhill side of the cut. (for example, extend the roadbed width at finished grade slope and elevation to the downhill side to where it "daylights" with the ground surface beyond the proposed cut.) Daylighting can increase construction efficiency and reduce maintenance costs. Daylighting should not be indiscriminately specified, since excessive use of this practice can increase construction costs. Daylighting criteria should be determined and documented when other design standards are established for the road.

42.5 - Speed and Sight Distance

1. <u>Design Speed</u>. The design of road speed is an iterative process between RMOs and road design elements and has a direct impact on cost, safety, driver comfort, and convenience. In new construction design, layout the horizontal and vertical road alignment, and check it against design criteria such as level of service, maximum grades, and curve requirements. Determine what speed the geometry allows. Compare this with the speed to accommodate RMOs. Adjust the design elements as necessary, considering roadside design features such as recovery and clear zones. Consider that consistent road designs reduce unexpected conditions and the need of warning devices.

For reconstruction projects, field-verify the design speed for the existing road segments, and research crash data to identify the need for any adjustments in the design speed. Perform a site visit to determine if any visual clues are available, such as skid marks, damaged guardrail, or damaged trees.

Terrain and other physical constraints may dictate a change in the design speed for certain road segments. For example, a change in the design speed may be warranted for road segments traversing major changes in topography or at intersecting roads. Consider posting signs on level of service G and H roads to warn users of short segments with a different design speed.

Avoid road designs on level of service G and H roads, that allow most segments to be driven at more than the design speed, to the extent practicable. If these designs are used, analyze the segments that can be driven safely only at the design speed to determine whether redesign could economically eliminate the hazard by providing for safely negotiating them at higher speeds. If not, use traffic control devices or other means to address the potential hazard to the extent practicable.

Other factors besides the design speed, such as weather, time of day, driver proficiency, level of maintenance, and change in design elements, also affect the safe speed along a road or road segment.

a. Level of Service G and H Roads. Speed is an important consideration in evaluating the convenience and economics of level of service G and H roads. When determining the design speed, evaluate user costs, which usually increase as the design speed decreases. The design speed establishes the minimum sight distance for stopping and passing and the minimum radius of curvature, may establish the gradient, and may establish the type of running surface. Evaluate alternative combinations of horizontal and vertical alignment to obtain the greatest sight distance within economic and environmental constraints (sec. 43).

b. Level of Service I and J Roads. The design speed for level of service I and J roads are not as significant as for level of service G and H roads. For level of service I and J roads with a design speed of 15 miles per hour or less where cost is a minor factor, shift the emphasis in design from speed to vehicle operational controls. In determining the design speed for level of service I and J roads:

(1) Fit the vertical and horizontal alignments to the natural terrain as closely as possible without considering the design speed.

(2) Consider soil types and environmental constraints as well as the standard design criteria.

(3) Analyze the vertical and horizontal alignments to determine the design speed.

(4) Apply additional design standards as appropriate to accommodate the design vehicle upon the determination of the design speed. For example, if the desired

design speed has been identified in the planning process, compare it to the design speed determined in paragraph 1b(3). If improvements to the design are necessary to accommodate the desired design speed, weigh the cost of these improvements against the benefits of the desired design speed; this should be based on construction, operating cost, and maintenance. Modify the design or employ traffic control devices or other measures, to the extent practicable and as appropriate, at those locations if the speed is likely to create safety problems.

2. Sight Distance. Evaluate sight distance when designing crest and sag vertical curves, horizontal curves, intersections, and passing areas (secs. 43.1 and 43.2).

Sight distance is an important factor to consider in road design because it cannot easily be judged by drivers. Inadequate sight distance does not readily cause the driver to slow to a safe driving speed. Reduce the design speed or include traffic controls, to the extent practicable if the sight distances appropriate for the design speed cannot be provided.

On two-way single-lane roads, provide minimum sight distance equal to twice the stopping sight distance for the design speed. Provide sight distance on one-way single-lane roads equal to or greater than the stopping sight distance for the design speed.

3. Stopping Sight Distance. The stopping sight distance varies with the type of vehicle, skill of the driver, condition of the road surface, geometry of the road at a given point (primarily gradient), and number of lanes (single or double). For example, the stopping sight distance needed for a two-way single-lane road, where opposing traffic is confined to one lane, is commonly twice as much as that required for a double-lane road.

a. Use the following equation to compute stopping sight distance for double-lane roads. This equation takes into account varying road surface conditions, for example, loose gravel, wet earth, wet asphalt, and wet-packed gravel.

Stopping Sight Distance Equation

$$SSD = 1.47VT + 1.075\left(\frac{V^2}{a}\right), where:$$

SSD = stopping sight distance in feet;
V = approach or initial speed in miles per hour;
T = perception reaction times:

- 2.5 seconds for level of service G and H roads,
- 2.0 seconds for level of service I and J roads; and

a = driver deceleration (ft/sec^2)
(14 ft/sec^2 for trucks; 21 ft/sec^2 for cars).

Use the following table for stopping sight distances, calculated using the equation in paragraph 3a, for trucks with a deceleration rate of 14 ft./sec.2.

Truck Stopping Sight Distance (in feet)				
Double-Lane			Single-Lane	
Speed (MPH)	T=2.0 (sec.)	T=2.5 (sec.)	T=2.0 (sec.)	T=2.5 (sec.)
10	37	44.5	74	89
15	61.5	72.5	123	145
20	89.5	104	179	208
25	121.5	139.5	243	279
30	157	179	314	358
35	197	222.5	394	445
40	240	269.5	480	539

Perception-reaction time (T) can vary considerably. Two T values are used in this chapter. A T of 2.5 seconds is used for designing level of service G and H roads. Roads at these two levels of service involve mixed traffic, which can result in relatively complex driving situations. A T of 2.0 seconds is used for level of service I and J roads, where the driving situation is less complex.

The following equation takes into account the effects of road surface condition and gradient:

Stopping Site Distance with Grade and Surface Consideration

$$SSD = 1.47V_1T + \frac{(V_1{}^2)}{30\,(f_f \pm G)}\text{, where:}$$

SSD = stopping sight distance in feet;
V_1 = approach or initial speed in miles per hour;
T = preception/reaction time:

- 2.5 seconds for level of service G and H roads,
- 2.0 seconds for level of service I and J roads;

f_f = coefficient of friction between tires and roadway (expressed as a decimal); and
G = gradient (expressed as a decimal).

The following table displays friction and traction coefficients. The friction coefficients are based on the traction coefficients, which are reduced by 0.2 as a safety factor (ff = Tf - 0.2). Use these factors when calculating stopping sight distance using the equation above.

42.5 – Exhibit 01

Friction Coefficients, F_f, for Traction Coefficients, T_f

Material	Dry Surface		Wet Surface	
		$f_f = T_f - 0.2$	T_f	$f_f = T_f - 0.2$
Concrete	0.75-0.90	0.55-0.70	0.55-0.70	0.35-0.50
Asphalt	0.55-0.70	0.35-0.50	0.40-0.70	0.20-0.50
Stabilized gravel	0.50-0.85	0.30-0.65	0.40-0.80	0.20-0.60
Loose gravel	0.40-0.70	0.20-0.50	0.36-0.75	0.16-0.55
Crushed rock	0.55-0.75	0.35-0.55	0.55-0.75	0.35-0.55
Wet earth	0.55-0.65	0.35-0.36	0.40-0.50	0.20-0.35
Dry-packed snow	0.20-0.55	0.00-0.35	-	
Loosely packed snow	0.10-0.60	0.00-0.40	-	
Lightly sanded snow	0.29-0.31	0.09-0.11	-	
Lightly sanded snow, with chains in use	0.34	0.14	-	

Reference: Stryker, E. R. "Gradeability of Log Trucks." Oregon State University, Table 3, Appendix II, from Taborek (1957) and Western Highway Institute (1976).

On single-lane level of service G and H roads, where the sight distance is less than the stopping sight distance, the road should either have a double lane segment or the necessary sight distance should be provided by other means, such as by adjusting the cut slopes or selective clearing. (Only use selective clearing if it can be maintained on this and similar roads within the limits of expected levels of annual road maintenance appropriations). On level of service G and H roads, constructing turnouts to provide sight distance is not desirable. Level of service G and H roads are intended for all users, including drivers who may be unfamiliar with driving NFS roads. These users may not understand the need to drive into turnouts, when sight distance is restricted, to avoid potential head-on collisions with oncoming traffic.

4. Stopping Sight Distance on Horizontal Curves. The lateral clearance for stopping sight distance on horizontal curves is the offset distance from the centerline of the inside lane of a double-lane road or from the centerline of a single-lane road to a visual obstruction along the side of the road. Provide lateral clearance to allow drivers to see obstructions on the road or approaching traffic when traveling around a horizontal curve.

Stopping sight distance on horizontal curves is an important consideration on both single-lane and double-lane roads. Minimum lateral clearance is a function of design speed and radius of curvature. If appropriate lateral clearance can be provided by the traveled way, shoulders, and ditch, no further adjustments are needed. If additional clearance is needed, slopes, ditch widths, or clearing may be adjusted to provide the desired sight

distance. Post signs to reduce speed or redesign the road when stopping distance is inadequate for the design speed of the road, to the extent practicable.

Stopping sight distance on horizontal curves is covered extensively in AASHTO's "A Policy on Geometric Design of Highways and Streets," which is not duplicated in this chapter. Due to the number of variables, it is not practical to include illustrations to depict all conditions. Sight distance is not limited to the distance between the PC and PT of a curve, but can also include part of the adjacent tangents. Steep grades and other variables, such as reaction time, road conditions, speed, central angle, and type of vehicle, may increase the stopping sight distance. AASHTO recommends a case-by-case analysis of the stopping sight distance using graphs.

When considering stopping sight distance on horizontal curves, also consider the stopping distance required due to the side friction factor. See section 43.1 for additional information on stopping sight distance on horizontal curves. For horizontal curves without superelevation, the side slipping factors may be more restrictive than the factors used for forward motion.

