Roadway Geometric Design II: *Cross-Sections and Road Types*

Course No: C06-017
Credit: 6 PDH

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INTRODUCTION

This course is the **second** in a series of three volumes that summarizes and highlights the geometric design process for modern roads and highways. Subjects covered include: *cross-section elements (lane widths, shoulders, roadside design, medians, drainage channels); local roads; collector roads; rural and urban arterials;* and *freeways.* The contents of this document are intended to serve as guidance and not as an absolute standard or rule.

When you complete this course, you should be familiar with the general guidelines for roadway cross-sections and different road types. The course objective is to give engineers and designers an in-depth look at the principles to be considered when selecting and designing roads.

The *American Association of State Highway and Transportation Officials (AASHTO)* publishes and approves information on geometric roadway design for use by individual state transportation agencies. The majority of today's geometric design research is sponsored and directed by AASHTO and the Federal Highway Administration (FHWA) through the National Cooperative Highway Research Program (NCHRP).

For this course, AASHTO's **A Policy on Geometric Design of Highways and Streets** (also known as the "Green Book") will be used primarily for fundamental geometric design principles. This text is considered to be the primary guidance for U.S. roadway geometric design.

This document is intended to explain some principles of good roadway design and show the potential trade-offs that the designer may have to face in a variety of situations, including cost of construction, maintenance requirements, compatibility with adjacent land uses, operational and safety impacts, environmental sensitivity, and compatibility with infrastructure needs.

The practice of geometric design will always be a dynamic process with a multitude of considerations: driver age and abilities; vehicle fleet variety and types; construction costs; maintenance requirements; environmental sensitivity; land use; aesthetics; and most importantly, societal values. Despite this dynamic character, the primary objective of good design will remain as it has always been – to provide a safe, efficient and cost-effective roadway that addresses conflicting needs or concerns.

ROADWAY CROSS-SECTIONS

Roadway geometric design consists of the following fundamental three-dimensional features:

Vertical alignment - grades and vertical curves ("profile")
Horizontal alignment - tangents and horizontal curves ("centerline")
Cross section - lanes, shoulders, curbs, medians, slopes, ditches, and sidewalks

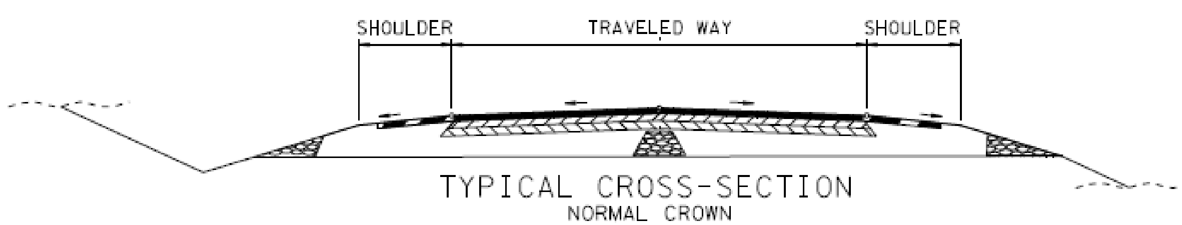
Combined, these elements contribute to the roadway's operational quality and safety by striving to provide a smooth-flowing, crash-free facility.

Roadway geometric design is a dynamic process with a multitude of considerations, such as *driver age and abilities; vehicle fleet variety and types; construction costs; maintenance requirements; environmental sensitivity; land use; aesthetics;* and most importantly *societal values.*

Engineers must understand how all of the roadway elements contribute to overall safety and operation. Applying design standards and criteria to 'solve' a problem is not enough.
The fundamental objective of good geometric design will remain as it has always been **– to produce a roadway that is safe, efficient, reasonably economic and sensitive to conflicting concerns.**

TRAVELED WAY

AASHTO defines the roadway's traveled way as *"the portion of the roadway for the movement of vehicles, exclusive of shoulders and bicycle lanes".* This area usually contains two or more lanes for roadway traffic.



(Ref: TDOT, Standard Roadway Drawings)

Surface Type Criteria

Initial cost	Traffic volume & composition
Soil characteristics	Climate
Maintenance cost	Pavement performance
Availability of materials	Energy conservation
Service-life cost	

Important geometric design considerations include the effect on driver behavior, surface resiliency, drainage ability, and skid resistance (see *AASHTO Mechanistic-Empirical Pavement Design Guide).* The number of required roadway lanes is typically determined by the analysis procedures in the *Highway Capacity Manual* for the level of service desired. Signalized intersections are also an important factor controlling the capacity of an urban roadway.

Cross Slope

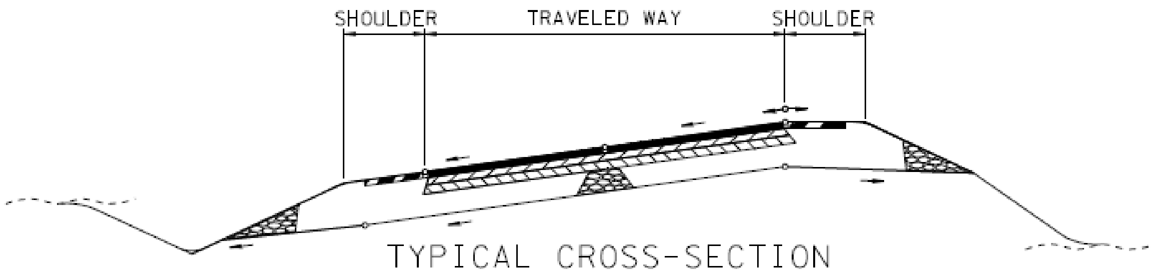
Cross slopes on **undivided** roads have a high point (crown) in the center and slope downward toward the roadway edges. These downward slopes can be plane, rounded, or a combination of both.

Plane - *Slope break at crown line*
Uniform slope on each side

Rounded - *Parabolic cross-section*
Rounded surface at crown line
Increasing slope toward edges

The rounded section is beneficial for roadway drainage due to its steepening cross slope toward the edge of traveled way. However, disadvantages include: difficult construction; excessive outer lane cross slopes; and pavement transitions at intersection areas.

Pavement cross slopes on **divided** roadways can be unidirectional or crowned separately (i.e. undivided road). Roadways with separate crowns may be advantageous for their drainage ability but may require more drainage facilities for stormwater runoff. Unidirectional cross slopes provide more driver comfort for lane changing and drain toward or away from the roadway median. Drainage toward the median helps free the outer lanes from surface water. Drainage away from the median minimizes drainage (savings in structures) and simplifies intersection treatment.



(Ref: TDOT, Standard Roadway Drawings)

The rate of roadway cross slope is a crucial design element for cross-sections. For curved locations, the outside edge of the road is **superelevated** above the centerline. Since the road is banked toward the inside of the curve, gravity forces the vehicle down near the inside of the curve and provides some of the centripetal force needed to go around the curve.

Cross slopes over 2 percent are perceptible to motorists and may require a conscious effort in terms of vehicle steering. Steep cross slopes increase the chances of lateral skidding on wet or icy roadways or when making emergency stops on dry pavement.

The accepted range of cross slope for paved two-lane roadways (**normal crown**) is *1.5 to 2 percent*. Any effect on steering is barely perceptible for vehicles operating on crowned pavements. Cross slopes should not exceed 3% on tangent alignments – unless there are three or more lanes in one direction. Cross slope rates over 2 percent are unsuited for high-speed roadways (crowned in the center) due to a total rollover rate over 4 percent. Heavy vehicles with high centers of gravity would have difficulty in maintaining control when traveling at high speeds over steep slopes.

Steeper cross slopes (2.5 percent) may be used for roads subject to intense rainfall that need increased surface drainage. Reasonably steep lateral slopes are desirable to minimize ponding on flat roadway sections due to imperfections or unequal settlement. Completely level sections can drain very slowly and create problems with hydroplaning and ice. Open-graded pavements or pavement grooving may be used to help water drain from the roadway surface.

Greater cross slope rates need to be used for unpaved roadways. Due to surface materials, increased cross slope rates on tangent sections are needed to prevent water absorption into the road surface.

A minimum cross slope of 1.5% is suggested for curbed pavements. Steeper gutter sections may permit lower cross slope rates.

AASHTO provides tables from which desired superelevation rates can be determined based on design speed and curve radius. These tables are incorporated into many state roadway design guides and manuals.

Skid Resistance

With skidding incidents being a major safety concern, roadways need to have adequate skid resistance for typical braking and steering maneuvers. Crashes due to skidding cannot be written off simply as *driver error* or *driving too fast for conditions.* Vertical and horizontal geometric design should incorporate skid reduction measures (pavement types, textures, etc.) for all new and reconstruction roadway projects.

Causes of Poor Skid Resistance

Rutting – causes water accumulation in wheel tracks
Polishing – reduces pavement surface microtexture
Bleeding – covers pavement surface microtexture
Dirty pavements – loses skid resistance when contaminated

Skid resistance corrective actions should produce high initial durability, long term resistance (traffic, time) and minimum resistance decrease with increasing speeds.

LANE WIDTH

The selection of a roadway lane width can affect the facility's cost as well as its performance. Lane widths are influenced by: driver comfort; operational characteristics; crash probability; and level of service.

Drivers typically increase their speeds with wider traffic lanes - so it may be appropriate to use narrower lane widths that are compatible with the alignment and intended speed at locations with low design speeds and restricted alignments. Using a **typical lane width of 12 feet** reduces maintenance costs and provides adequate clearance between heavy vehicles on two-lane, two-way rural highways with high commercial vehicle traffic.

Typical Lane Widths

Range: *9 to 12 feet*
High speed, high volume highways: *12 feet (predominant)*
Urban areas with lane width controls: *11 feet*
Low-speed facilities: *10 feet (acceptable)*
Rural low-volume roads & residential areas: *9 feet (acceptable)*

Narrow lanes and restricted clearances make vehicles operate closer laterally than normal – affecting the roadway's level of service. The capacity is impacted by the reduced effective width of the traveled way due to restricted lateral clearance. The *Highway Capacity Manual* provides further information regarding the effect of lane width on capacity and level of service.

Although the total roadway width is a critical design decision, pavement marking (stripes) actually determines lane widths. For locations with unequal-width lanes, outside (right) wider lanes provide more space for heavy vehicles, bicycles, and lateral clearance.

At intersections and interchanges, auxiliary lanes (10-ft minimum) should be wide enough to facilitate traffic. An optimal lane width of 10 to 16 feet is appropriate for continuous left-turn lanes.

AASHTO Guidelines for Geometric Design of Very Low-Volume Local Roads provides alternative design criteria for local roads and collectors with less than 400 vehicles per day. It may not be cost-effective to design low-volume roadway cross-sections using the same criteria for high volume roads. *NCHRP Report 362 – Roadway Widths for Low-Traffic Volume Roads* contains additional details for low-volume rural and residential roadways.