5. Passing Sight Distance. The passing sight distance allows a driver, when passing, not to interfere with the speed of an oncoming vehicle traveling at the design speed that comes into view after the driver has begun passing. Passing sight distance is not a factor on single-lane roads because of the assumption that slower vehicles pull into turnouts to allow other vehicles to pass when necessary. For information on passing sight distance on double-lane roads, see AASHTO's "A Policy on Geometric Design of Highways and Streets."

43 - Alignment

43.1 - Horizontal Alignment

1. Curvature. Roads should be designed so that they are composed of sections of circular curves and tangents. For roads with a design speed of 15 miles per hour or less, it is acceptable to use a field-designed horizontal alignment that approximates the geometric requirements of circular curves and tangents. Check the horizontal and vertical alignment (sec. 43.2) to ensure that they allow other design elements, such as curve widening and stopping sight distance, and geometric design standards, such as ensuring a minimum 50-foot curve radius, to be addressed appropriately.

The relationships of vehicle speed, radius of curvature, superelevation rate, and side friction factor are expressed in the following equation:

Calculating Horizontal Curve Radius

$$R = \frac{V^2}{15\,(0.01e + f)}\ , where:$$

R = curve radius in feet,
V = vehicle speed in miles per hour,
e = rate of superelevation, and
f = side friction factor.

Factors to consider in determining the minimum radius include:

a. Grade.

b. Vehicle speed.

c. Vehicle's center of gravity.

d. Tire condition.

e. Driver comfort and proficiency.

f. Wet or dry conditions.

g. Variability of crushed rock and other road surfacing.

h. Considerations related to any intended use during wintry conditions, including characteristics of wintry precipitation; intended winter maintenance operations

(plowing, abrasives, and so forth); and restrictions on users, including timing of use, allowable equipment, and use of traction devices.

i. Frequency of use.

Traction on dry pavement is lost at a side friction factor of approximately 0.4 or 0.5. National Cooperative Highway Research Program (NCHRP) Report 37 indicates that the traction coefficients for the side friction factor are approximately half of the traction coefficients for the forward motion. Another factor to consider is the driver's comfort level. AASHTO recommendations for side friction factors vary with speed and pavement condition. For more information on the side friction factor, see Clarkson H. Oglesby, Highway Engineering, 3d ed., AASHTO's "A Policy on Geometric design of Streets and Highways," and NCHRP Report 37.

Designers may approximate the relationship between T_f and f_s as shown in the equation and table below.

43.1 – Exhibit 01

Side Friction Factors, f_s, for Traction Coefficients, T_f
$f_s = T_f *0.5$, where T_f = the traction coefficient of the traveled way for various road surfaces in a forward direction.

Material	Dry Surface		Wet Surface	
	T_f	$f_5 = T_f *0.5$	T_f	$F_s = T_f *0.5$
Concrete	0.75-0.90	0.35-0.45	0.55-0.70	0.27-0.35
Asphalt	0.55-0.70	0.27-0.35	0.40-0.70	0.20-0.35
Packed and oiled gravel	0.50-0.85	0.25-0.42	0.40-0.80	0.20-0.40
Loose gravel	0.40-0.70	0.20-0.35	0.36-0.75	0.18-0.37
Crushed rock	0.55-0.75	0.27-0.37	0.55-0.75	0.27-0.37
Wet earth	0.55-0.65	0.27-0.32	0.40-0.50	0.20-0.25
Dry-packed snow	0.20-0.55	0.10-0.27		
Loosely packed snow	0.10-0.60	0.05-0.30		
Lightly sanded snow	0.29-0.31	0.14-0.15		
Lightly sanded snow, with chains in use	0.34	0.17		

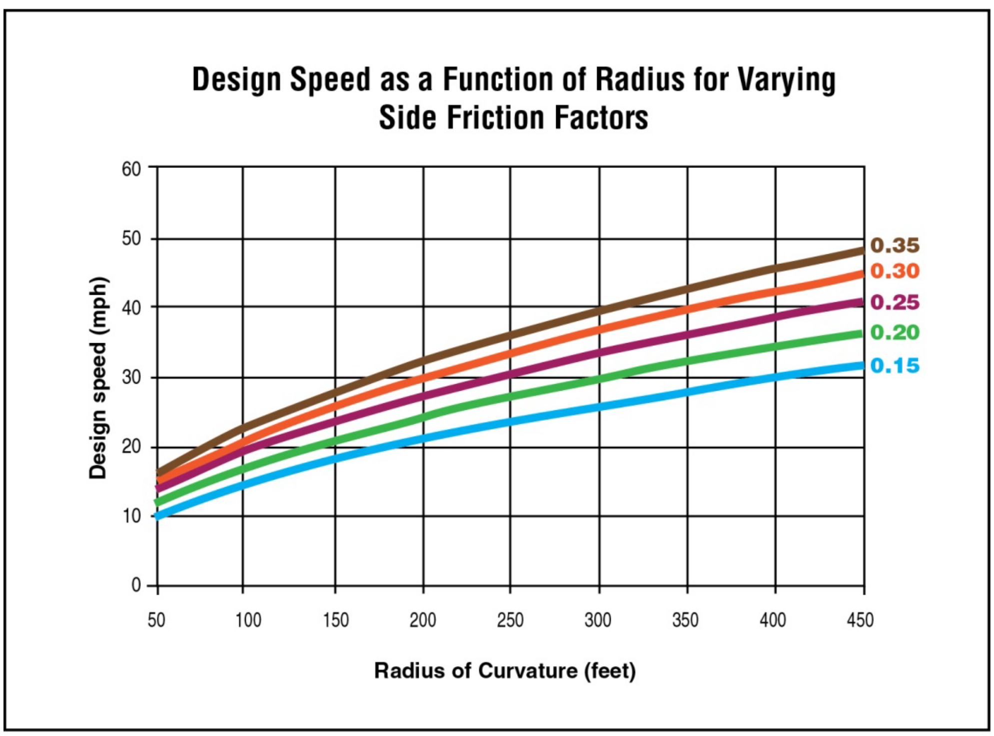
Reference: Stryker, E. R. "Gradeability of Log Trucks." Oregon State University, Table 3, Appendix II, from Taborek (1957) and Western Highway Institute (1976).

2. <u>Radius of Curvature and Speeds</u>. The design speed for each curve is affected by the radius of the curve, superelevation rate, and the traction coefficient of the surface material. Use the values of T_f to determine the side friction factor (f_s) in the equation above. The reduced value of f_s provides a reasonable margin of safety for the average driver. It is not always necessary to select a traction coefficient value for inclement weather conditions because the average driver reduces speed under these conditions. Inclement weather coefficients should be selected when the road is specifically intended for use during inclement weather conditions or when there is a significant volume of traffic during those conditions.

Exhibit 02 shows the relationship of design speed to radius of curvature for various traction coefficients where there is no superelevation. Exhibit 02 is based on rider comfort and safety and the traction coefficients in exhibit 01 of this section. Exhibit 02 shows that speed can be increased by improving the quality of the road surfacing. Surface improvements for increased speed is normally justifiable only for flatter grades where the gradient controls the speed.

43.1 – Exhibit 02

<u>Relationship of Design Speed to Radius of Curvature</u>



For curves with no superelevation

3. Superelevation. Superelevation is an important consideration on level of service G and H roads. Superelevation is usually not important on level of service I and J roads, where user comfort, convenience, and speed of travel are generally not management considerations and road use can be restricted.

To the extent practicable, avoid using superelevation for design speeds of less than 20 miles per hour. Where there is a possibility of encountering snow and ice, the superelevation rate should not exceed 6 percent and should be reduced further on grades to accommodate slow truck traffic. In warmer climates where snow and ice are not factors, the superelevation rate may be increased to 12 percent. For more information on superelevation, refer to AASHTO's "A Policy on Geometric Design of Highways and Streets."

Achieve superelevation through the rotation around the elevation of the center or a side of the traveled way. Design the rotation point and the superelevated segment to protect environmentally sensitive areas adjacent to the segment. This includes the:

a. Prevention of ponding near the lower edge of the road, on flatter slopes;

b. Provision for surface drainage prior to the superelevated curve;

c. Provision for ditches through the superelevated segment to carry surface drainage to an appropriate termination; and

d. Placement of a designed surfacing course on the superelevated curve.

4. Superelevation Transitions. Provide transitions into and out of superelevated sections to avoid abrupt changes in the roadway template. Transitions from tangents to superelevated curve sections are covered in detail in AASHTO's "A Policy on Geometric Design of Highways and Streets."

5. Minimum Radius of Curvature. National Forest System roads should have a minimum centerline radius of curvature of 50 feet, except for some recreation and administrative National Forest System roads where the design and critical vehicles do not include heavy commercial trucks. Check the configuration of the design vehicle and the critical vehicle to validate that they can negotiate the road when designing roads with minimum radius curves. See AASHTO's "A Policy on Geometric Design of Highways and Streets," chapter 2, for design vehicle dimensions. Vehicle overhang and swing may affect cut bank slopes as well as lane width. The effects of sharp curves and vehicle configuration in critical locations can be determined by the use of simulators or computer applications. See AASHTO's "A Policy on Geometric Design of Highways and Streets," chapter 2, for the minimum turning path for most vehicles, including cars, buses, large recreational vehicles, and trucks.

43.2 - Vertical Alignment

1. Grade. Vertical alignment is a very important design element. Road gradient has a major effect on the environmental impact of a road, particularly in terms of erosion. Gradient is the predominant factor affecting speed in many cases, and grade also has a significant effect on maintenance and user costs.

It is advisable to establish a minimum grade of 2 percent on native soil or on aggregate-surfaced roads to facilitate surface drainage where possible. Flat grades do not shed water sufficiently and tend to develop potholes. Where flat grades are used on hillsides, outsloping the road surface can be an effective way to provide surface drainage. Where flat grades occur on level ground, crowning the road surface is recommended (sec. 44.1).

The adverse environmental effects of road gradient become increasingly apparent as the grade increases. For example, erosion potential increases as a function of the square of the slope and of the third power of the water velocity. The intensity of erosion changes with the type of soil and/or aggregate of the roadbed, ditch, cut bank, and fill slope

Safety, State laws, and economic and environmental constraints govern selection of the maximum grade or at least require mitigating measures to lessen the impacts of steep grades. The maximum grade varies with the ability to resist erosion of each type of road surfacing material. Steeper grades normally require additional costs for drainage, surface stabilization, maintenance, and use. Use caution when considering gradients steeper than 8 percent.

Strive to fit the best combination of design elements to the range of grades available for the road. Determine the most desirable combination of grades and other design elements before reaching the design phase. By the time the project progresses to the design phase, little opportunity exists to make significant grade changes within the reconnaissance and survey limits.

Vertical alignment normally governs the speed of empty trucks and light vehicles for grades of 15 percent in the favorable (downhill) direction and 11 percent in the adverse (uphill) direction. The vertical alignment normally governs the speed of loaded trucks for grades exceeding 8 percent in the downhill direction and 3 percent in the uphill direction. The ability of a vehicle to traverse a particular grade depends on vehicle weight, horsepower, and the traction coefficient of the driving surface. If steep grades are necessary, a higher-quality surfacing may be needed to provide the necessary traction and to resist erosion (sec. 44).

Maximum grades should be as follows:

a. Passenger car traffic: 12 percent.

b. Motor homes or vehicles pulling trailers: 12 percent for pitches up to 300 feet.

c. High clearance and four-wheel drive vehicles: 18 percent or as required by State safety regulations.

2. <u>Grade Reduction for Horizontal Curves</u>. It is often advisable to reduce the gradient through a horizontal curve, particularly on steeper grades at shorter radius curves. These curves result in a steeper grade because of the shorter distance traveled along the inside track of the curve. For example, if the centerline grade is 10 percent on a 75-foot radius curve with a centerline length of 100 feet, the grade along the inside track is approximately 12 percent.

Grade reduction is important for switchbacks. When determining road gradient, it is important to consider loaded trucks traveling in both directions. Use the following guidelines for maximum gradients and gradient reductions.

43.2 – Exhibit 01

Grades on Switchbacks

Hauling Direction	Above the Switchback Curve	At the Switchback Curve	Below the Switchback Curve
Favorable	5 percent or less for 150 to 200 feet.	6 percent preferred; 8 percent maximum.	See section 43.2, paragraph 2a.
Adverse	See section 43.2, paragraph 2a.	6 percent maximum.	1 to 2 percent less than the switchback curve grade for 100 feet.

a. Strive to maintain a constant grade through the switchback. To the extent practicable, avoid locating vertical points of curvature within a switchback.

b. To minimize gear shifting and to equalize curve resistance to the vehicle, reduce the switchback curve grade by 0.04 percent per degree of curvature in the approaching grade. For example:

Degree of Curve	Radius of Curve (in feet)	Percentage Reduction
50	115	2
75	76	3
115	50	4.5

Trucks may have difficulty hauling in the adverse direction when they travel on level of service J roads that have a sharp horizontal curve in combination with a steep grade. The position of the trailer in relation to the tractor may cause the outside drivers on the truck to lift, resulting in a loss of traction on the curve. A flat grade or reverse superelevation will aid in providing traction, but should be used only in special situations when advised by engineering judgment. Reverse superelevation should not be used where speed is a factor or where downhill haul will occur.

3. Vertical Curves. Vertical curves are the transition zones between different gradients. Design vertical curves with consideration for environmental effects. Do not locate the low point of a sag vertical curve directly over a culvert or fill where fill slope erosion may be a concern. Instead, locate the low point of a sag vertical curve at a transition point between cut and fill.

Sight distance is the primary consideration in designing vertical curves because changes in grade result in sight restrictions. Attain the desired sight distance by making adjustments in the length of vertical curves. Crest vertical curves present sight distance problems under all conditions. Sag vertical curves normally present a sight distance concern only in terms of providing headlight sight distance during periods of darkness or reduced visibility.

Avoid placing a sharp crest vertical curve at the same location as a horizontal curve to the extent practicable. Avoid minimum length vertical curves to the extent practicable. The following chart shows the guidelines for the minimum length of vertical curves:

Minimum Lengths for Vertical Curves
For crest vertical curves, $L = 3V$ or 50 feet, whichever is greater,
For sag vertical curves, $L = \frac{AV^2}{46.5}$ or 50 feet, whichever is greater, where:
L = length of curve in feet, V = design speed in miles per hour, and A = algebraic difference in grades as a percentage.

Check crest vertical curves against the ground clearance of the design vehicle. To the extent practicable, avoid reducing the ground clearance of the design vehicle by more than 50 percent.

For roads with a design speed of 15 miles per hour or less, it is acceptable to use field-designed vertical alignment that approximates the geometric requirements of vertical curves. Check the vertical alignment to ensure that it allows other design elements, such as stopping sight distance, to be addressed appropriately.

4. Stopping Sight Distance. Stopping site distance is covered in detail in the AASHTO Guidelines. The stopping sight distance for single-lane roads is twice that required for double-lane roads. If adequate stopping sight distance cannot be achieved, construct turnouts or use appropriate signing, to the extent practicable.

43.3 - Intersections

A substantial number of crashes on all roads under all jurisdictions nation-wide occur at intersections. The preponderance of these crashes are the result of driver errors. One type of error is failure to prudently accomplish the task of making decisions about route following. That can distract from the basic driver responsibility of recognizing hazards and taking appropriate action to avoid them. Drivers make navigational mistakes; some drivers make mistakes stop in the roadway; sometimes backing up, instead of proceeding to a location where it is safe to pull off the road and turn around. Another cause of intersection crashes is lack of attention to driving. When drivers are not expecting intersecting traffic; they are unprepared to take appropriate action when surprised by a conflict such as congestion.

While responsibility for driving safely and prudently for conditions is always that of the driver, the design of alignment, grade, cross section, signs, and traffic control devices at or near intersections is important. Doing it well can minimize opportunities for driver error. The following guidelines apply to the design of intersections on National Forest System roads:

a. The sight distance along the main road, as viewed from the main road or from the intersecting road, should be at least equal to the stopping sight distance for the design speed of the main road.

b. Roads intersecting at acute angles tend to limit visibility and restrict the flow of entering traffic to one direction. Thus, the smallest angle formed by intersecting roads should not be less than 60 degrees. Right angle intersections are desirable.

c. To the extent practicable, avoid designing intersections on sharp curves or with grade combinations that make vehicle control difficult.

d. To the extent practicable, avoid intersections that are slightly offset on opposite sides of the main road. More than two roads intersecting at one location may cause traffic management problems.

e. Carry the grade of the main road through the intersection, and adjust the grade of the intersecting road to the grade of the main road. The grade of the intersecting road, as it approaches the main road, should be 6 percent or less. On the intersecting road, at the main road, it is advisable to provide sufficient width for another vehicle to pass a stopped design vehicle and to provide one design vehicle length at a grade of approximately 1 percent for stopping.

f. The width of the main road combined with the radius of the taper of the intersecting road must be wide enough for off-tracking of vehicles entering or leaving the main road.

g. On level of service G and H roads, provide warning, regulatory, and guidance signs and traffic control devices at intersections, as advised by the Manual on Uniform Traffic Control Devices (MUTCD) and engineering judgment.

h. When use of an intersecting road is restricted by a gate, provide for the design vehicle to turn around safely when the gate is closed. In addition, check for consequences for critical vehicles, particularly when critical vehicles may be driven by recreation visitors.

43.4 - Railroad Grade Crossings

Design railroad grade crossings in accordance with applicable laws and regulations. Obtain consultation and review by railroad officials, and obtain their approval when necessary.

Legal and real property rights can differ greatly from crossing to crossing. The situation where the railroad existed before reservation or acquisition of the underlying lands for the NFS is much different from the situation where the railroad was constructed under a special use permit after reservation or acquisition of the underlying lands. Consult with the local Lands staff and the local Office of the General Counsel, as appropriate, regarding rights, permits, and ownership issues at railroad grade crossings.

The geometric design of a road at a railroad grade crossing involves the elements of alignment, profile, sight distance, and cross section. Verify that the critical vehicle can negotiate the vertical curve at the crossing. The requirements may vary somewhat with the type of protective or signal devices used. The traveled way width should be the same on either side of railroad grade crossings and should have all-weather surfacing for a suitable length. It may be advisable to provide sufficient width for vehicles to pass on each side of a railroad grade crossing. The following provide additional guidance on railroad grade crossings:

1. FHWA's The Railroad-Highway Grade Handbook, Publication TS-86-215.

2. The MUTCD.

3. AASHTO's "A Policy on Geometric Design of Highways and Streets."

43.5 - Roadside Design

National Forest System (NFS) roads vary from high-standard, high-speed roads in level of service G to single-lane, native-surface roads built for a specific purpose in level of service J. Engineering judgment should be used to determine appropriate roadside design standards. For roads with more than 400 ADT, use AASHTO's "A Policy on Geometric Design of Highways and Streets" and AASHTO's "Roadside Design Guide" for specific roadside design standards. For roads with less than 400 ADT, use the guidelines in chapter 4 of AASHTO's "Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT <400)." These guidelines state that roadside barriers and clear zones are not cost-effective and should be provided only case by case where advised by engineering judgment. Document design decisions, and maintain the documentation in the project file.

Roadside design can affect safety on low-volume roads. Identify potential hazards based on local conditions, road geometry, and traffic characteristics. Mitigation of potential hazards should include consideration of probability and severity of accidents, environmental impacts, economic factors, and management objectives.

In roadside design, consider the following factors when assessing the probability and severity of crashes, forecasting their effects, and recommending mitigating roadside design measures:

1. Roadside Design Factors:

    a. Crash history (frequency and severity).

    b. Traffic volume and type.

    c. User speed.

    d. Topography and road template.

    e. Visibility.

    f. Horizontal and vertical alignment.

    g. Climatic and surface conditions.

    h. Roadside conditions.

2. Factors Decreasing Crash Probability:

    a. No known crashes or visible evidence of crashes.

    b. ADT of 400 or less.

    c. Drivers who are familiar with the road.

    d. Low speeds on roads with low levels of service (G, H, and I).

    e. Driver expectations of road conditions ahead are met.

    f. Consistent cross-section.

    g. Good visibility.

    h. Changes in alignment and grade do not require rapid deceleration.

    i. Traveled way is clear of snow and ice.

    j. Recoverable shoulders.