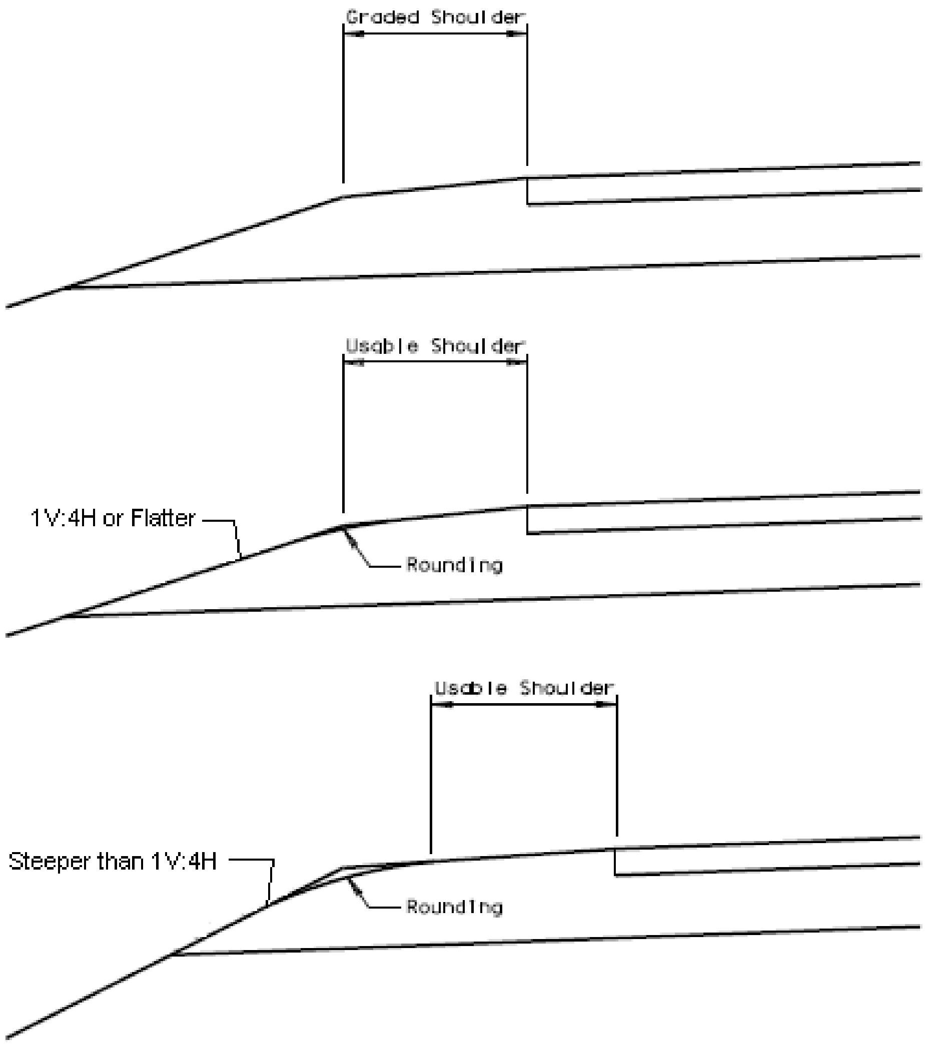
SHOULDERS

Roadway shoulders are defined by AASHTO as "the portion of the roadway contiguous with the traveled way that accommodates stopped vehicles, emergency use, and lateral support of subbase, base, and surface courses". Shoulders are one of the most important safety features for roadways.

Type of Roadway	Shoulder Width
Minor rural roads (with or without surface)	2 feet
Major roads (with stabilized or paved shoulder)	12 feet

The limits of **graded** shoulders are from the edge of traveled way to the intersection of the shoulder slope and foreslopes. The **usable** shoulder width is the actual shoulder for parking and emergencies. This width is equal to the graded shoulder for sideslopes of 1V:4H or flatter.

Shoulder surfacing provides better all-weather load support versus soil. Typical shoulder surface materials include: *gravel; mineral/chemical additives; shell; asphaltic/concrete paving; crushed rock; and bituminous surface treatments.*



Shoulder Width

Design guidelines for roadway shoulder widths vary by design speed, functional class, and traffic volume. AASHTO recommends a minimum lateral clearance of 1 foot (preferably 2 feet) between a stopped vehicle on a roadway shoulder and the edge of the traveled way.

Facility	Shoulder Width	
High speed, high volume roadways	10 feet	normal width
Low volume highways	2 feet	6 to 8 ft preferable
High speed, high volume roadways with trucks	10 feet	12 feet preferable
Bicycles and pedestrians	4 feet	no rumble strips

For roadsides with *barriers, walls, or vertical elements*, the graded shoulder should have a minimum offset of 2 feet (measured from outer shoulder edge to vertical element). Vertical elements on *low-volume roads* can be used on the outer edge of shoulder with a minimum clearance of 4 feet (traveled way to barrier).

Roadway shoulders should be continuous along the route. Benefits include: providing driver refuge areas; fostering motorist security; and furnishing an area for bicyclists. Intermittent shoulder sections should be avoided – their use can result in driver stops in the traveled way and increased opportunities for potential collisions.

Shoulder Cross-section

Roadway shoulders need to be flush and adjoin the edge of traveled way in order to help drainage. They should have sufficient slope to drain surface water but not restrict vehicle usage. The cross slope for curb locations should be designed to prevent ponding.

Shoulder Surface	Cross Slope
Bituminous/Concrete	2 to 6%
Gravel/Crushed rock	4 to 6%
Turf	6 to 8%

The maximum algebraic difference between the traveled way and shoulder grades should range from *6 to 7 percent* (tangent sections with normal crown and turf shoulders). This range is adequate due to the resulting gains for pavement stability by preventing stormwater detention on the pavement.

Shoulders that drain away from the pavement should be designed without a significant cross slope break. The shoulder should be sloped at a rate comparable to the superelevated traveled way. For locations with stormwater, snow, and ice drainage on the road surface, the maximum grade break should be limited to 8 percent (by flattening the outside shoulder).

Shoulders with curb or gutter on the outer edge may be installed to keep runoff on the paved shoulder and serve as a longitudinal gutter. All of the roadway runoff is handled by these curbs as part of the drainage system that drains at designated outlets. Significant advantages of this shoulder type include: keeping stormwater off the travel lanes; and not deterring motorists from leaving the traveled way.

Shoulder Stability

Roadway shoulders need to be able to support various vehicle loads in different kinds of weather without rutting. Regular maintenance is crucial for all types of shoulders to perform as intended.

Unstabilized shoulders consolidate over time producing a drop-off at the edge of the traveled way. This difference can affect driver control of speeding vehicles, and reduce the operational advantage of driving close to the pavement edge.

Stabilized shoulders help to prevent erosion and moisture penetration which enhances the pavement's strength and durability. They provide emergency vehicle refuges; prevent drop-off & rutting prevention; furnish adequate roadway drainage cross slope; reduce maintenance; and provide lateral roadway base/surface support.

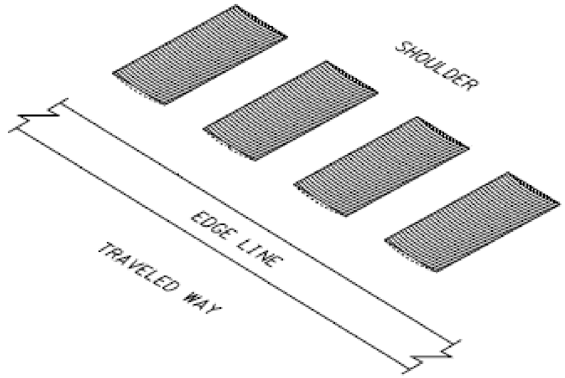
Some rural highway designs use surfacing over the entire roadway width (including shoulders). This surfacing may range from *28 to 44 feet* for two-lane roads. Edge line pavement markings are typically installed to delineate the edge of traveled way.

RUMBLE STRIPS

Rumble strips are raised or grooved designs that are intended to alert drivers of potential dangers through vibration and audible rumbling. These strips are applied in the direction of travel as part of the edge line or centerline to alert motorists when they drift from their lane. While rumble strips are effective (and cost effective) in reducing crashes due to inattention, they may also have issues pertaining to noise levels, bicyclists, motorcycles, and roadway maintenance.

Basic Rumble Strip Designs

Milled-in: cut into existing hardened asphalt or concrete
Rolled-in: applied to malleable freshly laid asphalt paving
Formed: corrugated form pressed into new pavement
Raised: prefabricated units connected to asphalt or concrete pavement



Typical Rumble Strip

Uses of Rumble Strips

- Continuous Shoulder Rumble Strip (most common)
  Installed on shoulders to prevent potential run-off-road (ROR) collisions
- Centerline Rumble Strips
  Used on two-lane rural highways to reduce potential head-on collisions
- Transverse Rumble Strips
  Placed in travel lanes where the majority of traffic will cross
  Installed on intersection approaches, toll plazas, horizontal curves, work zones

Rumble stripes combine rumble strips with pavement markings to provide increased visibility in inclement weather or nighttime conditions. These may be installed using raised plastic pavement markers or conventional pavement markings.

ROADSIDE DESIGN

Roadsides are a crucial component for safe highways by providing a recovery zone for errant drivers, and reducing vehicle crash severity. The fundamental design considerations for roadsides are **clear zones** and **lateral offsets.**

The **clear zone** concept is defined in the *AASHTO Roadside Design Guide* as "the unobstructed, transversable area provided beyond the edge of the through traveled way for the recovery of errant vehicles. The clear zone includes shoulders, bikes lanes, and auxiliary lanes, except those auxiliary lanes that function like through lanes". This area needs to be as free of objects or hazards as practical, and sufficiently flat (1V:4H or flatter) to enable driver recovery.

Historically, most roadway agencies have tried to maintain a **30-foot clear zone** for high-volume, high-speed rural roads. This is the result of studies that showed that using this minimum width permitted 80% of vehicles leaving the roadway to recover (*Highway Design and Operational Practices Related to Highway Safety*, 1974). Past obstacle treatments within clear zones have included: *removal, relocation, redesign, or shielding (barriers or crash cushions)*. However, for low-volume, urban, or low-speed highways, clear zone distances of 30-feet may be excessive or unjustified due to engineering, environmental, or economic reasons.

The *AASHTO Roadside Design Guide* supplies specific details regarding the clear zone concept and provides design procedures based on vehicle encroachment frequency, collision severity with roadside obstacles, and costs of providing greater clear recovery areas. The optimal roadside design solution is to balance engineering judgment with current roadside safety practices.

Lateral Offsets

The Federal Highway Administration (FHWA) defines the **lateral offset** to an obstruction as "the distance from the edge of traveled way, shoulder, or other designated point to a vertical roadside element". These offsets are typically considered to be *operational* offsets – providing adequate roadside clearance without affecting vehicle performance. Lateral offsets are generally suitable (in lieu of a full-width clear zone) for urban environments with lower operating speeds that have limited right-of-way or constraints (on-street parking, sidewalks, curb & gutter, drainage structures, frequent traffic stops, and fixed roadside objects).

Advantages of Lateral Offsets

- Improves sight distances
- Minimizes contact between obstructions & vehicles
- Improves travel lane capacity
- Reduces lane encroachments from parked/disabled vehicles
- Avoids adverse lane position impacts & lane encroachments

For sites with curbs, the offset should be measured from the curb face. Any traffic barriers should be placed in front or at the face of the curb. The *AASHTO Roadside Design Guide* provides further guidance for using lateral offsets.

CURBS

Roadway curbs may use raised or vertical elements to influence driver behavior, and therefore → roadway utility and safety.

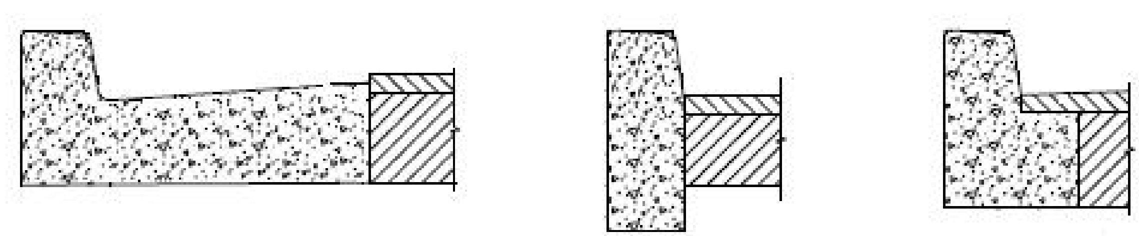
<u>Purposes of Curbs</u>

Drainage control	*Roadway edge delineation*	*Right-of-way reduction*
Aesthetics	*Delineation of pedestrian walkways*	*Maintenance reduction*
	Assistance in roadside development	

Curbs can influence the trajectory of errant vehicles and affect a driver's ability to control a vehicle after impact. The extent of this effect is due to vehicle speed, impact angle on the curb, curb configuration, and vehicle type.

The main curb configurations are **vertical** and **sloping**. These designs may be separate or integrated units that include gutters.