3. Factors Increasing Crash Probability:

    a. History of crashes.

    b. ADT exceeding 400.

c. Drivers who are unfamiliar with the road.

d. Speeds exceeding 40 miles per hour.

e. Driver expectations regarding the road ahead are not met.

f. Abrupt changes from the expected road width, shoulder, or surface type.

g. Abrupt changes in vertical or horizontal alignment.

h. Fog, snow, or ice is present during normal seasons of use.

4. Factors Decreasing Crash Severity:

   a. Speeds of 15 miles per hour or less.

   b. Adequate clearance from potential roadside hazards.

   c. Flatter fill slopes.

   d. Good alignment and visibility.

   e. Segregated use (for example, commercial and noncommercial are not mixed).

5. Factors Increasing Crash Severity:

   a. Speeds of 40 miles per hour or more.

   b. Little clearance for roadside hazards or intrusions, or deep or fast water adjacent to the traveled way.

   c. Steep grades.

   d. Abrupt changes in grade or alignment.

   e. Mixed use (for example, commercial and noncommercial).

If an engineering analysis identifies a roadside hazard that should be mitigated, assess the most cost-effective method of managing the accident risk. Balance reduction of risk against the investment required to reduce the risk, and use engineering judgment in the selection of mitigation measures.

Mitigation measures may include clear zones, shielding, or protecting drivers from roadside obstructions with traffic barriers such as guardrails and jersey barriers. The use of guardrails to protect drivers from obstructions generally is not cost-effective for very low-volume roads. Other methods such as delineators, berms, insloping, or varying alignment may be an appropriate and less costly means of reducing hazards. Traffic barriers may be appropriate at sites on low-volume roads where engineering judgment indicates there is a high probability of crashes and barriers are the only practical and feasible means of reducing crash severity. When a guardrail is

determined to be appropriate, apply the most current Federal or State Department of Transportation standards for rails, posts, and terminal sections.

For more information on roadside design, see NCHRP Publication No. 214, "Design and Traffic Control for Low-Volume Roads," and AASHTO's "Roadside Design Guide."

44 - Road Drainage

Drainage is one of the most important elements in road design. All drainage can be classified as surface or subsurface. The classification depends on whether the water is on or below the surface of the ground at the point where it is first intercepted.

1. Surface Drainage. Surface drainage provides for the interception, collection, and removal of water from the surface of roads and slopes. Surface drainage is important, because water on the surface may interfere with traffic or cause erosion and, if allowed to infiltrate, may cause damage to the subgrade.

   There are four principal elements to consider when designing surface drainage systems: surface shapes, surface cross drains, ditches, and culverts. The design may need to allow for debris passage, mud flows, and water heavily laden with silt, sand, and gravel. For projects with small drainages or intermittent streams that might affect fish and other aquatic species migration, consult with appropriate resource specialists to ensure that the design conforms to resource management objectives for the site and applicable directives. FSM 7722 and FSH 7709.56b provide guidance regarding design of bridges and structures.

2. Subsurface Drainage. Road prisms may intercept subsurface water. Subsurface drainage structures collect and remove subsurface water that may weaken the subgrade or road embankment. Properly designed and maintained surface drainage systems may reduce the need for special subsurface drainage structures and may minimize effects on the natural hydrological system. Consider relocating roads whose detrimental effects on subsurface flows cause reduction in soil moisture or drainage of sensitive wetland habitat.

The natural equilibrium of slope hydrology is easily upset by the introduction of manmade systems like roads. The results of poor or improper drainage design can be dramatic and destructive. While road drainage systems collect and efficiently move water away from roads, the results can have unexpected negative aspects. Examples include drainage of meadows and wet areas, reduction of soil moisture, conversion of vegetation, increased runoff rates from the interception of surface and subsurface flow, and increased channel scour and head-cutting from concentration of water flow. Strive to design drainage systems that maximize water dispersion and that use natural sediment filters. To the extent practicable, road drainage should mimic natural drainage patterns and should not interrupt natural hydrological processes.

There are 3 elements critical to road drainage design:

1) Disconnecting the road from the stream system.

2) Preventing storm damage to the road, surrounding cut slopes, fill slopes and ditch lines.

3) Implementing local best management practices in conjunction with National Core Best Management Practices (BMPs) (FS-990a, 2012).

Consult with appropriate resource specialists such as hydrologists, soil scientists and biologists, to ensure that all watershed protection measures are met. For specific drainage design guidance refer to "Water/Road Interaction Technology Series," Publication 9777 1806-SDTDC, San Dimas Technology Development Center.

Only after watershed protection and storm-proofing requirements are met should minimum lifecycle costs be considered. Minimum lifecycle costs should include construction, maintenance and operating costs. Cost should also consider the physical attributes of the watershed and the risk presented by road generated mass failure. Use the most economical drainage measures available that meet RMOs and BMPs. Consult with resource specialists to assess the risk of mass failure, debris delivery and aquatic habitat concerns.

Drainage design should include consideration of rainfall, surface runoff, subsurface flow interception, and stream crossings. Use the best combination of various design elements, such as surface shape, ditches, ditch relief culverts, surface cross drains, fords, subsurface drains, culverts, and bridges. Consult with appropriate resource specialists in ascertaining water and aquatic management objectives for the site.

44.1 - Traveled Way Surface Shapes

Traveled way surfaces may be insloped (toward the cut slope), outsloped (toward the embankment), or crowned (highest point near or at the road center sloping to both sides). Crowned traveled way surfaces are typically used for level of service G and H roads, while insloped or outsloped traveled way surfaces are typically used for level of service I and J roads. The amount of crown or slope varies with the type of surface and is generally less for impervious surfaces, such as asphalt, and more for relatively pervious surfaces, such as gravel or native soils. If the cross slope is too flat, water remains on the traveled way surface for a longer period and may penetrate into the base course and subgrade. A large buildup of moisture below the surface may cause instability and severely reduce the road's load-carrying capabilities. Drainage designs that result in water concentrations usually require more maintenance and present more risk to watersheds if maintenance is deferred than drainage designs that disperse water.

Decisions on traveled way surface shape should consider the resistance of the soil to erosion and the benefits of dispersing water gradually (outslope) or concentrating it at a specific location (inslope). If the road surface is unstable soil and subject to major erosion, then design considerations should include removal, surfacing, hardening, restricted use, or relocation. It may be necessary to stabilize ditches or the toe of the cut slope on insloped or crowned roads to reduce erosion. Removal of water from the traveled way surface becomes more difficult as grade increases.

The decision to inslope or outslope also depends, in part, on the natural slope hydrology; that is, how the undisturbed slope handles water. Convex topography tends to disperse water, and

concave topography tends to concentrate water into defined drainages. Outsloping roads complement convex topography, while insloping roads with well-placed cross drainage tend to work best with concave topography.

1. Crown. Double-lane roads usually have a crown surface. Single-lane roads may have a crown surface. Crown surfaces are more expensive than other traveled way surface shapes to maintain on single-lane roads. A crown surface shares some of the characteristics of both an outsloped and insloped surface.

2. Outslope. Outsloping maximizes the dispersion of surface runoff and, when properly applied, minimizes hydrological impacts. Outsloped roads have the additional advantages of reducing road cut depth, reducing roadway width, and usually lowering construction costs. A ditch is usually not necessary, but drainage concentration from upslope areas may be handled with short ditch sections, culverts, or surface cross drains. Make this determination based on the erosive characteristics of the soil, precipitation, runoff ratios, gradients, and the length of run before the water may be removed.

   Outsloping is generally not appropriate on levels of service G and H roads intended for all weather use. Cross slopes generally between 2 and 4 percent are designed to disperse surface runoff but become slippery when wet or frozen. Consider vehicle stability on the road surface when design elements of outsloping, steep down grades, and sharp outside curves are combined. Consideration to season of use is necessary in choosing the design template.

3. Inslope. Where embankment soil is unstable or on steeper grades where outsloping is not recommended, consider applying an inslope road template. Depending on local conditions, a ditch may be required. Inslope sections collect water and will require cross drains.

For additional guidance on traveled way surface shapes, refer to “Traveled Way Surface Shape,” Publication 9777 1808-SDTDC, San Dimas Technology Development Center.

44.2 - Surface Cross Drains

Surface cross drains intercept and remove surface water from the traveled way, wheel tracks, and shoulders before the combination of water volume and velocity begins to displace the surface materials. Surface cross drains also can serve as ditch relief structures in lieu of a culvert. Surface cross drains are particularly useful for low-volume, low-speed roads during periods of storage (maintenance level 1). When properly constructed, the drains can provide a relatively maintenance-free traveled way. They are beneficial in areas where culverts may plug and overtop resulting in diversion of water down the road surface. Surface cross drains should be designed to prevent erosion and maintain functionality in wet conditions.

There are a variety of surface cross drains, including broad-based (drivable) dips, drain dips and waterbars, open-top culverts, slotted metal pipe, and flexible rubber stripping. For design guidance on surface cross drains, refer to “Water/Road Interaction: Introduction to Surface Cross Drains,” Publication 9877 1806-SDTDC, San Dimas Technology Development Center.

The initial cost of constructing dips and water bars is less than the cost of constructing roadside drainage ditches and purchasing and installing culvert pipe. If dips and waterbars are properly located, designed, and constructed, their maintenance cost is also less than the cost of maintaining roadside ditches and culverts. The costs of other types of surface cross drains may not be less than the cost of culverts.

The disadvantages of surface cross drains are lower travel speeds, poor riding comfort, and discontinuity of blading operations for all drain types except broad-based dips.

To the extent practicable, avoid constructing dips on level of service G and H roads on grades greater than 10 percent, unless specifically designed for the critical vehicle and constructed to appropriate tolerances. On these roads, consider other surface drainage methods such as open-top drains or broad-based (drivable) dips designed to accommodate the critical vehicle.

Dips should discharge runoff in small amounts before runoff can significantly accumulate. For recommended spacing for surface cross drains on insloped, crowned, or unsurfaced roads with no ditch, see section 44.4, exhibit 01. The location of surface cross drains should be reviewed and adjusted as necessary in the field to account for geomorphic features such as stream locations and suitable release areas. Dips skewed from a line perpendicular to the centerline of the road may drain and self-maintain better than dips that are not skewed. However, an unskewed dip normally results in better driving characteristics, minimizes twisting of truck frames, and is easier to maintain with a motor grader.

On roads which are not likely to receive regular surface maintenance, dips and waterbars provide a safety valve for removing water from any wheel ruts that may develop. The design of dips and waterbars on these roads must be done with rutting in mind. The down-grade end of dips (crest) should be designed so that ruts do not readily cut through the crest and fail the dip. The height of the rise at the crest should be at least as high as the depth of potential ruts. The transition back to grade on either side of the crest is a designed length. It may be desirable to stabilize the crest and trough portions of the dips with aggregates or in-place soil treatments to reduce deformation and to maintain stability.

Where a low-clearance truck or tractor-trailer is the design vehicle, the following guidelines apply:

1. Dips should not be located on gradients steeper than 8 percent.

2. Do not locate drainage dips within curves that have radii of less than 100 feet.

3. Maintain constant inslope or outslope throughout the length of dips to avoid the twisting of truck frames.

4. Do not deepen the outlet dips unless the dips are perpendicular to the road.

5. Construct transitions at least 60 feet long in both directions from the low point and the crest to avoid abrupt changes in grade.

6. When appropriate, design to accommodate surfacing or armoring placed through the dip.

Long continuous grades have a tendency to transport large volumes of water and sediment and therefore should be avoided. The use of a grade breaks allow long continuous grades to be broken into smaller segments. A reduction in grade combined with outsloping at convex topography can have the same effect as a surface drain dip and may be easier to maintain than a surface dip.

44.3 - Ditches

When developing the geometric design of ditches, consider the resource objectives for soil, water, and visual quality, maintenance capabilities and associated costs, and construction costs. Ditches can be a major source of sediment if left unarmored or if frequently bladed. Designers should consider larger ditches and erosion control measures to reduce the frequency of required maintenance. Ditch grades should be no less than 0.5 percent to provide adequate drainage and to avoid siltation. Consider outsloping the road and eliminating the ditch when the grade of the road is less than 2 percent.

The following lists typical types of ditches and describes their use.

1. Drainage Ditch. A drainage ditch transports water collected from the road surface or cut slope to the nearest ditch relief culvert or outlet ditch and also drains subsurface water from the roadbed. The ditch is constructed between the traveled way and the adjacent terrain in subgrade material. It should not have slopes steeper than 1V:1.5H.

2. Trap Ditch. A trap ditch is a large drainage ditch that is designed to catch and hold cut bank slough and snow as well as provide effective drainage. Future maintenance requirements need to be considered when designing a trap ditch. Because it is a type of drainage ditch, a trap ditch can perform all the functions of a drainage ditch.

3. Intercepting Ditch. An intercepting ditch protects cut and fill slopes. Consider the use of intercepting ditches in areas with extremely high cut slopes or high embankments in erosive soils or areas that have experienced high-intensity fire with significantly increased surface runoff. To the extent practicable, locate and design intercepting ditches so that erosion caused by intercepted water is no greater than what would have occurred had the water sheeted down the cut slope. Use energy dissipation and erosion control measures to prevent erosion, gullying, and connectivity with streams.

4. Outlet Ditch. An outlet ditch carries water away from a road to prevent the road subgrade from being saturated or eroded. An outlet ditch is typically used in fairly flat ground when the topography does not allow water to run off the road. Locate an outlet ditch at the lower end of a culvert or drain dip or at the point where a roadside ditch daylights onto natural ground. Consider use of energy dissipation measures as needed.

44.4 - Culverts

Low-volume roads are often steep due to economic factors, the need to avoid unstable areas, and a desire to disturb the least amount of land. Ditch relief culverts installed in roads with steep grades, particularly in steep, mountainous terrain with high-intensity storms, have an increased potential for failure. Failure of ditch relief culverts may result in increased ditch scour, extensive erosion of road surfacing, and broad-scale failure of roadway fills. The alternative combination of outsloped roads and surface cross drains to help shed and disperse water quickly from the road surface should be considered. To the extent practicable, avoid draining water onto steep slopes.

Drainage failures may also have a detrimental effect on land below the road. Siltation may degrade water quality and may damage aquatic habitat. Runoff concentration increases surface erosion, mass soil movement, and stream channel scour. Consult with appropriate resource specialists, such as a hydrologist, fluvial geomorphologist, soil scientist, and biologist, as appropriate to address site-specific issues regarding culverts. Follow agency guidelines for designing structures for fish and aquatic organism passage. FSM 7722 and FSH 7709.56b include design data and guidance regarding design and risk analysis of bridges and structures.

Some culverts are considered “bridges” under the requirements of the National Bridge Inspections Standards (NBIS). The classification of and the authority for approval of design of culverts is shown in exhibit 01 of this section.

44.4 - Exhibit 01

Classification and Responsibility for the Design of Culverts and Bridges

Classification and Responsibility for the Design of Culverts and Bridges						
		Any Single Opening Structure with a bottom, regardless of fill depth or depth of invert burial (fn 2)		Any Single Opening Bottomless (Natural channel) Structures with footings that will not have wheel loads in direct contact with the top of the structure [2]		Any Single or Multiple Opening Bottomless (Natural channel) Structures with footings that **has** wheel loads in direct contact with the top of the structure [2]
		(CS) [1] ≤ 20 feet	CS > 20 feet	CS ≤ 20 feet	CS > 20 feet	All spans
Design[3]	Classification	Culvert		Culvert		Bridge
	Responsibility	Forest Design with standards or by qualified engineer.	Design by a certified Bridge Design Engineer (FSM 7722.1 and .2).	Forest Design with standards or by qualified engineer;	Design by a certified Bridge Design Engineer (FSM 7722.1 and .2).	Design by a certified Bridge Design Engineer (FSM 7722.1 and .2).

1. Clear span (CS) is defined as the NBIS opening for a single or multiple opening structures.
2. Design all structures to have a clear span ≥ the design bankfull width.
3. For information concerning multiple opening culverts see FSH 7709.56b, sec. 76 for design, and sec. 91.6 for operation.

All culvert designs should consider storm flows, sediment, and debris. Consider debris loading, access for debris removal, and potential effects from upstream blockages.

1. <u>Ditch Relief Culverts</u>. Ditch relief culverts periodically relieve ditch flow by directing water to the opposite side of the road where the flow can disperse away from the traveled way. Use energy dissipation and erosion control measures to prevent erosion, gullying, and connectivity with streams.

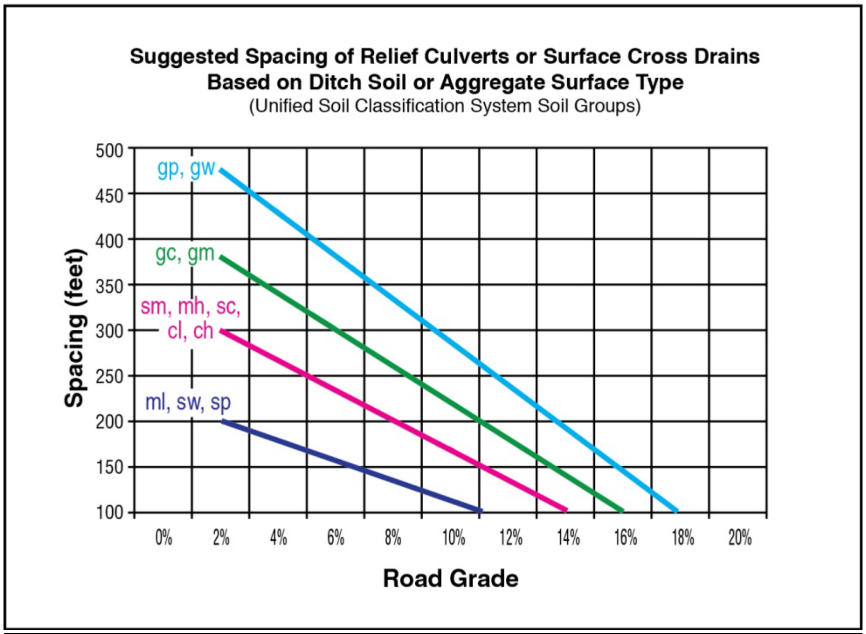
The spacing of ditch relief culverts depends on the road gradient, road surface, ditch soil types, runoff characteristics, and the effect of water concentration on slopes below the road. See section 44.4, exhibit 02, for recommended spacing of relief culverts based on ditch or road surface soil type. The location of culverts should be reviewed and adjusted as necessary in the field based on geomorphic features such as stream locations and suitable release areas.

Ditch relief culvert maintenance can be minimized by proper design. Culverts should be no smaller than 18" diameter or equivalent size pipe arch. When plugging by sediment and debris is a concern larger diameter culverts should be used. A decision to use a culvert smaller than 18" should be supported by a written statement in the project file signed by a qualified engineer that there is no possibility of the culvert plugging.

The following table is intended for reference, actual culvert location depends on the topography as site specific conditions. Consult with appropriate resource specialists to determine site specific BMP’s with respect to culvert spacing on the road segment being designed.

44.4 - Exhibit 02

Recommended Spacing of Relief Culverts or Surface Cross Drains Based on Ditch Soil or Aggregate Surface Type



Ensure pipes are buried at an appropriate depth to prevent damage to the culvert. Provide adequate depth of cover to account for expected surface material losses from traffic, maintenance, and erosion over the design life of the culvert. The minimum depth should equal or exceed the manufacturer's specifications for the particular installation.

Skewing ditch relief culverts from a line perpendicular to the centerline of the road may increase culvert grade and flow velocity, reducing siltation and the possibility of debris plugging the culvert inlet. Do not use skewing to increase the distance between ditch relief culverts. Do not use skewing when water is flowing toward the culvert inlet from both directions, except to reach or fit a natural channel. Skewing may increase the length of culvert necessary for the site. When determining whether to use skewing, consider:

a. Improved bedload and debris flow.

b. Proper dispersion of water below the road surface.

c. Improved flow through the pipe.

d. The additional cost caused by the additional culvert length.

It is also possible to use culverts placed in natural drainages for ditch relief. However, consider the effect of possible sedimentation or increased flows on the natural drainage.

Do not drain ditches into live streams or streams with aquatic life. For more information on culverts, refer to “Relief Culverts,” Publication 9777 1812-SDTDC, San Dimas Technology Development Center.