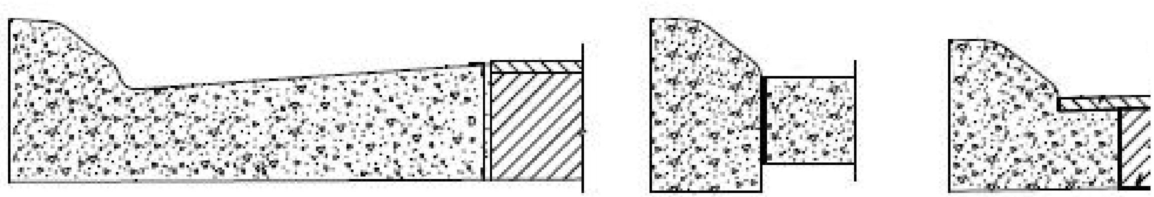
The purpose of **vertical (non-mountable)** curbs is to discourage errant vehicles from leaving the road. These types of curbs are not suitable for high-speed roadways due to vehicle tendencies to overturn or become airborne from curb impact. Vertical curbs (typically range from 6 to 8 inches) can also be used along tunnels or long walls to discourage close vehicle proximity and reduce risks to pedestrians.



VERTICAL CURBS (Non-mountable)

Sloping curbs (mountable) are designed to be easily crossed by vehicles when needed. These are well-rounded, low curbs with flat sloping faces.

<u>Slope of Curb Face</u>	**<u>Curb Height</u>**	
>1V:1H	4 inches (maximum)	easily mountable
1V:1H to 1V:2H	6 inches (maximum)	



SLOPING CURBS (Mountable)

- **4-inch Sloping Curb:** Suitable for high-speed facilities with drainage issues, restricted right-of-way, or access control
- **6-inch Sloping Curb:** Appropriate for high-speed urban/suburban roadway sections with multiple access points

Some sloping curbs are created with small vertical sections (2 inch maximum for 6 inch curbs) on the lower curb face for future resurfacing. If this vertical section exceeds 2 inches, it may be treated as a vertical curb instead of a sloping one.

Typical Uses of Sloping Curbs

Median edges
Islands at intersections
Shoulder outer edges

Sloping curbs at outer shoulder edges are used for drainage control, delineation, access control, and erosion reduction. These curbs should be easily mountable for vehicle parking clear of the traveled way for constricted sections. There should also be adequate clearance to prevent conflicts between bicycles and motorists.

Gutters may be combined with vertical or sloping curbs for roadway drainage systems. Typical gutter sections are 1 to 6 feet wide on a 5 to 8% cross slope to increase hydraulic capacity. Typically, this cross slope is limited to the 2 to 3 feet adjacent to the curb. It is unrealistic to expect gutter sections to contain all drainage – overflow is typical.

Research has shown that drivers tend to shy away from curbs with significant height or steepness – reducing effective lane width. Sloping curbs may be placed at the edge of the traveled way for low-speed urban sections (with preferred offsets of 1 to 2 feet). If used intermittently along streets, vertical curbs should be offset 2 feet from the edge of traveled way. For medians or islands, the offset for vertical curbs should be a minimum of 1 foot (preferably 2 feet).

High visibility treatments may include: *reflectorized markers on curb tops*
reflectorized paints
reflectorized surfaces (thermoplastics, etc.)

Periodic maintenance (cleaning or repainting) is typically required to keep the curbs fully effective.

DRAINAGE CHANNELS AND SIDESLOPES

Drainage design considerations (safety, aesthetics, pollution control, maintenance) are an essential part of modern roadway geometric design. By using flat sideslopes, broad drainage channels, and liberal transitions, highway drainage facilities can be used to intercept and remove stormwater from the roadway. The drainage channel - sideslope interface is also important for reducing potential crash severity (vehicles leaving the road).

Types of highway drainage facilities include: bridges; culverts; *channels; curbs; gutters;* and *drains.* The location and hydraulic capacities of these drainage facilities should consider the likelihood of upstream/downstream damage, and potential flooding impacts on roadway traffic . Any **new** culverts should meet the minimum *HL-93* design loads. **Existing** culverts that are considered appropriate to remain in place must have a structural capacity that meets *HS-15* for live loads.

Stream crossings and flood plains can impact both roadway horizontal and vertical alignments. These crossings and encroachments should be located and aligned to retain the natural flood flow properties (distribution and direction). Any roadway design should also address stream stability and environmental concerns.

Drainage inlets are used to limit the spread of surface water on the traveled way. These inlets need to be located as such as to prevent silt/debris deposits on the roadway. Additional inlets may be used near vertical sag points for any overflow. All pipes need to have sufficient capacity to avoid ponding on the roadway and facilities.

Urban drainage design is typically more expensive and more complex than rural facilities. Potential urban drainage impacts may include *rapid runoff rates, larger volumes of runoff, costly flood damage, higher overall costs, greater restrictions – urban development, lack of receiving waters,* and *high vehicular/pedestrian traffic.*

Drainage Channels

Drainage channels intercept and remove surface water by providing adequate capacity, and a smooth transition for stormwater. These channels can be lined with vegetation, or rock/paved linings at locations where erosion cannot be controlled by normal vegetation. Roadway runoff typically drains down grass slopes to roadside and median channels. Various measures (curbs, dikes, inlets, chutes, flumes, etc.) can be used to prevent slope erosion from roadway runoff.

<u>Types of Drainage Channels</u>

Roadside channels in cut sections
Toe-of-slope channels
Intercepting channels
Flumes

The purpose of roadside channels is to control surface drainage. These are typically built as open-channel ditches that are cut into the natural terrain. Roadside channels containing **steep sides** are usually preferred due to their hydraulic efficiency. Slope steepness may be restricted by soil stability, construction, maintenance, and right-of-way factors.

Roadside designs need to consider the impact of slope combinations on vehicles leaving the roadway. The effects of traversing roadside channels with widths less than **4 to 8 feet** are similar for slope combinations despite channel shape. Flatter foreslopes allow greater vehicle recovery distance, and better flexibility in choosing backslopes for safe traversal. Foreslopes greater than **1V:4H** seriously limit the types of backslopes for use. The channel depth depends on soil characteristics and should be able to remove surface water without subgrade saturation.

Roadway channel grades do not have to mimic that of the roadway's vertical alignment. The minimum grade should be developed from drainage velocities that avoid sedimentation. Depths, widths, and lateral offsets for roadside channel designs can vary to meet runoff amounts, channel slopes, lining types, and distances between discharge points. Measures should be taken to avoid violating driver expectancy, or major channel grade changes that produce scouring/siltation.

Intercepting channels are typically the result of a dike built to prevent disturbing the existing ground surface. These usually have a flat cross section with substantial capacity that follow natural contours, when possible.

Median drainage channels are formed near the center of the median by flat sideslopes and are typically very shallow. Drainage is intercepted by inlets or channels and discharged by culverts.

Flumes may be either **open (channels)** or **closed (culverts)** to transport water from intercepting channels down cut slopes, and release water from curbs. Open channels are ill-suited for higher velocities or sharp turns, and may need some type of energy dissipation. Culverts are generally preferred for preventing settlement and soil erosion.

Channel linings *(vegetation, concrete, asphalt, stone, and nylon)* are designed to prevent channel erosion by resisting storm runoff velocities.

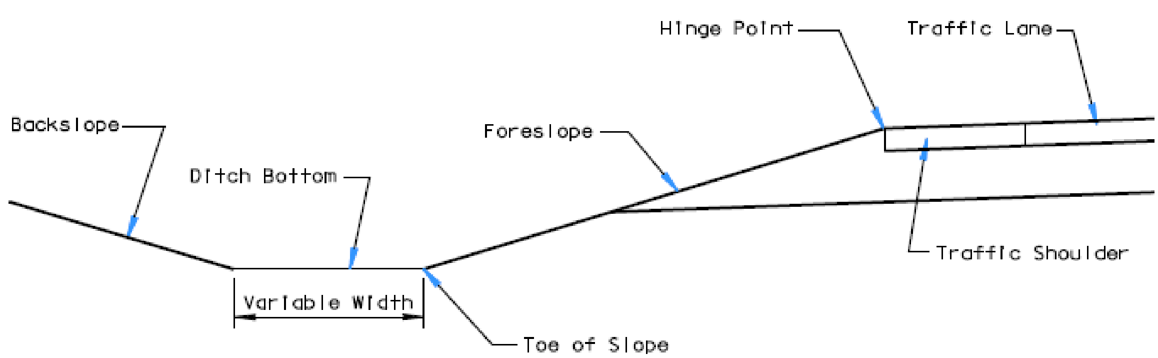
<u>Roadside Channel Lining Criteria</u>

- Velocity of flow
- Type of soil
- Grade of channel
- Channel geometry

Vegetation provides the most economical lining but is unsuitable for steep slopes or high velocities. Smooth linings create high-velocity flows that need some sort of energy dissipation before releasing.

Sideslopes

Sideslopes adjoin the roadway shoulder - located between the edge of shoulder and the right-of-way boundary. Any sideslope design needs to improve road stability and provide adequate recovery space for errant vehicles.



Regions of the Roadside

Hinge Point (top of slope) - contributes to loss of steering control
- vehicles may become airborne at this point
- rounding may increase general roadside safety

Foreslope - provides area for recovery maneuver or speed reduction prior to impact

Toe of Slope - intersection of foreslope with level ground or backslope
- usually within clear zone and impacted by vehicle

Reducing crash severity at intersections is a major concern for designers. Potential design solutions include: flatter slopes between the shoulder edge and ditch bottom; longer lateral offset from the roadway; and enclosed drainage facilities.

Foreslopes

Steeper than 1V:4H	*Not desirable – limits choices of backslopes*
1V:3H or steeper	*For locations where flatter slopes cannot be used*
	May require roadside barriers

Backslopes

1V:3H or flatter	*Typically used – accommodates maintenance equipment*
Steeper than 1V:3H	*Needs evaluation for soil stability & crash impacts*
Steeper than 1V:2H	*Retaining walls may be required*
1V:2H or flatter	*May be determined by soil characteristics*

For major roadways (freeways, arterials) with wide roadsides, sideslopes should provide an adequate area to avert potential crashes and for out-of-control vehicles to recover. Embankment slopes of 1V:6H or flatter are traversable, recoverable, and ought to be used when practical. Flat, rounded recovery areas adjacent to the roadway need to be provided as far as conditions permit.

Embankment Slope

1V:6H or flatter	*Good chance of vehicle negotiation & recovery*
1V:3H or flatter	*Possibly traversable – possibly recoverable*

The use of turf may be suitable for flat, well-rounded sideslopes (1V:2H favorable climates, 1V:3H semiarid climates). Steeper slopes (2V:3H or steeper) make it difficult for grass to be established – even with sufficient water. Slopes of 1V:3H or flatter are easier to mow and maintain.

Flat, well-rounded sideslopes are recommended for creating a natural roadside appearance. Rounded landforms are a stable, natural result of erosion – so using rounded sideslopes should result in greater stability. A **streamlined cross section** is the resulting combination of flat and rounded slopes. This produces roadways that operate with fewer severe crashes, and need minimal maintenance/operating costs.

Rock cuts depend on the material and may involve bench construction for deep cuts. These slopes may range from 2V:1H (typical) to 6V:1H (good-quality rock).

Vegetation may be used to enhance slope stability and aesthetics of poor-quality rock. Any rock outcroppings within the clear roadside recovery area should either be removed or shielded by a roadside barrier. The toe of the rock-cut slope needs to be beyond the minimum lateral offset from the traveled way required by errant vehicles to recover.

TRAFFIC BARRIERS

Traffic barriers (*guardrails, concrete barriers, and attenuation devices*) are used to keep vehicles on the road and prevent them from colliding with dangerous objects. Determining their need (including location and type) are critical factors in roadway design. The "clear zone" distance should be considered when determining the need for roadside protection.

Barriers should only be used where the crash severity is less with the barrier than a collision with the hazard behind it. The barriers themselves may be an object that can be struck with a significant crash severity and require continual maintenance.
The potential danger that a roadside hazard might have to roadway users should be assessed based on *size, shape, rigidity, and distance from the traveled way*.

Common Traffic Barrier Locations

Bridge ends
Near steep roadway slopes
Drainage facilities with steep drops
Signs/poles or other roadside hazards

Longitudinal barriers are used along roadsides and medians to redirect errant vehicles. These are subdivided into types (*flexible, semirigid, or rigid*) based on the amount of deflection that occurs upon impact by a vehicle.