2. Inlet Structures. Inlet structures may consist of hand-laid rock headwalls, ditch dams, inlet basin liners, drop inlets, metal end sections, or other structures designed for specific conditions at the site. Determine the location of the inlet of relief culverts during design to provide for design of inlet structures. The design of inlet basins should include adequate width for the culvert entrance and for any structure necessary to prevent erosion of the road bed and back slope. Design inlet basin back slopes at a stable slope to minimize the possibility of the culvert’s plugging from ravel or slumping.

Inlet basins trap sediment due to a decrease in water velocity and are a maintenance commitment once installed. Strive to prevent the velocity of ditch water from decreasing in the culvert inlet basin. This results in transported sediment settling and accumulating in the basin, eventually blocking the culvert inlet. The slope of the culvert invert should be greater than the slope of the road ditch to avoid a decrease in ditch water velocity.

Catch basins should be designed for mechanized maintenance. Mechanized maintenance is usually cheaper than hand methods, and it is often necessary to use machinery to load sediment on trucks for hauling to waste disposal areas. An alternative to an inlet basin is to increase the size of the pipe and ensure that skew of the pipe captures and transports the water and sediment delivered to that pipe.

3. Wetland and Meadow Crossings. Care should be exercised in designing wetland and meadow crossings, as they are sensitive to unnatural fluctuations in water level. Since marshy and swampy terrain may contain bodies of water with no discernible current, designing culverts for roads crossing these locations involves unique considerations. Consult with resource specialists, and refer to the “Road/Water Interaction: Introduction to Surface Cross Drains,” Publication 9877 1806-SDTDC, San Dimas Technology Development Center, in connection with design of wetland and meadow crossings.

Design wetland culverts with a nearly flat grade so that water can flow either way and so that the natural water level can be maintained on both sides. The culvert may be partially blocked by aquatic growth and installed with the flow line below the standing water level at its lowest elevation. Consider selecting culvert materials that resist corrosion.

For wetlands and wet meadows that have a slight gradient, place the culvert at the stream gradient, and dissipate the flow at the culvert outlet. Culverts placed too low at the inlet and unchecked flow through the culvert can cause erosion and gullying upslope for considerable distances, lowering the water table and reducing the extent of the wet area. Permeable dams constructed around inlets and outlets can dissipate erosion. Erosion control blankets may be used at outlets, but need to be long and wide enough to dissipate the flow fully before release.

Crossing wet areas may require special subgrade treatment due to wet, soft, organic soils. Geotextile-reinforced fill or subgrade reinforcement may be used. The design should consider the hydraulic effects of the materials used to avoid disrupting wet area drainage. When crossing meadows with more than one defined channel, install culverts in all identified channels. When crossing meadows without a defined channel, use a permeable fill or multiple culverts installed at the same elevation of the meadow surface to allow the natural sheet flow to continue. Head-cuts and erosion in meadows can be restored by employing this strategy and filling in the eroded sections. Always consult resource specialists before undertaking watershed restoration such as repairing head cuts or wet meadow restoration.

44.5 - Subdrainage Systems

1. The design of subdrainage systems should remove water from the subgrade or pavement structure to improve stability and load-bearing capacity, decrease the adverse effects of frost, and reduce safety hazards caused by freezing on the traveled way.

2. Design subsurface drainage systems to:

   a. Intercept groundwater that cannot be intercepted by side ditches before entering the traveled way.

   b. Reduce the hydrostatic pressure behind structures.

   c. Release collected groundwater without causing erosion or silting.

   d. Last as long as the roadway or structure.

3. Because each site is different, conduct a field investigation to determine the best solution. The field investigation may necessitate the:

   a. Review of available soil and geological studies or gathering new data.

   b. Borings or digging test holes to locate groundwater.

   c. Inspection of natural lakes and slopes in the area and studying the natural drainage patterns.

   d. Measurement of discharge when possible.

   e. Test of slope stability.

4. Perforated pipe drains are a common solution, but they do not function properly unless some method is used to prevent the perforations from plugging. The following alternatives prevent plugging, depending upon the characteristics of the soil:

   a. Use of a prefabricated drain, which consists of a geotextile covering one or both sides of a drain core. The core provides open channels for water flow.

b. Surround the pipe with an open-graded aggregate material, which, in turn, is surrounded by a geotextile. The use of fabric eliminates the need for an inverted filter consisting of various-sized gravel and sand layers.

c. Use of a graded aggregate filter. Use of this filter has diminished with the advent of geotextiles.

5. Other types of subsurface systems include:

a. Drilled Drains. For this system, place perforated pipes in holes drilled into cut or fill slopes to intercept the groundwater flow.

b. French or Trench Drains. This system is identical to the drilled drain system, except a perforated pipe is not used. Use open-graded drain rock for the drainage path.

c. Engineered Drainage. This system usually consists of a porous, chemically inert medium covered on one or both faces with a geotextile. Place the system directly in a trench or against a structure and backfill it with excavated material. This system can eliminate the need for special backfill necessary when the drilled drain and French drain systems are used.

6. Select a system that best meets the structural requirements and the corrosive conditions of the soil and water at the site. Because of the complexity of soils in many areas, it is advisable to consult geotechnical engineering specialists about the use and performance of various types of geotextiles and graded aggregate filters.

7. Subdrainage systems may effectively reduce final road costs by decreasing the depth of base rock and subgrade widths, resulting in less clearing and excavation. Lower maintenance costs also may result from a more stable subgrade.

8. The solutions to subdrainage problems can be expensive. Consider as alternatives road use restrictions, such as seasonally reducing or prohibiting traffic until a subgrade dries out. Also consider incorporation of new materials and technology specifically developed for roads in wet regions.

44.6 - Drainage Systems on Stored Roads

Road surface drainage should also be considered if the road is in storage or going to be placed in storage. Installing waterbars and outsloping should be a preferred surface drainage treatment on stored roads. Serious consideration should also be given to the removal of stream crossing structures that are near the end of their service life, smaller than bankfull width, or are a high risk to the watershed and could fail during storage. High risk structures may be structures in very sensitive habitat that have a plugging or overtopping flow risk. Watershed specialists should be consulted on whether stored structures are high risk structures.

45 - Erosion Control and Watershed Protection

Minimize soil displacement from roads. Factors that influence road impacts on soil and water resources include route location, geometric standards, drainage design, and long-term erosion control features. Include measures to avoid or mitigate erosion and to provide structural or vegetative treatments.

45.1 - Permanent Erosion Control and Watershed Protection

Mitigate long-term impacts on soil and water quality by incorporating cost-effective measures into the design. Specific requirements may be found in applicable Forest Service directives, regulations, and statutes, including Section 10 of the National Forest Management Act (16 U.S.C. 1600), the Clean Water Act, and their implementing regulations. Additional requirements may be outlined in BMPs at the regional or forest level.

Consider the following erosion control and mitigation strategies during road design:

1. Design, treatment, and revegetation of cut and fill slopes to control surface erosion. This includes conservation of top soil during initial excavation, temporarily placing it in stockpiles, and using it for revegetation of slopes once the road is constructed.

2. Inclusion of mitigation measures such as berms, dips, oversized drainage features, and debris control to minimize runoff. Additional slope protection measures that may be beneficial when significant amounts of water are anticipated on slopes include but are not limited to rock blankets, gabion blankets, down spouts, flumes, mulch netting, and plantings.

3. Use of smaller cuts and fills pose less significant erosion problems. Erosion potential is reduced because the area exposed or disturbed is smaller, and if a failure does occur, much less material is involved.

4. Design of flatter slope ratios to reduce soil loss from slides and slumps. One way to determine mass stability is to analyze successful practices on similar land types. Geotechnical assistance may be necessary where bedrock characteristics or soil stability is unknown.

5. Control of erosion by placing sedimentation basins between large cuts or fills and critical waterways.

6. Use of full bench construction when the natural side slopes exceed 55 percent. This method usually results in excavating and end-hauling throughout the steep area.

Where problem cut and fill slopes are encountered in the vicinity of perennial streams, consider using more extensive erosion control measures. Use erosion control references specific to local conditions and the geographic location. Federal agencies such as the Natural Resources Conservation Service, FHWA, and the U.S. Environmental Protection Agency as well as many

State agencies publish erosion control references. The most current erosion control strategies are available on the internet.

45.2 - Temporary Erosion Control and Watershed Protection

Temporary erosion control measures are incorporated during construction. Ensure that road construction contracts specify contractor responsibility for mitigation of erosion from construction activities. Develop erosion control plans for road construction projects that address implementation as well as removal of temporary erosion control measures. For example, the requirements may include constraints on how much pioneer road or excavated area may be open at any given time or the amount of work that may be done without requiring seeding or revegetation. Include winterization if construction is likely to extend beyond one construction season. Specify that the contractor's operations must meet all applicable legal requirements. Water quality standards may vary State to State. Therefore, consult with local resource specialists to identify applicable Clean Water Act and other water quality requirements.

45.3 - Aquatic Habitat Protection

As appropriate and applicable, include design measures to protect aquatic habitat. Consult local resource specialists regarding site-specific issues and appropriate potential mitigation measures. As appropriate and applicable, conduct field reviews to verify that the design provides adequate protection for aquatic resources. To the extent practicable, avoid channelizing streams.

45.4 - Disposal of Waste

Deposit waste from road construction at locations that are not susceptible to erosion and mass failure. In some cases, it may be necessary to designate separate disposal areas for specific types of waste, such as rock and common excavation.

If it is not possible to find flat sections of ground to deposit the excavated fine material in fills or to haul the waste to a designated disposal area, consider mitigating measures, such as relocating the road, installing retaining structures, or constructing silt basins.

Coordinate the location of waste areas with the appropriate resource managers or specialists. If waste may be used as construction material incorporated in another project, consider stockpiling the waste. In some areas, construction of low earth mounds can reduce landform contrasts associated with road construction. For further discussion of aesthetic treatment of waste, see "National Forest Landscape Management," Volume 2, chapter 4, Roads.