Flexible barriers deflect considerably when struck by dissipating energy through tension in longitudinal members, deformation of posts/rail elements and vehicle bodywork, and friction between vehicle and barrier. Flexible barriers are meant to contain and not redirect vehicles. These systems also need more lateral clearance from fixed objects due to the resulting deflection from vehicle impact.

For **semirigid barriers,** impact energy is dissipated through deformation of the rails, posts, soil and bodywork, plus rail/vehicle friction. Longitudinal members spread the impact force over a number of posts – posts near the impact area are designed to break or tear away. Semirigid systems maintain controlled deflection limits and redirect errant vehicles.

Rigid systems are typically made of reinforced concrete with negligible deflection when struck by a vehicle. Impact energy is dissipated through vehicle deformation and redirection. The shape of the barrier is designed to redirect vehicles into a path parallel to the rigid barrier. These are most appropriate for locations with shallow impact angles or where deflection cannot be tolerated (work zones, hazards, etc.). Rigid barriers typically require very minimal maintenance.

Roadside Obstacles Options

- Remove or redesign the obstacle
- Relocate the obstacle
- Reduce impact severity with appropriate devices
- Redirect vehicles by shielding the obstacle
- Delineate the obstacle
- Take no action

Roadside Barriers

Roadside barriers are longitudinal systems designed to protect vehicles from roadside obstacles or hazards (steep slopes, fixed objects, sensitive areas, pedestrians, bicycles, etc.) on either side of the roadway. These barriers should be installed beyond the edge of the roadway's shoulder in order to use full shoulder width. Any fill needs to be wide enough to provide adequate lateral support for the barrier. Exposed barrier ends should be properly treated to prevent the creation of a dangerous roadside hazard. Typical treatments include: *buried ends; earth mounds;*

flared ends; crash cushions; and crash-tested terminals.

Median Barriers

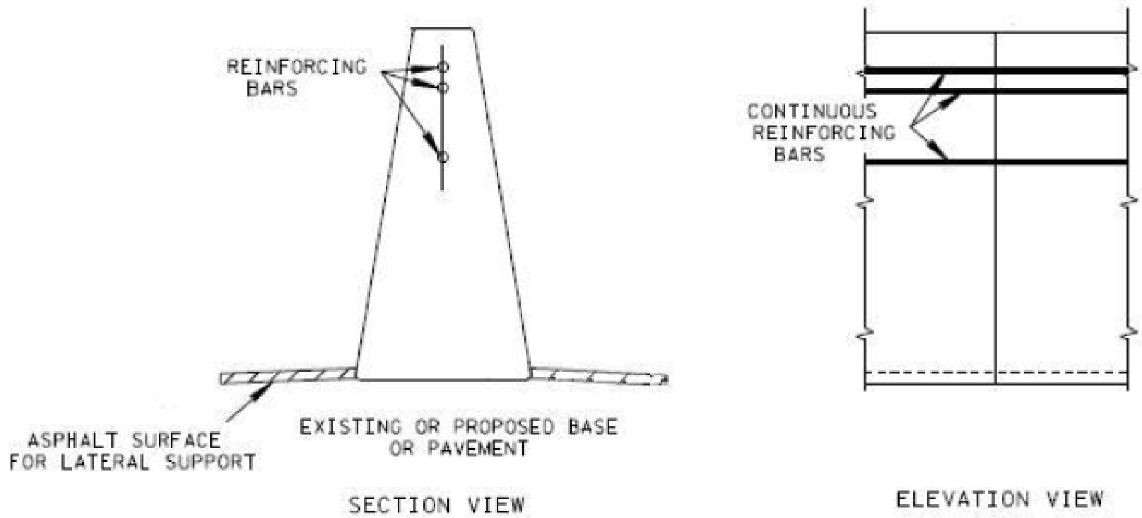
Median barriers are another type of longitudinal system used to prevent vehicles from crossing the median and crashing head-on into oncoming traffic. For roadways with low traffic volumes or wide medians, the likelihood of errant vehicles crossing the median and hitting an opposing vehicle is relatively low. In this case, median barriers are typically used at locations with a history of collisions or new roads where high crash rates are expected.

Cross-median crashes are typically reduced by median barriers – however, total crash frequency usually increases due to the decreased space available for return-to-the-road maneuvers.

Median Barrier Considerations

- Alignment
- Crash history
- Median openings
- Sight distance
- Design speed
- Traffic volume
- Median width

The potential impact of median barriers on horizontal curve sight distance should also be considered during the selection and design of the median barrier.



Typical Concrete Barrier Wall

Unlike roadside systems, median barriers are designed to be struck from either side. Types of these barriers include: *doublefaced steel W-beam on strong posts; box-beam on weak posts; concrete barriers; and cable barrier on light steel posts.* Each type has its own unique performance characteristics and applicability, depending on the design circumstances. It is crucial to tailor the dynamic lateral deflection to the location – **maximum deflection should be less than one-half the median width.** This should prevent travel into opposing traffic, and redirect the errant vehicle in the same direction as flowing traffic.

Bridge Railings

Bridge railings are used to restrain and redirect errant vehicles and prevent them from crashing off the structure onto whatever is below. These longitudinal traffic barriers differ from other types by being a structural extension of the bridge as opposed to having a foundation in/on soil. Typical bridge rails are either multi-rail tubular steel or concrete barriers that are higher than roadside barriers to prevent users from vaulting over the rail and off the bridge.

Bridge railings can be extended with roadside barriers and crashworthy terminals for approaches to a bridge. Any end treatments should help reduce crash severity but not impede pedestrian usage for bridges with walkways.

Crash Cushions

The main function of crash cushions is to bring errant vehicles to a safe stop after head-on collisions or redirect vehicles away from a hazard. These may be used to shield rigid objects, roadside and median barrier terminals.

Typical Crash Cushion Applications

- End of bridge rails
- Bridge piers
- Overhead sign supports
- Abutments
- Retaining wall ends

Locations for curb cushions require a level area without curbs or other hazards or obstacles.

The *AASHTO Roadside Design Guide* contains warrants and design guidelines for determining the need, selection and design for barriers.

MEDIANS

Roadway medians separate opposing lanes of traffic and are suitable for multilane arterials. This area is located between the edges of opposing traveled ways (including any left shoulders). Median width and design characteristics are among the most important safety features of high-speed highways in both urban and rural areas.

Principal Median Functions

- Separate opposing traffic
- Provide clear recovery area (errant vehicles)
- Provide emergency stopping areas
- Allow space for speed changes
- Provide storage for left-turns and U-turns
- Lessen headlight glare
- Provide space for future widths

Medians need to be highly visible regardless of time of day and should contrast with the traveled way to ensure maximum efficiency. Benefits of medians include: providing an open green space; offering a pedestrian refuge area; and controlling intersection traffic conflicts.

Median widths are dependent on the roadway type and location. Any proposed median widths should be evaluated for potential barrier needs. Ideally, median widths (typically 4 to 80 feet) should be sufficient so that no barrier is needed, when practical. The wider medians are safer but more costly - requiring more right-of-way, construction, and maintenance. These costs often limit median widths – costs increase as median widths increase.

In rural areas, medians are normally wider than in urban and suburban areas. Medians at unsignalized intersections need to be wide enough for selected design vehicle crossroads and U-turn traffic. In urban and suburban areas, narrow medians work better operationally – wide medians being used only if large vehicles are anticipated. Wide medians may not be suitable for signalized intersections due to the increased time for crossing vehicles and leading to inefficient signal operation.

Depressed medians (with typical sideslopes of 1V:6H) are normally used for freeways due to drainage efficiency. Any drainage inlets need to be flush with the ground. Culvert ends should have traversable safety grates.

Raised medians are generally used to regulate turning movements on arterials. This area is frequently used for landscaping and plants/trees. It is vital to prevent these from becoming visual obstructions and impacts to sight distance. Please consult the *AASHTO Roadside Design Guide* when designing for planting and/or landscaping within median areas.

Flush medians are typically crowned (to eliminate ponding) and used on urban arterials. This type of median can be used on freeways but may require some type of median barrier. Slightly depressed medians with steepened roadway cross slopes (approximately 4 percent) are generally preferred.

For median widths of **40 feet or wider**, drivers are separated from opposing traffic with greater ease of operation, less noise, and reduced headlight glare at night.

For widths of **60 feet or greater**, medians can be landscaped as long as it does not compromise the roadside recovery zone. This width may not be appropriate for urban or signalized intersections.

ROADSIDE CONTROL

The amount and character of roadside interference determines the performance of roadways without access control. Uncontrolled land development and access points typically produce *lower roadway capacity, increased vehicle conflicts,* and *premature* *obsolescence.* By regulating the location, design, and operation of ramps and roadside elements (mailboxes, signs, etc.), interference to through traffic can be minimized.

PEDESTRIAN FACILITIES

Due to roadway interactions between pedestrians and motorized traffic, it is critical to integrate these concerns during the project planning and design phases. The *Americans with Disabilities Act (ADA) of 1990* also requires that any new or reconstructed pedestrian facilities (sidewalks, shared-use paths, shared streets, or off-road paths) **must** be accessible to disabled individuals.

The typical range of values for walking speed varies from 2.5 to 6.0 ft/sec^2. The MUTCD recommends using a **4.0 ft/sec^2** as the walking speed value when calculating pedestrian clearance intervals for signalized intersections.

In order to accommodate pedestrians with visual, hearing, or cognitive impairments, various types of information (auditory, tactile, and kinesthetic) should be combined to render assistance. Different treatments may include: curb ramps; pedestrian islands; fixed lighting; pedestrian signals; audible signals; etc.

Sidewalks

Sidewalks are pedestrian paths that are located beside roadways and streets. Generally, anywhere roadside and land development impact pedestrian movement along a highway – a sidewalk should be provided. These are typically used in urban areas but rarely in rural areas. A border area is generally used in suburban and urban areas to separate roads from homes and businesses. Its primary function is to provide space for sidewalks. The minimum border width of **8 feet** is considered appropriate to provide space for sidewalks, lighting, fire hydrants, street hardware, vegetation, and buffer strips.

Sidewalk width (residential areas)	4 to 8 feet
Sidewalk width (adjacent to curb)	2 feet wider than minimum
Planted strip (between sidewalk and curb)	2 feet minimum
Sidewalk cross slopes	2 percent maximum

The additional sidewalk width (2 feet) for locations adjacent to the roadway curb provides sufficient space for roadside hardware, snow storage, open vehicle doors, bumper overhang, and moving traffic.

Pedestrian paths for bridges may differ from those of its roadway approaches due to costs and unique operational features. Flush shoulders should continue across bridge locations with low pedestrian traffic in order to provide sufficient escape areas. These shoulders should not be interrupted by raised walkways, where possible.

Vertical curbs are typically adequate on low-speed streets to separate pedestrians from motorized traffic. A barrier-type rail may be used for high-speed roadways on structures with a pedestrian-type rail/screen on the walkways's outer edge. Approach walkways need to provide safe, direct access to the bridge walkway.

For sidewalk locations along high-speed roads, buffer areas may be utilized to distance the sidewalk from the traveled way.

Advantages of Buffer Areas

- Increased pedestrian distance from moving traffic
- Aesthetics of the facility
- Reduced width of hard surface space
- Space for snow storage

A major disadvantage of buffers or plant strips is the possible need for additional right-of-way.

Grade-Separated Pedestrian Crossings

Grade-separated pedestrian crossings are generally used at locations where at-grade treatments are not feasible. These are used for separating pedestrians from vehicular traffic, enhancing pedestrian access, and improving the overall level of service. Grade-separations permit crossings at different levels (over or under the roadway) by pedestrians and vehicles. They also provide a pedestrian-safe refuge for crossing. The *AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities* provides more specific information for these structures.

Grade-Separated Pedestrian Crossing Factors

Pedestrian volume
Intersection capacity
Traffic volume
Conditions favoring usage

Heavy peak pedestrian movements (central business districts, factories, schools, athletic fields, etc.) may also need grade-separated pedestrian crossings. Governmental laws and codes should be consulted for pedestrian separation criteria and design guidelines.

Grade-separated crossings need to be located where pedestrians are naturally likely to cross the roadway. Pedestrians will typically use a crossing if it does not deviate significantly from a more direct route. They consider the safety of the grade separation versus the extra time and effort needed to cross the roadway. People are typically more resistant to use undercrossings versus overcrossings – mainly due to sight constraints. This may be minimized by providing continuous user vision, adding lighting, and installing ventilation systems.

Possible Grade-Separated Crossing Locations

Moderate to high pedestrian demand to cross roadway
Large numbers of children regularly crossing high-speed/high-volume roads
Unacceptable number of pedestrian conflicts with traffic
Documented collisions or close calls with pedestrians and vehicles

Pedestrian separation walkways should have a minimum width of **8 feet** – greater widths may be used for tunnels, high pedestrian traffic areas, and overpasses with a tunnel effect (from screens).

Presently, no universal treatment exists to prevent vandals from dropping objects from overpasses. There are no absolute warrants to address as to where and when barriers should be used to discourage the throwing of objects. The economy in design plus clear sight lines must be balanced against limiting potential pedestrian damage.

Possible Overpass Locations (with screens)

- Schools, playgrounds, etc. – where children may be unaccompanied
- Large urban pedestrian overpasses – not under police surveillance
- Where history indicates a need

Curb Ramps

Curb ramps provide access between the roadways and sidewalks for pedestrian crossings. These facilities are required by law to be accessible to and usable by disabled individuals (i.e. mobility, visual impairments, etc.).

Curb Ramp Design Factors

sidewalk width	sidewalk location	curb height & width
turning radius	curve length	street intersection angle
sign & signal locations	drainage inlets	utilities
sight obstructions	street width	border width

The *Public Rights-of-Way Accessibility Guidelines* provide the following guidance for curb ramps:

Minimum curb ramp width	4 feet
Maximum curb ramp grade	8.33%
Sidewalk cross slopes	2% maximum
Top level landing area	4 ft x 4 ft (no obstructions, 2% maximum cross slope)

Basic types of curb ramps have been established for use at intersections – depending on their geometric characteristics.

Perpendicular curb ramps contain the entire grade differential outside of the sidewalk. This design does not require any walking across the ramped area.

Parallel curb ramps are incorporated into the sidewalk. The designer should take measures to avoid any potential ponding or sediment accumulation.

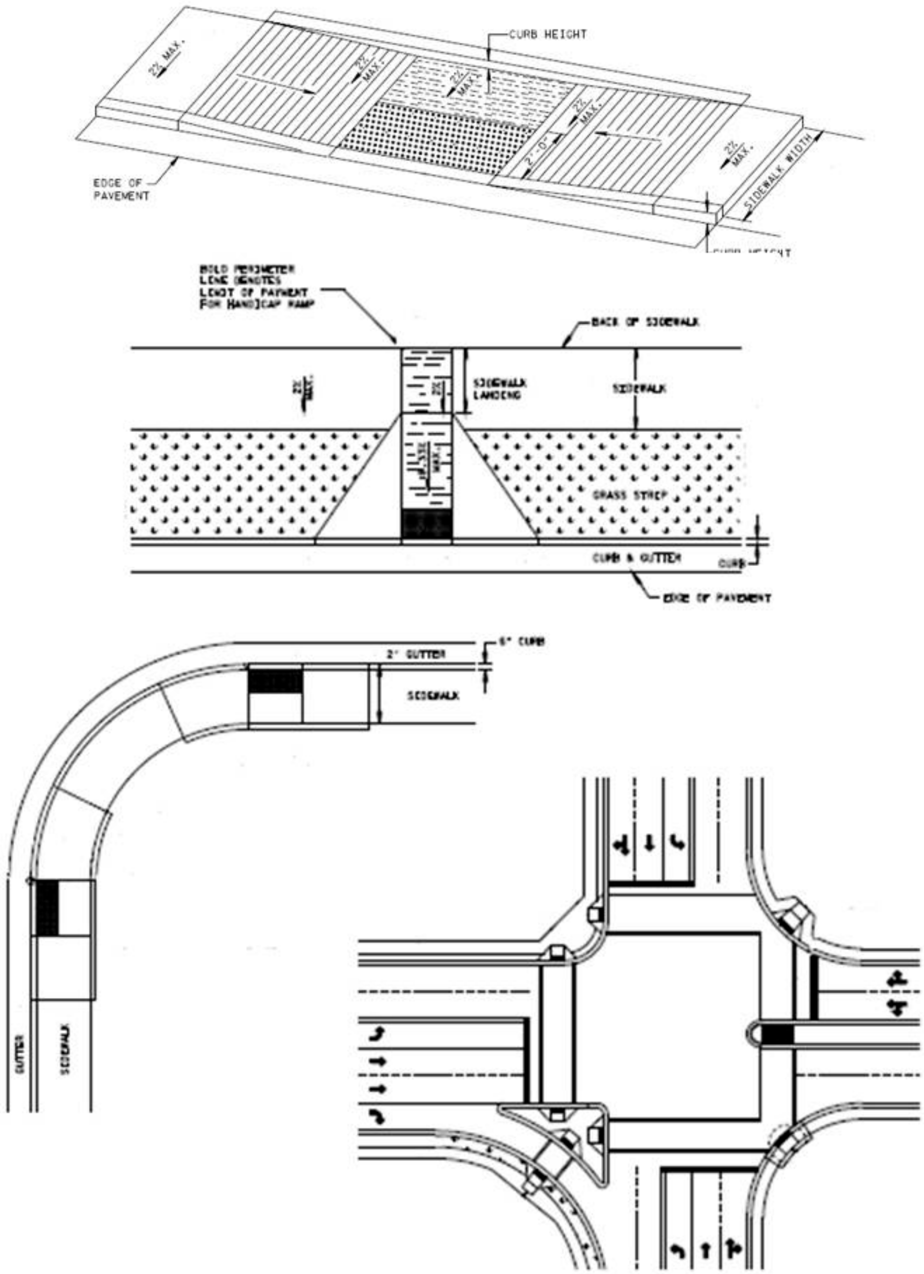
Combination curb ramps merge aspects of both perpendicular and parallel ramps. A sloped section ascends to a lower landing (lower than full curb height) and then from the landing to the sidewalk. This design prevents water and debris accumulation.

Diagonal curb ramps are single perpendicular ramps at corner apexes that serve two crossing directions. This configuration is typically not suitable for moderate to high traffic areas due to possible user confusion – separate curb ramps for each crossing is the preferred treatment.

Curb Ramp Guidelines

Curb ramps should not project into the traveled way
Ramp area should be protected
Curb area should be used at sites with parking lanes
Locations should be coordinated with crosswalk lines

For additional guidance, please refer to the *MUTCD*, the *Public Rights-of-Way Accessibility Guidelines*, and *AASHTO's Guide for the Planning, Design, and Operation of Pedestrian Facilities.*



Curb Ramp Examples

(Ref: TDOT, Standard Roadway Drawings)

BICYCLE FACILITIES

Bicycles continue to be a popular mode of transportation and their facilities should be a major consideration for any roadway design. The main factors to consider for accommodating bicycles include:

- Type of bicyclist being served by the route (experienced, novice, children)
- Type of roadway project (widening, new construction, resurfacing)
- Traffic operations & design characteristics (traffic volume, sight distance, development)

Existing roads and streets provide the majority of the required network for bicycle travel. Designated bikeways may be needed at certain locations to supplement the existing road system. Transportation planners and designers list the following factors as greatly impacting bicycle lanes: *traffic volume; average operating speed; traffic mix; on-street parking; sight distance; and number of intersections.*

Basic Types of Bicycle Facilities

Shared lane: typical travel lane shared by both bicycles & vehicles
Wide outside lane: outside travel lane (14 ft minimum) for both bicycles & vehicles
Bicycle lane: part of roadway exclusively designated (striping or signing) for bicycles, etc.
Shoulder: roadway paving to the right of traveled way for usage
Multiuse path: physically separated facility for bicycles, etc.

At locations without bicycle facilities, other steps need to be considered for enhancing bicycle travel on roads and streets. The following improvements (low to moderate cost) can help to reduce crash frequency and allow for bike traffic:

Paved roadway shoulders
Wider outside traffic lanes (14 ft min.) – if no shoulders
Bicycle-friendly drainage grates
Manhole covers at grade
Smooth, clean riding surface

AASHTO's *Guide for Development of Bicycle Facilities* provides specific guidance regarding bicycle dimensions, operation, and needs – which determine acceptable turning radii, grades, and sight distance.

The main differentiation between bikes and other vehicles is that the bicycle and rider are considered together as a system. Driver characteristics for motor vehicles are important but the driver-vehicle interface is rarely considered.

Typical bicyclist requirements: 3 feet lateral space
7.5 feet height

Required track width: 0.7 feet @ 7 mph or greater
2.5 feet @ 3 mph or greater

These track widths are not comfortable for riders – greater separation from traffic, and more maneuvering space is preferable.

ON-STREET PARKING

On-street parking facilities for urban and rural arterials may be considered to accommodate existing and proposed land use. These facilities are typically the most common and convenient type of short-term parking. On-street parking is suitable for low-speed (less than 30 mph) and low-volume (less than 15,000 vehicles/day) roadways. Any urban space available for parking may be competing with bicycle lanes, pedestrian walkways, or roadway enhancements.

Considerations For On-Street Parking

Specific function of street
Traffic operations (existing and proposed)
Roadway width
Adjacent land use
Traffic volume

Parallel parking spaces are used for the majority of on-street parking. Dimensions for these spaces depend on whether maneuvering space is included in the stall or separate. The *Manual on Uniform Traffic Control Devices (MUTCD)* contains further details regarding parallel parking dimensions.

Length of parking space (including maneuvering space) – 22 to 26 feet
(separate maneuvering space) – 20 feet

Minimum width of a parking lane – 8 feet

Desirable width – 10 to 12 feet (commercial vehicles, buses and bikes)

Space widths of 7 feet have been successfully used for roads with low-speeds (30 mph or less) and mainly passenger vehicle traffic.

Angle parking is another type of on-street parking. Extra care should be taken when using this design due to different vehicle lengths and sight distance problems associated with heavy vehicles (long vehicles can interfere with the traveled way).

Back-in/head-out diagonal parking is another viable parking option due to its improved visibility upon exiting. Vehicle maneuvering is typically easier and simpler with convenient placement for loading and unloading. Caution should be taken to prevent interference with utility poles, parking meters, etc. from vehicles with long overhangs.

Land access and mobility demands are equally important for urban collector streets. A 36 ft roadway cross-section consisting of two 11 ft travel lanes and a single 7 ft parking lane on each side is frequently used for urban residential collectors with passenger vehicle traffic.

Local Streets

A 26 ft wide urban roadway with a single through lane and parking on both sides is typically used for residential streets. Adequate roadway width ensures that at least one travel lane is available in areas with heavy parking. Two-way movement can usually be accommodated in areas with intermittent parking on both sides of the roadway.

Traffic markings for parking spaces are highly recommended to identify the available areas, encourage orderly and efficient usage, and prevent encroachment on other designated areas (bus stops, loading zones, approaches, fire hydrants).

For areas with a significant number of pedestrian crossings, the relationship between parking lanes and intersections should be considered. At sites where parking lanes are carried to the intersection, vehicles may use the parking lane as a right-turn lane resulting in operational inefficiencies or crashes with roadside elements.