45.5 - Retaining Structures

Consider using retaining structures to reduce disturbance to the landscape and environment by decreasing the quantities of excavation and fill material for construction. In steep terrain where there are slope stability problems or environmental constraints, retaining walls may be a practical

and economical solution. When visual quality is a concern, design should strive to conform to natural topography and the surrounding terrain. Visual quality concerns may also require careful selection of materials or modification of the form and line of finished structures.

Retaining structures should be designed by qualified engineers (FSM 7722). Specific information on types and use of retaining structures can be found in the Retaining Wall Design Guide, EM-7170-14, and the Slope Stability Guide, EM-7170-13.

46 - Utilities and Other Existing Uses, Rights-of-Way and Construction Easements

1. Utilities and Other Existing Uses. Utilities and other uses operated by the Forest Service, other governmental agencies, utility companies, or individuals may be located in the project area. Before beginning the preliminary survey for road construction projects, obtain information about the exact location, type, and size of existing utilities and other uses in the project area. Design documents should include a list of the holders of special use authorizations and their authorized uses in the project area.

Before beginning the design, become familiar with Forest Service utilities, other utilities, and other uses authorized by a special use authorization in the project area. Furnish the local Lands staff with the inventory of utilities and other uses in the proposed route, an assessment of potential conflicts, and a list of the resource specialists required for their resolution. Work closely with the local Lands staff to coordinate issues involving other authorized uses in the project area. Special use authorizations typically reserve the right of the Forest Service to use or allow others to use any part of the permit area for any purpose, including road construction. Authorizations also typically provide that permit holders must move permitted utilities at the holder’s expense, should those utilities interfere with future Government needs for construction of infrastructure.

As necessary, develop criteria to address requirements for specific types of utilities to be accommodated. Utilities such as above-ground power and telephone lines, underground power lines, water mains, sewers, fiber optic cables, telephone lines, irrigation pipes, and oil and gas lines have specific requirements that must be addressed. Refer to AASHTO’s “A Guide for Accommodating Utilities within Highway Rights-of-Way,” for general criteria in this context. Utility owners may wish to prepare the designs, drawings, and specifications for any revision or relocation of their utilities needed for road construction. Their road drawings and specifications must include criteria to address applicable requirements and must provide for coordination of any adjustment in their utilities with appropriate phases of the road design. An alternate road location may be necessary to avoid existing utilities that cannot be relocated or crossed economically. Coordinate with affected utility owners during the design phase. Strive to resolve conflicts during the early stages of design. To avoid lengthy delays, submit preliminary drawings to the utility owners as early as possible for their comments and recommendations.

There are hazards associated with constructing roads near gas and oil pipelines and high tension power lines. It may be necessary to use special safety measures and features to protect both the utility installation and road users. Where possible, ensure that utilities are not situated under the traveled way, except where a utility must cross a road. Utilities

should be placed through larger conduits when they cross roads. These measures minimize road damage and disturbance to traffic during maintenance and reconstruction of utilities.

In the road construction contract, identify the location of affected utilities, and enumerate the contractor's responsibilities for them. Identify who is responsible for any work, necessary permits, coordination, and relocation costs involving the utilities.

2. Rights-of-Way. The Forest Service must obtain a right-of-way for road construction projects that will cross private land or other lands not under the administration of the Forest Service. Consult with the local Lands staff and, if appropriate, the local Office of the General Counsel, during project planning to coordinate right-of-way acquisition. Failure to do so may delay the project, create complications during construction and operation of the road, or result in project cancellation. See FSM 5460 and FSH 5409.17 for further guidance on obtaining rights-of-way.

To establish a right-of-way on the ground, it may be necessary to have a right-of-way plat showing the road centerline and widths, metes and bounds for the right-of-way, a legal description and identification of ownership of the underlying land, ties to survey monuments, and other figures and measurements. Show the scope of rights-of-way obtained for a project on construction plans.

Determine the approximate right-of-way width during design. Make the right-of-way width sufficient to accommodate the roadway and roadside. Often the Forest Service has existing agreements with non-Federal landowners that provide for a specified right-of-way width. Uniform widths are easier to describe and locate on the ground. However, vary widths as necessary to minimize the acquisition of rights-of-way across high-value or intensively used land.

3. Construction Easements. Acquire short-term easements when road construction cannot be accomplished within the existing right-of-way. Identify temporary easement requirements during project development. Consult with the local Lands staff before beginning the design to plan and coordinate easement acquisition and to avoid complications during construction.

47 - Materials

A geotechnical and materials investigation is an integral part of any road project design. The investigation should include the delineation, classification, and description of the engineering characteristics of the road construction materials and should locate potential drainage, erosion, settlement, and stability problems. A layer of topsoil may hide defects or abrupt changes in materials. Knowledge of subsurface conditions helps in anticipating many design problems.

Before starting a road design, review any information available about the materials for the project (secs. 22.3 and 36). At a minimum, obtain the materials classification notes compiled by an experienced person who has walked over the proposed route. For more complex projects, it may be necessary to obtain more detailed information, such as:

1. Environmental features and concerns, such as mine tailings, leachate from abandoned mines, materials containing heavy metals, or other potentially hazardous materials.

2. Geological features such as bedrock type and characteristics, rock fall areas, existing landslides, and earthquake potential in the area.

3. The depth, thickness, and classification of each layer of material that may influence the design.

4. The engineering or behavioral properties of the materials along the proposed route and in proposed borrow sources.

5. The depth and character of groundwater in the project area.

If problem areas are identified, it may be necessary to conduct an intensive materials investigation prior to design.

47.1 - Slopes

Selection of cut and fill slopes may have a significant effect on initial, operating, and maintenance costs and environmental disturbance. Therefore, consider:

1. Classification, strength, and variation of materials in the project area.

2. Resource management objectives, including acceptable level of risk.

3. Design criteria.

4. Requirements for revegetation.

Consideration of these factors may result in selection of slopes that allow ravel and small slumps in areas where environmental constraints would not be exceeded, where the road's level of service is low, or the use of the road is intermittent.

When selecting slope ratios in design, balance the additional cost of constructing roads with flatter slopes against the additional cost of maintaining roads with steeper slopes. Factors that affect slope stability include the material used, their steepness and height, subsurface moisture, rainfall, exposure to sunlight, compaction, and vegetative cover. When available, use data from geotechnical investigations and testing in designing slopes. Use slope stability analysis to select proper slope ratios. The use of compound slopes can be effective when material types change within the cross section.

Rounding at the tops and ends of cut slopes may reduce erosion. However, given its cost, rounding is usually appropriate only when trying to retain a natural effect by blending the disturbed area with the natural ground.

Use cut ratios appropriate for the rock type and orientation when designing rock cuts to minimize raveling or falling rock. A true vertical slope next to a traffic lane cut can create a roadside

hazard with no room for rock fall. Laying back the slope is an appropriate measure for safety even if the rock will stand at a vertical slope. A common slope in solid rock is 4V:1H. Consider using benching and trap ditches when designing rock cuts to plan for debris from raveling or falling rock.

In steep, mountainous terrain, it is sometimes difficult to establish catch points without developing long sliver cuts or fills. Avoid sliver fills by using full bench construction on slopes greater than 55 percent. If necessary, employ special drainage and stabilization features, construction techniques, or retaining structures. Fill slopes can sometimes be steepened by using special compaction, reinforcement methods, or constructing fills composed of rock.

47.2 - Pavement Structure

The pavement structure consists of one or more layers of base material and a surfacing course. The structure supports the traffic and reduces the load on the subgrade by distribution through designed layers.

Pavement structures are either rigid or flexible. Rigid pavement includes plain or reinforced concrete and soil cements with or without a surface course. All other pavement, such as macadam, bituminous concrete, cold road mix asphalt, and bituminous surface treatment, is flexible. Most pavement structures on NFS roads are surfaced with native soils or aggregates such as gravel, stone, slag, or volcanic cinders. Aggregates may be screened, crushed, or hauled directly from pits.

The pavement structure is used to stabilize the roadbed and support the estimated volume of traffic. Additional benefits include dust control and reduced sediment transport. Land management plans, sound engineering principles, adequate geotechnical expertise, and economic analysis influence selection of the appropriate pavement structure.

Roadbed widths should be constructed to accommodate future pavement structures, including widening and surfacing.

1. Surfacing Considerations. Considerations for surfacing include cost, efficient traffic management, structural requirements, and resource protection.

   a. The following factors apply to consideration of traffic management and structural requirements:

   (1) Current and projected road use.

   (2) Current and projected traffic type and volume.

   (3) Seasons of desired use.

   (4) User safety, such as past accidents, near misses, and the current and proposed design speed and alignment.

(5) Available resources to construct and maintain the road at the desired level of service.

(6) Tire pressure management.

b. The following factors apply to consideration of resource protection:

(1) Requirements of applicable BMPs.

(2) Whether road use restrictions or roadway surface drainage and erosion protection can adequately mitigate adverse impacts.

(3) Whether road impacts during periods of use and non-use significantly affect water quality.

(4) Whether adverse impacts outweigh repair and maintenance costs.

(5) Availability of resources to address traffic-generated maintenance needs, such as rutting of native-surfaced roads that might result from late fall use by hunters.

If traffic considerations do not require surfacing, and if resource impacts are not significant or may otherwise be mitigated, do not use any surfacing. Instead, implement other mitigation measures, such as drainage and dust abatement. Use the surfacing decision tree found in the Earth and Aggregate Surfacing Design Guide, EM-7170-16, to determine the need for surfacing.

Aggregate Surfacing Considerations. Aggregate surface courses are used to:

1. Support traffic within acceptable deformation limits,

2. Resist the abrasive action of traffic, and shed a large portion of precipitation, thereby reducing erosion.

The primary purpose of aggregate base courses is to transfer traffic loads to the underlying layers within acceptable deformation limits. The base course may also be designed to shed water that infiltrates the surface course depending on the type of aggregate surface course used. If the surface course is designed to shed surface water, the base course would normally have less fines than the surface course.

When advised by engineering judgment, use an aggregate subbase or geosynthetic subgrade reinforcement as an additional layer for distributing traffic loads when subgrades are extremely weak or when frost action is severe and would seriously damage an asphalt surface course.