Two methods are commonly used to address this problem:

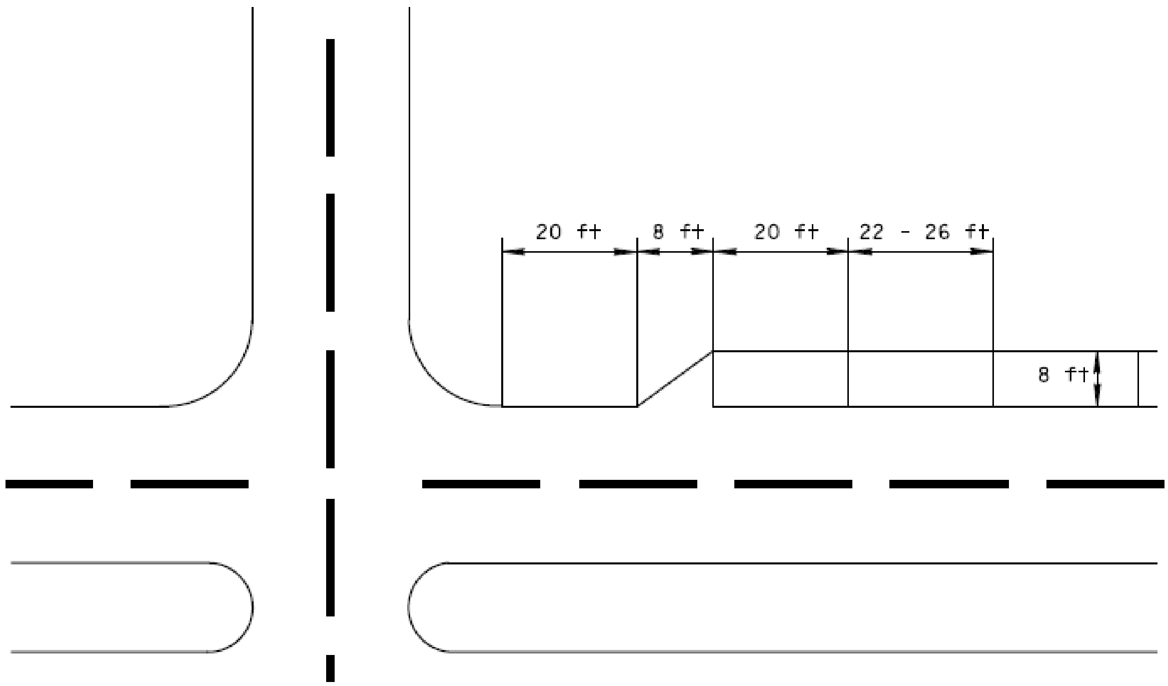
- End the parking lane a minimum of 20 feet prior to the intersection
- Prohibit parking at a specified distance to create a short turn lane.

Negative Aspects of On-Street Parking

Decreased through-traffic capacity

Disrupted traffic flow

Increased crash potential



Parking Lane Transition at Intersection

LOCAL ROADS

Local roads and streets make up the majority of U.S. roadways. These are used to provide direct access to various properties. Local roads are typically intended to serve a variety of local users for short travel distances. Low traffic volumes (due to short trips) and extensive roadway mileage have resulted in low order design criteria. However, local roads and streets should be planned for consistency with existing land usage and traffic operations to provide safety and mobility – as well as economy in construction, maintenance, and operations.

LOCAL RURAL ROADS

Two-lane local roads comprise a significant portion of rural highways and should be designed using the highest practical criteria.

Design Speed determines various geometric design features that are to be used for a roadway (see Table 5-1, "Green Book"). Above-minimal design criteria should be used, where practical. *Low* design speeds are typically suited for rolling or mountainous terrains with winding alignments. *High* design speeds are more applicable to level terrains or favorable environmental conditions. *Intermediate* speeds can be used where conditions are a combination of those for low/high design speeds.

Design Traffic Volume is typically used to determine roadway geometric designs. The Average Daily Traffic (ADT) volume represents the average traffic volume per day and should be the basis for design (usually projected *20 years* into the future). Two travel lanes can normally meet local rural traffic volumes. A level of service analysis may be used to determine the need for additional lanes in areas with exceptional traffic volumes.

Level of Service (LOS) is an indicator of the quality of traffic service provided by a roadway under specific demands. The traffic performance measures are related to speed, travel time, maneuverability, traffic interruptions, comfort, and convenience. These levels range from **A** (least congested) to **F** (most congested). While designers should strive for the highest LOS practical, a *Level of Service D* is acceptable for local roads since they are mainly used for property access.

Alignments for local rural roads (as with any other type of roadway) should be designed to be suitable to the location's topography, terrain, design traffic, environmental impacts, and rights-of-way. Any sudden roadway alignment changes that could violate driver expectations should be avoided. Adequate sight distance and passing opportunities should also be provided.

Maximum Grades for local rural roadways are a function of design speed and terrain type. These limits are shown in Table 5-2 of the "Green Book". They range from 9% @ 15 mph for *level terrain* to 12% @ 15 mph for *rolling terrain* to 17% for *mountainous terrain.*

Cross slopes for rural road traveled-ways are used to properly drain the roadway's surface. Typical cross slope values range from 1.5 to 2 percent for paved surfaces (asphalt, concrete) and 2 to 6 percent (3% desirable) for unpaved ones (gravel, stabilized earth).

Superelevation for rural roads should not exceed 12 percent. The maximum superelevation rate for snow and ice locations is 8 percent for paved rural roads.

Minimum Roadway Widths consist of traveled way and graded shoulder widths (see Table 5-5, "Green Book"). Depending on design speed and traffic design volume, traveled way values range from *18 to 24 feet* with graded shoulder widths (measured from edge of traveled way to shoulder slope/foreslope intersection) of *2 to 8 feet.* A minimum roadside barrier offset of 4 feet from the traveled way should be used where barriers are proposed.

LOCAL URBAN STREETS

Local urban streets consist of the area within the right-of-way limits that accommodates public utilities as well as vehicular travel (passenger cars, trucks, public transit, pedestrian and bicycle traffic).

Major Local Urban Design Controls

- Type and extent of development – often limits available right-of-way
- Zoning or regulatory restrictions

Design Speed for local urban streets is usually not a major design consideration due to closely-spaced intersections that naturally limit traffic speeds. Speeds of *20 to 30 mph* may be appropriate for urban design based on terrain, pedestrian traffic, available right-of-way, area development, and other controls. Typical design speeds should not exceed 30 mph.

Design Traffic Volume is not a major geometric design factor for residential streets – most use a two-lane cross section. However, traffic volume is a major factor for industrial/commercial streets. A design traffic volume preferably estimated 20 years into the future should be used for roadway design.

Level of Service D is acceptable for local roads since they are used to access various properties.

Alignments for residential streets should be designed to fit existing topography in order to minimize earthwork grading and crash severity. Residential alignments provide direct land access and discourage through traffic while commercial/industrial roads should be as direct as practical. Roadway curves should be large – 100 feet minimum. Lower radii may be used in superelevated areas (75 ft minimum for 20 mph design speed).

Grades for local residential streets need to be as level as practical (15 percent maximum). Drainage design is crucial for grades steeper than 4 percent. Grades for commercial and industrial streets should be less than 8 percent.

Superelevation is usually not used on local residential and commercial streets due to adjacent development, vast paved areas, profile for drainage, cross street frequency, control of cross slope, and other urban factors. It may be suitable for local industrial streets to facilitate operations.

A maximum superelevation rate of 4 percent should be used for street curves – if applicable. A maximum rate of 6 percent may be suitable for long, sharp curves with adequate superelevation transitions.

Lane Widths for urban streets should be 10 to 11 feet (preferable) – 12 feet in industrial areas. Narrower widths (9 ft residential and 11 ft industrial) may be justified for locations with severe right-of-way limitations. Additional lanes at intersections should have a minimum width of 9 feet (preferably 10 to 12 feet) depending on traffic.

For residential streets, a minimum of one unobstructed travel lane must be provided (even for locations with on-street parking on both sides). A typical residential roadway width of 26 feet (minimum) curb-to-curb provides a 12 ft center travel lane and two 7 ft parking lanes. Any conflicting traffic will be required to yield.

Parking Lane Widths in residential areas should be a minimum of 7 feet (parallel spaces) and meet lot size/development conditions. These minimum lane widths should increase to 8 feet for commercial and industrial areas. Parking lanes may also be used for traffic during peak times with high industrial movement.

Curbs on urban streets (4 to 6 inches high) permit greater use of roadway width, control drainage, delineate, and protect pedestrians. Vertical curbs (6 inch minimum) should be offset a minimum of 1 foot from the traveled way.

Border Areas between the roadway and right-of-way line should be used for urban streets for safety reasons as well as aesthetic areas. This buffer space can serve many purposes including: pedestrian sanctuary, snow storage, sidewalk space, utility areas, and landscaping. This border needs to have a minimum width of 5 feet (10 ft or wider preferable). Border widths of 2 feet may be justified for areas without sidewalk in locations with limited right-of-way or high costs.

	Vertical Clearance
Underpass*	14 feet minimum
Pedestrian, bicycle, and sign structures	15 feet minimum

* Allow for future resurfacing

Lateral Offsets (1.5 feet minimum) between curb faces and obstructions (utilities, light poles, fire hydrants, etc.) should be used on all urban streets. Vertical curbs may be suitable to delineate areas with dense pedestrian traffic. Trees may be planted along low speed streets (40 mph maximum) with curbs and adequate sight distances. A minimum lateral offset of 4 feet from edge of traveled way should be used on urban streets without curb and shoulders less than 4 feet wide.

COLLECTOR ROADS

Collector roads are public roadways with moderate traffic volumes that link traffic between arterials and local streets while providing access to various properties. As with any other roadway, designers should strive to produce the optimal vertical and horizontal alignments, sight distance, and drainage plans for collectors that are compatible with funding, safety, traffic volumes, terrain, and land development.

RURAL COLLECTORS

High design speeds (50 mph and above) are normally suited for rural collector roads on level terrain or favorable environmental conditions. **Low** speeds (45 mph and below) are appropriate for curvilinear roadways in rolling/mountainous terrain (see Table 6-1, "Green Book").

Level of Service C is the desired value for rural collector roads – a LOS of D may be justified for rolling or mountainous terrain.

Maximum Grades for rural collectors depend on roadway terrain and design speed – these values range from 5% @ 60 mph (level terrain) to 12% @ 20 mph (mountainous terrain). See Table 6-2, "Green Book".

Superelevation for rural collectors should not exceed 12 percent. A maximum rate of 8 percent may be used in areas prone to snow and ice.

URBAN COLLECTORS

Urban collector roads and streets are designed for mobility and access. Driveway access management is crucial to prevent facility obsolescence. Additional guidelines are also important to expedite traffic mobility – adequate turning movement storage, minimal conflict points, signal location, and efficient circulation maintenance.

Design Speeds of 30 mph (minimum) are appropriate for urban collector streets, depending on site controls (right-of-way, pedestrian traffic, terrain, location development, etc.). Intersection spacing typically limits actual traffic speeds and makes design speed consideration less relevant.

Level of Service C or D is typically acceptable for urban collector designs. A LOS value of D may be used for highly developed metro areas or locations with high traffic.

Minimum Grades of 0.3 percent (0.5 % recommended) are used in urban collector design for drainage purposes. Maximum grades of 5 percent are recommended for locations with adjacent sidewalks. Maximum values range from 6% @ 60 mph (level terrain) to 14% @ 20 mph (mountainous terrain) – see Table 6-8, "Green Book".

Parking Lanes – On-street parallel parking may be used for urban collectors with sufficient street width – 7 to 8 feet wide (residential) and 8 to 11 feet (commercial and industrial). Diagonal or angle parking should only be used for urban collectors in special cases.

Medians should be included for urban collectors with four or more traffic lanes. Minimum median opening lengths are equal to the width of the intersecting road or driveway. The preferred length should be wide enough for a 50 ft turning radius or the turning radius for the design vehicle.

Types of Collector Medians

Type	Width	
Paint-striped separation	2 to 4 feet	
Narrow raised-curbs	2 to 6 feet	
Raised curbs	10 to 16 feet	Left turn lanes
Paint-striped	10 to 16 feet	Two-way, left turn lanes
Raised curbs	18 to 25 feet	Left turn lanes, vehicle stops

Wider medians (27 to 40 feet) can be used for areas with available design space for landscaping.

Curbs are typically used on collectors to allow better utilization of roadway width and for delineation, drainage, and pedestrians. The curb type and height should be based on design speed and other factors. Vertical curbs (6 inches high) are appropriate for low-speed roadways (less than 45 mph). Sloping or mountable curbs (6-inch) should be used on roadways with speeds in excess of 45 mph. Four-inch sloping curbs may be used on higher speed collectors with few intersections. A minimum lateral offset of 1.5 feet should be provided from the face of curb – 3 feet at intersections for trucks and sight distance.

Lateral Offsets to vertical obstructions are used for urban collectors to: improve roadway capacity; improve sight distances; prevent vehicle encroachment into other lanes; and minimize contact between obstructions.

ARTERIALS

Arterial roadways provide high-volume, high speed travel between major population or activity areas. Generally, these roads do not enter neighborhoods and may contain a mix of truck/passenger car traffic. Although arterials make up the least amount of US roadway mileage – they carry the majority of vehicle traffic.

RURAL ARTERIALS

Rural arterials play a crucial role within the rural highway system. These contain roadway cross-sections that may range from two-lane to divided, multilane highways with access control. The roadway geometry may depend on several variables, such as design speed, traffic volume, terrain, alignment character, and traffic composition.

<u>Rural Principal Arterial</u>

- Suitable corridor movement for statewide and interstate travel
- Movements between urban areas with minimum 50,000 population and populations over 25,000
- Integrated movement without stub connections
- Interstate highways, freeways/expressways, and other principal arterials

<u>Rural Minor Arterial</u>

- Linkage of cities, larger towns, and other traffic generators
- Integrated interstate/inter-county systems
- Consistent internal spacing with population density
- Consistent corridor movements greater than rural collector or local systems
- High travel speeds and minimum interference to through movements

AASHTO defines **Design Speed** as "the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern". Design speed is a *primary factor in roadway design* which may equal or exceed the legal statutory speed limit. It is the selected speed for determining various roadway geometric designs. Design speed is used as an overall design control for horizontal alignments in roadway design. Posted speed limits are typically the 85^{th} percentile speed of traffic – within a 10 mph speed range of most drivers. Other characteristics not directly related to design speed may affect vehicle speeds. Therefore, changes to design speed may result in changes to many elements of the roadway design.

Terrain	Rural Arterial Design Speed	Maximum Grade
Level	60 to 75 mph	3%
Rolling	50 to 60 mph	4 to 5%
Mountainous	40 to 50 mph	7 to 8%

(Ref: AASHTO Table 7-1)

Low-volume rural arterials provide free flow under all conditions. Their design is normally based solely on average daily (ADT) values. **High-volume** rural arterial designs typically use the design hourly volume (DHV) – normally 30 HV (30^{th} highest hourly volume of the year) which is approximately 15 percent of rural road ADT.

A *Level of Service B* is considered acceptable for rural arterials and their associated facilities. Mountainous designs may have an acceptable *Level of Service C.*

Minimum Sight Distances for Arterials

Design Speed (mph)	Minimum Stopping Sight Distance (ft)	Minimum Passing Sight Distance (ft)
30	200	500
40	305	600
50	425	800
60	570	1000
70	730	1200
80	910	1400

(Ref: AASHTO Table 7-1)

Rural arterial maximum superelevation rates should not exceed 12% - except in areas with ice and snow where maximum rates should stay under 8 percent.

Shoulders are one of the most important safety features for roadways. They need to be usable at all times regardless of weather conditions. Roadway shoulders are typically paved (2 ft minimum width) for high-volume highways in order to support the paving and provide vehicle refuge area. A minimum paved shoulder width of 4 feet should be used where bicycles need to be accommodated.

The minimum width (feet) of traveled way depends on design speed (mph) and specified design volume (vehicles/day). These values range from 22 to 24 feet for speeds of 40 to 75 mph with usable shoulder widths of 4 to 8 feet (see AASHTO Table 7-3).

Two crucial aspects of rural arterial roadside design are **clear zones** and **lateral offsets**. Although unobstructed roadsides are preferred, AASHTO's *Roadside Design Guide* provides appropriate treatment guidance for fixed objects or non-traversable slopes within the clear zone. Lateral offsets to vertical obstructions help accommodate operating and parked vehicles. A minimum lateral offset of 4 feet (from edge of traveled way) should be used on roadways without curbs and shoulders less than 4 feet wide. Overpasses should be designed so that piers/supports have a lateral offset not less than the approach roadway.

Divided Arterials

Divided arterial roadways contain separated lanes (on single or separated roadbeds) for opposing traffic. Medians with a minimum width of 4 feet are typically used to divide the direction of travel.

Advantages of Dividing Multilane Arterials

- Reduced crash frequency (i.e. head-on collisions)
- Easier operation (pedestrian/driver refuge areas)
- Increase comfort (less headlight glare, etc.)

Lane widths for divided arterials are typically 12 feet wide due to high speeds and traffic volumes. Narrower lane widths of 11 ft may be acceptable on reconstructed arterials with acceptable alignments and crash patterns.

Pavement cross slopes on divided roadways can be unidirectional or crowned separately. Divided arterials should have a normal cross slope of 1.5 to 2 percent.

Usable outside **shoulders** (paving preferred) should be a minimum of 8 feet wide for divided arterials. Minimum paved shoulder widths of 4 ft should be used on rural arterials where bicycles need to be accommodated. A paved shoulder width of 4 feet should satisfy the needs of a shoulder within the median for divided arterials.

Median widths depend on highway type and location. Wider medians should be used where practical – these are safer but may prove costlier. Under constraining conditions, medians for roadways without at-grade intersections may be as narrow as 4 to 6 feet. Medians 12 to 30 feet wide provide a protected storage area for left-turns at intersections.

Median widths for rural unsignalized intersections are a function of the selected design vehicle. Medians of 25 feet or more provide adequate space for vehicles to turn or stop without lane encroachment. Narrower medians at rural intersections should be avoided in order to prevent vehicle exposure to through traffic. School bus design vehicles require median widths of 50 feet while larger vehicles (tractor-trailers, etc.) may need minimum widths of 80 feet.

Cases for Attaining Superelevation

I For median widths 15 feet or less
Traveled way (including median) is superelevated as a plane

II More appropriate for median widths between 15 and 60 feet
Median is held in horizontal plane and traveled ways are rotated separately around median edges

III Suitable for wide medians – 60 feet or more
Traveled ways are treated separately for superelevation with variable elevation differences at median edges

Multilane Divided Arterials

For certain locations, two-lane arterials may need to be modified to handle future traffic. If the design year's design hourly volume (DHV) exceeds the desired level of service (LOS) for the two-lane arterial, the improvement should be applicable to the ultimate four-lane divided arterial design. The *Highway Capacity Manual* can assist in determining the LOS and 4-lane considerations.

If an ultimate four-lane divided arterial is wanted in the future, the initial two-lane road should be built so that it may be converted into one of the two-lane, one-way roadways. Advantages include: less roadway costs; easier traffic control; potentially lower right-of-way costs; less modification of structures and vegetation; and minimal future impacts to wetlands.

The typical roadway cross-section for two-lane arterials planned for future divided facilities usually consists of a 24 ft minimum traveled way with 8 ft shoulders (which are compatible with four-lane divided arterial designs).

URBAN ARTERIALS

Urban arterials are high capacity roadways that carry traffic from collectors to freeways/expressways. Their purpose is to balance user mobility with the desired local level of service. Urban arterials are divided into two functional classifications – **urban principal** and **urban minor systems.**

Urban Principal Arterial

- For major urban areas, high traffic volumes, and largest trips
- Integrated internally and between major rural connections
- Carries important intra-urban and intercity bus routes
- Fully or partially access-controlled
- Spacing varies from 1 mile (central business districts) to 5 miles (less developed fringe areas)

Urban Minor Arterial

- For smaller areas, moderate length trips, and lower travel mobility
- Includes all arterials not classified as principal
- Places more emphasis on land access
- Does not typically penetrate neighborhoods
- Spacing ranges from 0.1 to 0.5 (central business areas) to 2 to 3 miles (suburban fringes) – normally 1 mile maximum in fully developed districts

For urban arterials – designers need to evaluate high speed compatibility with safety, pedestrians, driveway activity, parking, etc. Normally, **design speeds** range from 30 to 60 mph for urban arterial roadways.

The *design hourly volume (DHV)* is considered to be the most reliable traffic volume statistic for urban arterial design.

Choosing a design level of service balances the needs of users, context of the community, and confidence of future development/trip generation. **Level of service** C or D may be appropriate for designing urban arterials and their associated facilities for a future design year. A LOS of D may be acceptable for heavily developed metropolitan areas. Level of service C may be considered for rapidly expanding suburban areas for adequate drainage, grading, and right-of-way.

The **vertical grades** used for urban arterials can greatly impact roadway operational performance (truck speeds, stopping distance, overall capacity, etc.). Flat grades (0.3% minimum, 0.5% desirable) should be considered for arterials with heavy truck traffic or near full capacity to prevent speed reduction.

Table 7-4. Maximum Grades for Urban Arterials

	Metric						U.S. Customary						
	Maximum Grade (%) for Specified Design Speed (km/h)						Maximum Grade (%) for Specified Design Speed (mph)						
Type of Terrain	**50**	**60**	**70**	**80**	**90**	**100**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
Level	8	7	6	6	5	5	8	7	7	6	6	5	5
Rolling	9	8	7	7	6	6	9	8	8	7	7	6	6
Mountainous	11	10	9	9	8	8	11	10	10	9	9	8	8

Cross slopes of 1.5 to 3 percent should be considered to provide adequate pavement drainage on urban arterials. Lower values may be used for locations with drainage across a single lane while higher values may be usable for several lanes.

Lane widths of 10 feet may be used for constrained locations with low truck/bus traffic and speeds under 35 mph. Urban arterial streets can utilize 11 foot lane widths. Twelve (12) foot lanes are preferred for high-speed principal arterials with free-flowing conditions.

Lateral offsets to vertical obstructions in urban locations are needed to accommodate vehicles on the highway. The offset for curb locations is measured from the face of curb.

Lateral Offset Benefits

- Avoids adverse impacts on lane position into other lanes
- Improves sight distance
- Reduces lane encroachments from parked/disabled vehicles
- Improves roadway lane capacity
- Minimizes contacts from vehicle-mounted intrusions

Access management can enhance initial levels of service and preserve the LOS if future development occurs. Any method of access control should be coordinated with communities and adjacent property owners. These methods include access control by:

Statute *Zoning* *Driveway regulations* *Geometrics*

Different traffic control measures may be used on arterials to improve capacity and level of service. These measures may be classified as:

Traffic control devices – traffic signals, pavement markings, advance signs
Regulatory measures – turning movement restriction, curbside parking prohibition
Directional lane usage – one-way, reverse-flow operation

FREEWAYS

Freeways are control-access highways that are designed for high-speed traffic and regulated access. Advantages of this type of facility include: *improved roadway capacity; higher traveling speeds; and lower crash rates.*

Freeway Elements

Roadways
Medians
Grade separations at crossroads
Ramps to/from traveled way
Frontage roads

While design speeds should be consistent with roadway operating speeds, care should also be taken to ensure economic feasibility. **Design speeds** for freeways should be a minimum of 50 mph. Higher minimum speeds may be used depending on the location and alignment of the roadway – *70 mph (straight corridors); 50 to 60 mph (mountainous terrain); 60 mph (urban freeways); and 70 mph (rural freeways).*

Appropriate **design traffic** data chosen for a freeway may depend on the overall system's plan. Freeway segments may be built to meet either intermediate needs or future traffic projections of the completed facility – whichever is more suitable. Directional design hourly volumes (DDHV) should be used in determining the specific needs for the design period.

Level of service C is generally considered to be acceptable for freeways and their associated roadways (weave sections, ramps, collector-distributors, etc.). A LOS of D may be suitable for heavily developed metro areas where higher levels are not practical. For rural auxiliary/through lanes, level of service B is generally desired – but a LOS of C is acceptable for high traffic facilities.

Freeways should have a minimum of two (12 foot) through lanes in each direction. Tangent roadway segments should have pavement cross slopes between 1.5 and 2 percent – locations with heavy rainfall may need cross slopes of 2.5 percent for drainage.

Freeway Type	**Median (Left) Shoulder Width**	**Minimum Paved Width Left Shoulder**	**Minimum Paved Width Right Shoulder***
4-Lane	4 to 8 feet	4 feet	10 feet
6-Lane		10 feet	10 feet

* For locations with DDHV (truck traffic) exceeding 250 vehicles/hour – 12 ft shoulders should be considered

Maximum superelevation rates for freeways generally range from 6 to 12 percent with a maximum of 6 to 8 percent for snow/ice locations or viaducts.