Select the amount and type of aggregates based upon traffic, cost, road gradient, drainage, soil conditions, and available materials. Aggregate may not be necessary for level of service J roads. Assess physical conditions in the field and the natural variability of soils. For example, designs for wet seepage areas may be different from those for poor

soils in well-drained areas. The reduction of aggregate thickness from an optimum design perspective may be a valid management and technical decision, after assessment of possible risks, costs, and other relevant factors.

a. Seasonal Use. Considerable savings in aggregate surfacing are possible if traffic can be restricted during wet periods. If roads are designed for seasonal use, manage traffic to conform to that design. Include seasonal haul restrictions in timber sale contracts.

b. Specifications. Consider economically available materials and local experience to write specifications for aggregate surfacing based on the intended use. Marginal aggregates may be acceptable where high-quality, commonly specified materials are not economically available. Be specific as you draft the specifications for design conditions. Assess whether the requirements in the specifications are economically justified, and assess whether standard requirements in the specifications need to be modified or removed.

For example, naturally occurring materials which meet the plasticity index (PI) requirement (AASHTO T90) may not be available. However, some rock fines display adequate binding characteristics that do not show up in the PI test. If the PI requirement does not apply, delete it from the specifications. Another example is the use of aggregates with marginally low durability index test results (AASHTO T210) on low-volume roads. If the rock is crushed to a coarser grade initially, it may degrade under traffic and provide satisfactory performance for some time. Under these circumstances, it may be appropriate to remove the durability index test requirement from the specifications. In addition, marginal materials may be made acceptable by blending, scalping certain sizes, wasting certain sizes, or washing if these options are recognized in the design phase and provided for in the specifications.

When preparing specifications for surfacing of level of service I and J roads, user comfort, convenience, and speed of travel are not considerations. If surfacing is specified, there is a range of choices, such as pit run, shot rock, screened rock, crushed to a maximum size, and crushed to a specified gradation.

c. Correlation of Soil Strength to Soil Type. In the preliminary stage of road base and road surfacing design, correlate soil strength to soil type using the results of all soil strength tests, such as CBR and R-value, performed locally. Use the correlation to develop alternative designs with the minimum amount of new testing. If deemed appropriate based on an assessment of risks, costs, and other relevant factors, conduct a verification strength test on the selected design.

d. Variation of Surfacing Thickness. Road surfacing thickness is often designed to address worst-case soils and subgrade conditions. If worst-case conditions do not exist over a large portion of a project, it may be economical to vary surface thickness along the road. In addition, more aggregate wear may occur on steep grades and

horizontal curves than on flat segments. It may be appropriate to vary surfacing thickness depending on site-specific needs for aggregate replacement.

e. Spot Surfacing. Roads often include sections of structurally inadequate native soils. It may be difficult to locate the extent of these sections without an extensive subsurface soils investigation. The amount of spot surfacing may be adjusted during construction.

f. Traction or Erosion Control. Aggregate surfacing may be an effective way to improve traction or control erosion on steeper grades. In these cases, 1 to 2 inches of aggregate is usually adequate for the steeper grades.

g. Limiting Surfacing of Turnouts on Low-Volume Roads. Where traffic and subgrade conditions permit, it may be possible to reduce aggregate depth on turnouts on low-volume roads.

h. Use of Marginal Aggregates. Some aggregates do not meet common standards of quality aggregate, that is, they are in poor gradation, have excessive fines or poor resistance to traffic or weathering, or have excessively deteriorated to plastic fines. The use of marginal-quality aggregate at appropriate depths may be adequate. Mixing marginal aggregate with quality aggregate or other additives may be another cost-effective alternative. American Society of Testing and Materials (ASTM) Technical Publication 774 and FHWA Reports RD-81-176 and RD-82-056 include recommendations with regard to the use of a variety of marginal aggregates. When considering marginal aggregates, utilize the expertise of individuals who have experience with local materials and conditions.

i. Stabilization. Stabilization methods may be used to improve aggregate used for the road base or road surfacing. There are many different types of stabilization methods and materials available, including Portland cement, lime, fly ash, bitumens, chlorides, and organic cationic compounds. Stabilization may involve mixing a poor material with a higher-quality material, such as mixing clean sand in with a silty soil.

The type and amount of stabilizing agent depends on many factors, and each agent has its own strengths and limitations. There are many sources of information on the selection and use of these agents, including manufacturer's associations such as the Portland Cement Association, the Lime Association, and the Asphalt Institute; professional publications such as those of ASTM, AASHTO, and Transportation Research Board, FHWA and Forest Service reports; and manufacturers' technical literature. A good reference is FHWA's "Soil and Base Stabilization and Associated Drainage Considerations Volumes I and II," Report No. FHWA-SA-93-004. Local experience is an additional source of information.

j. Sand Stabilization With Topsoil or Geocells. Sand can be an excellent road building material if stabilized or confined. Mixing topsoil and organic duff during construction or maintenance helps to stabilize sand. Plastic geocells filled with sand or rock may also provide a stable surface.

k. Geosynthetics (sec. 47.4). Geosythetics may be used in designing aggregate-surfaced roads over poor subgrade soils. Geotextiles are used for separation and geogrids are used to reinforce soil structure. The amount of aggregate surfacing material required can be reduced by using appropriate geosynthetics.

l. Weak Subgrades. For weak subgrades, consider various stabilization techniques to strengthen the subgrade rather than increasing the pavement structure. In addition to the most common method, compaction (sec. 47.3), stabilization using lime, cement, asphalt, blends of sands and clays, various chemicals, or the use of fabrics has been successful. The references for stabilization (sec. 47.2, para. i) and geosynthetics (sec. 47.4) also apply to weak subgrades.

m. Surfacing Thickness. Use the Earth and Aggregate Surfacing Design Guide for Low-Volume Roads, EM-7170-16, to design the necessary thickness for aggregate-surfaced roads.

n. Seasonal Frost Conditions. For seasonal frost conditions, use "Revised Procedures for Pavement Design Under Seasonal Frost Conditions," published by the U.S. Department of Defense, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Special Report 83-27, to determine the appropriate pavement structure.

o. Dust Abatement. When addressing dust abatement, consult the Dust Palliative Selection and Application Guide, Publication 9977 1207, San Dimas Technology and Development Center.

3. Other Surfaces. Other surfaces may consist of a road mix or bituminous surface treatment, bituminous concrete, Portland cement concrete, or reinforced Portland cement concrete. The design of an asphalt or concrete surface course depends upon the volume and composition of traffic and available materials and construction funds. Usually, it is possible to achieve economy of construction by making full use of local materials. Design these pavement surfaces using the latest version of AASHTO's "Guide For Design of Pavement Structures."

47.3 - Compaction

Compaction should be considered to improve the stability of soil through the increase of soil strength and the restriction of water movement. Compaction:

1. Permits the construction of stable fills using local material;

2. Allows steeper fill slopes;

3. Decreases erosion on fill slopes, thereby decreasing the need for fill widening;

4. Increases the load-carrying capacity of the subgrades and base courses, thereby decreasing the need for surface rock (this may require compaction in cut areas as well as fill areas); and

5. Provides additional lateral support for structures such as culverts and bridge abutments.

Compaction can also reduce settlement of fills. Settlement can be problematic for deep fills, asphalt paved roads, or bridge approaches. Increasing compaction of most aggregate base and surface courses provides longer life with less maintenance. Asphalt concrete surface courses placed over well-compacted bases are less prone to cracking and deflection.

47.4 - Geosynthetics

Geosynthetics have various functions. Selection of the proper geosynthetic material is based on its properties and limitations. When considering geosynthetics, use FHWA's "Guidelines For Use of Fabrics in Construction and Maintenance of Low-Volume Roads," Report No. FHWA-TS-78-205, to determine the necessary geotextile and material depth. Geosynthetics may perform the following functions more economically and more effectively than other materials:

1. Separation. Geotextiles are useful for separation because they can keep two unlike materials apart. The following are typical applications:

    a. Separation of zoned sections of unlike materials within an embankment.

    b. Separation of an aggregate base from the subgrade.

    c. Separation of temporary and long-term aggregate or other material.

    d. Separation of frost-susceptible soils into distinct layers, thereby breaking the continuity of the capillary flow zone.

2. Reinforcement. Geosynthetics are useful for subgrade, base course, or pavement reinforcement because they decrease the level of stress in the foundation soil by spreading the load over a large area. Reducing the stress decreases the chances of failure and settlement. Geosynthetic reinforcement can be used to:

    a. Build roads over marshes, swamps, peat soils, or compressible fine-grained soils.

    b. Build roads of almost any type over permafrost, muskeg, and other soils in cold weather regions.

    c. Construct geogrid walls and reinforcing selected zones. In some instances, geotextiles may be used depending on the strength requirements.

    d. Reduce the need for removing material that may be unsuitable.

    e. Contain soils that would spread laterally if left unconfined.

    f. Place bituminous overlays on existing pavements reduces the amount of cracking in new pavement caused by upward reflection of cracks in the old pavement

g. Reduce the thickness required in asphalt pavements when used as base course reinforcement.

h. Construct reinforced embankments and subgrades (see "Deep Patch Road and Embankment Repair," Publication 0577 1204 — SDTDC, San Dimas Technology Development Center, October, 2005).

3. Drainage. Geotextiles are useful in many drainage installations because of their controlled permeability. Geotextile drainage applications can be used to:

a. Prevent migration of soil fines into aggregate or pipe underdrain systems, thereby eliminating the need for an inverted filter.

b. Prevent the migration of coarse material in a filter blanket into the adjacent soil.

c. Provide a flow path for water in an underdrain system and behind retaining walls.

4. Erosion Control. Geotextiles and geogrids can be used for erosion control to:

a. Protect embankments where the geogrid holds the soil in place while allowing vegetative growth.

b. Protect against erosion at culvert inlets and outlets.

c. In combination with riprap, acting as erosion control mattresses to protect slopes adjacent to flowing water.

d. Serve as silt fencing to block the movement of soil by water or wind.

5. Forms. Geotextiles can act as forms to be filled with other materials. They can conform to the shape and topography of the surface on which they are placed. Their controlled permeability allows the escape of air or water but contains the injected permanent material. The following are examples of applications for forming:

a. French drains.

b. Cellular mats.

c. Retaining wall construction.

d. Stream bank stabilization and erosion protection systems.