Table 8-1. Maximum Grades for Rural and Urban Freeways

Type of Terrain	Metric						U.S. Customary						
	Design Speeds (km/h)						Design Speeds (mph)						
	80	90	100	110	120	130	50	55	60	65	70	75	80
	Grades (%)[a]						Grades (%)[a]						
Level	4	4	3	3	3	3	4	4	3	3	3	3	3
Rolling	5	5	4	4	4	4	5	5	4	4	4	4	4
Mountainous	6	6	6	5	—	—	6	6	6	5	5	—	—

[a] Grades 1% steeper than the value shown may be provided in urban areas with right-of-way constraints or where needed in mountainous terrain.

RURAL FREEWAYS

Rural freeways typically contain more liberal design components (alignments, cross-sections, etc.) due to high vehicle traffic, high design speeds, and available right-of-way. These roadways normally have four thru-lanes but may have six or more when approaching urban areas. The level of service B is acceptable for rural freeways – but a LOS of C may be appropriate for high volume auxiliary facilities.

Horizontal alignments and **vertical profiles** for rural freeways should have a combination of flat curves and gentle grades in order to accommodate high volumes and high speeds. Due to fewer physical constraints, rural freeways can be built near existing ground with smooth flat grades. Drainage and earthwork concerns are major design controls for rural profiles. Minimum design criteria should be avoided, if possible, to prevent undesirable forced or angular vertical alignments. Both horizontal alignments and vertical profiles need to be evaluated simultaneously to obtain acceptable designs.

Median widths for rural freeways typically range from 50 to 100 feet. This dimension provides adequate space and flat slopes for vehicle recovery. A 100-ft median is suitable for flat terrains where stage construction will add two 12-ft future traffic lanes. Wide variable medians (150 feet or more) may be acceptable for rolling terrain. Median widths (paved) of 10 to 30 feet may be required for highways with restricted right-of-ways or mountainous terrain.

URBAN FREEWAYS

Urban freeways are designed to carry heavy vehicle traffic and can be classified as *depressed, elevated, ground-level,* or *combination-type.*

Depressed freeways are normally built 16 feet below the surface of adjacent streets (in addition to structural depth clearance). The vertical clearance should also allow for any future pavement overlays. Frontage roads may flank depressed freeways while major streets pass over the facility. Advantages include: *reduced roadway noise; less freeway prominence;* and *street crossings at normal grade.*

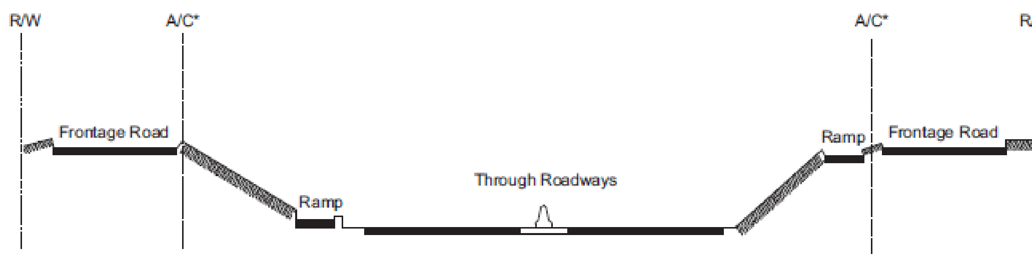


Figure 8-3. Typical Cross Section for Depressed Freeways

Roadway cross-sections for depressed freeways may vary considerably depending on location, required traffic lanes, available right-of-way, urban development, topography, soil, drainage conditions, and interchanges. A typical depressed cross-section contains a 10 to 22-ft median, 12-ft travel lanes, and 50 feet for frontage roads.

Elevated freeways may be appropriate at locations with restricted right-of-way, high water tables, numerous underground utilities, or other limitations. These types of roadways may be built using either a viaduct (more difficult) or an embankment. *Viaduct* designs can leave many cross streets open, minimally disturb existing right-of-way, and maintain traffic with fewer detours during construction. Disadvantages may include maintenance costs, icing susceptibility, aesthetics, and possible need for additional law enforcement. Elevated designs using *earth embankments* are appropriate in suburban locations with widely spaced cross streets, adequate right-of-way, available fill material, and sufficient vertical clearance.

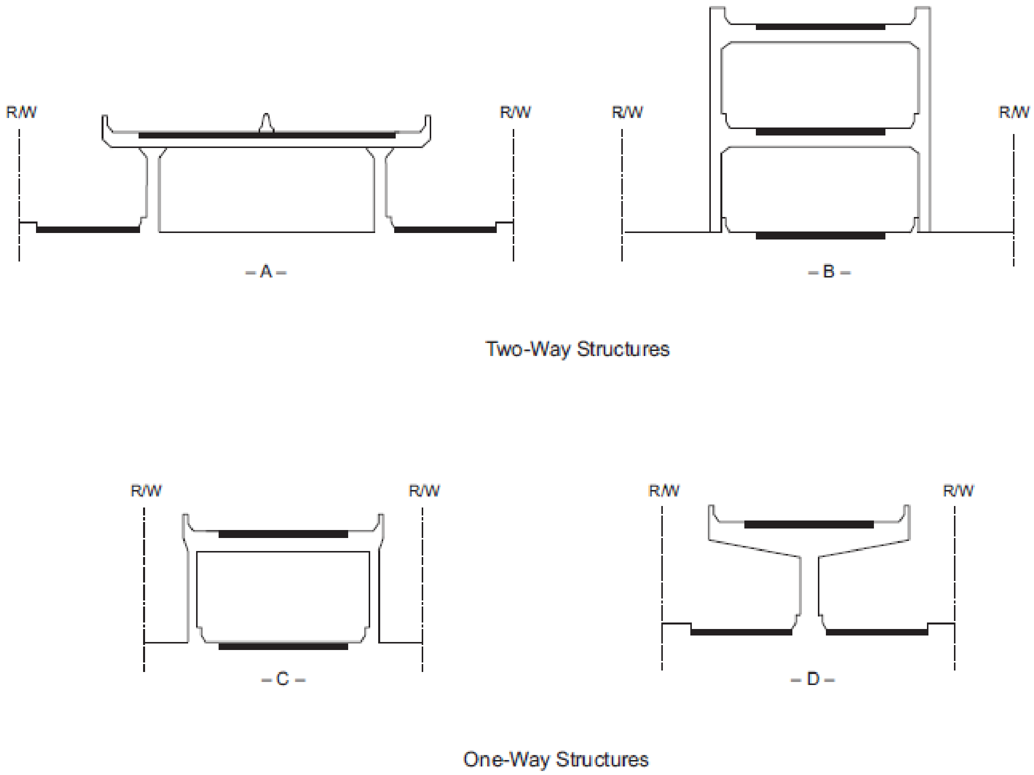


Figure 8-7. Typical Cross Sections for Elevated Freeways on Structures without Ramps

Total widths for elevated freeways on embankments may be similar to those required for depressed freeways.

<u>Typical Elevated Freeway Dimensions</u>

Lane Width:	12 feet		
Parapet Width:	2 feet		
Shoulder Width:	10 feet (Right)	4 feet (Left)	4 Lanes
	10 feet (Right)	10 feet (Left)	6 or More Lanes
Median Width:	10 feet (4 Lanes)	22 feet (6 or More Lanes)	
Minimum Offset Between Structure and Building Line:			15 feet
			20 feet (double deck)

Ground-level freeway designs contain long roadway segments at ground level that are suitable for flat terrains, areas along railroads/waterways, and urban locations with widely spaced cross streets (crossroad intersections are a major concern). This type of freeway is typically used in outlying metropolitan areas due to less expensive right-of-way costs. Therefore – medians, outer separations, and borders can be widened for roadway design or aesthetics.

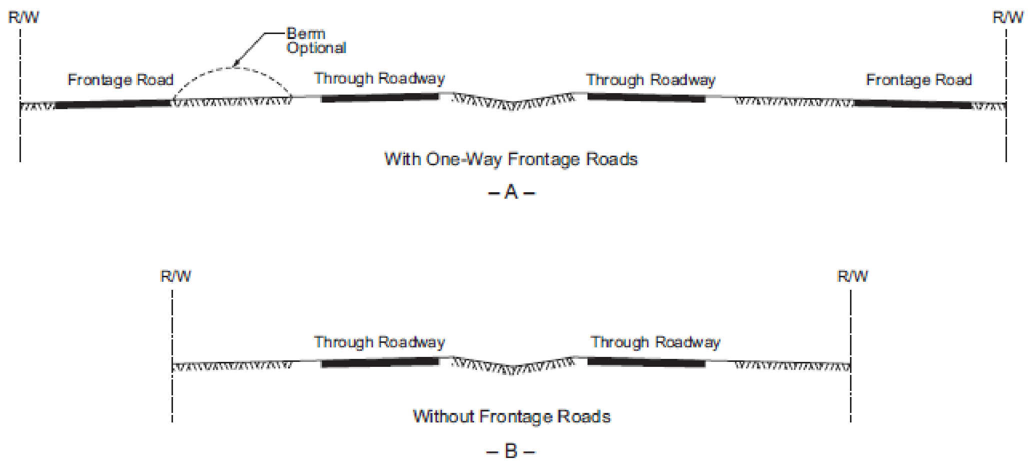


Figure 8-12. Typical Cross Sections for Ground-Level Freeways

At locations with four or six initial travel lanes, it may be advantageous to provide right-of-way for future possible lane additions (multiples of 12 feet). This will simplify any additional construction with minimal cost or traffic disruption.

Combination-type freeways incorporate aspects of other freeway designs (depressed, elevated, and ground-level) and may control conditions such as *profile control* or *cross-section control.*

The best profile for a combination-type freeway in *rolling terrain* underpasses some crossroads and overpasses others. Although this design is not considered to be depressed or elevated, it may display some of their principles. For example, one part of a facility may be depressed, another segment may be elevated on an earth embankment, and at ground level for another location.

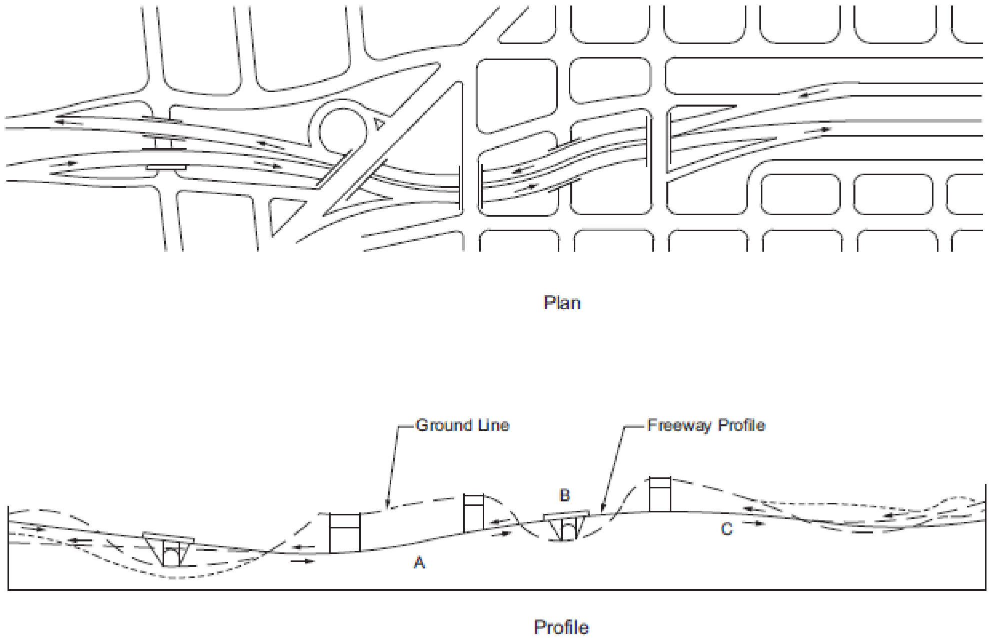


Figure 8-14. Profile Control—Combination-Type Freeway in Rolling Terrain

Combination-type freeways in *level terrains* closely follow the existing ground profile. This design may also overpass some important cross streets while elevating others.
Combination-types are appropriate for level terrains where

– *soil, groundwater or utilities prevent depressing the freeway*

and – *continuous viaduct construction is not practical.*

A possible design disadvantage is a rollercoaster profile resulting from close interval successive cross streets.

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Note: All figures, illustrations, tables, etc. contained within this course are from this text unless noted otherwise.

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