PDHonline Course C751 (6 PDH)

Roadway Cross-Sections

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Roadway Cross-sections

Gregory J. Taylor, P.E.

INTRODUCTION

The AASHTO "Green Book" defines a **roadway cross-section** as *"a vertical section of the ground and roadway at right angles to the centerline of the roadway, including all elements of a highway or street from right-of-way line".* Along with the vertical alignment (grades and vertical curves) and horizontal alignment (tangents and curves), the roadway cross-section (lanes and shoulders, curbs, medians, roadside slopes and ditches, sidewalks) helps to present a three-dimensional roadway model. Its ultimate goal is to provide a safe, smooth-flowing facility that is crash-free.

This course focuses on the geometric design of cross-sections for modern roads and highways. Its contents are intended to serve as guidance and not as an absolute standard or rule.

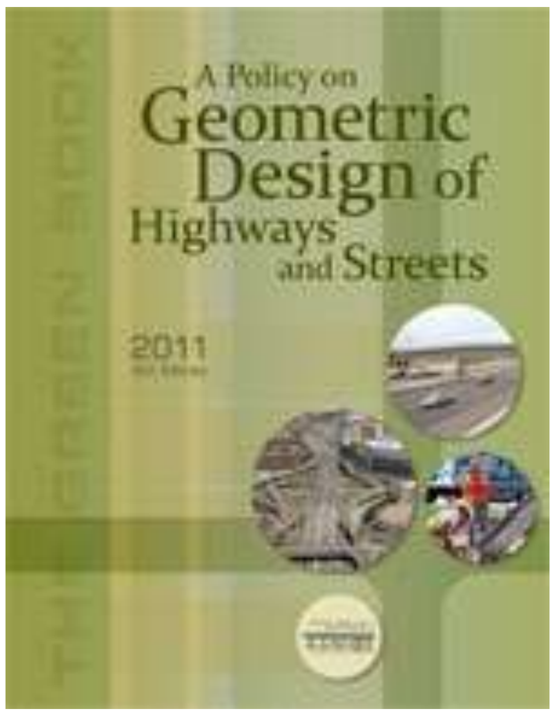
Upon course completion, you should be familiar with the general design concepts for roadway cross-sections. The course objective is to give engineers and designers an in-depth look at the principles to be considered when selecting and designing a roadway.

Subjects covered include:

Design guidelines
Traveled way
Lane width
Shoulders
Rumble strips
Roadside design
Curbs
Drainage channels & sideslopes
Traffic barriers
Medians
Frontage roads
Outer separations
Noise control
Roadside control
Tunnels

Pedestrian facilities
Bicycle facilities
Bus turnouts
On-street parking

A Policy on Geometric Design of Highways and Streets (also known as the "Green Book") published by the *American Association of State Highway and Transportation Officials (AASHTO)* is considered to be the primary guidance for U.S. roadway design. For this course, **Chapter 4 - Cross-Section Elements** will be used exclusively for fundamental roadway geometric design principles.



BACKGROUND

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 and shoulders, curbs, medians, roadside slopes and ditches, 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 will always be 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.**

DESIGN GUIDELINES

In today's world, designers need to understand how all elements of the roadway affect its safety and operation – *horizontal and vertical alignment, cross section, intersections, and interchanges.* Each location presents its own unique set of design challenges.

A designer's ability to make reasonable, cost-effective, and site-specific choices will be dependent on their understanding of the functional rationale behind their design guidelines. Design criteria reflect the research and experience which consider local site conditions, needs of space, and other transportation factors. Their use provides a measure of consistency and quality for roads designed by different individuals.

Design Criteria

Safety
Operational quality
Cost-effectiveness
Maintenance needs

Roadways are designed in conjunction with design guidelines and standards that take into account speed, vehicle type, road grade (slope), view obstructions, and stopping distance. Using these guidelines along with good engineering judgment will help produce a comfortable, safe, and aesthetically pleasing roadway.

AASHTO

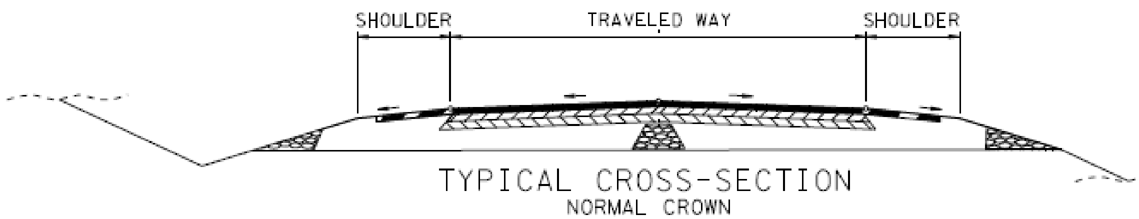
The *American Association of State Highway and Transportation Officials (AASHTO)* publishes and approves information on geometric roadway design for use by individual state transportation agencies. The majority of today's geometric design research is sponsored and directed by AASHTO and the Federal Highway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

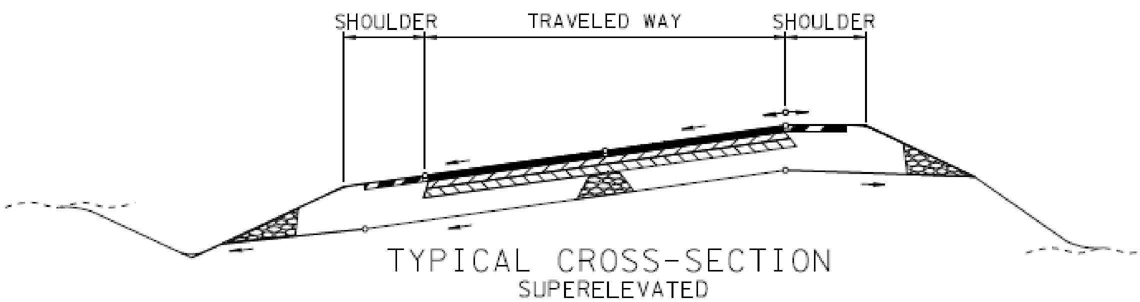
Individual transportation agencies adopt or develop their own design criteria, referencing approved AASHTO policies. Most states usually adopt major portions of the AASHTO design values or adopt the AASHTO policy completely as their design criteria.

CROSS-SECTION

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.





<u>Surface Type Criteria</u>

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. The *AASHTO Mechanistic-Empirical Pavement Design Guide* provides additional detailed information about the structural design of pavements.

The number of required roadway lanes is typically determined by the analysis procedures in the *Highway Capacity Manual* for the level of service desired.

Community input may also show that a lower level of service may be acceptable for *the situation versus the level of service* normally provided for new construction projects.

Signalized intersections are an important factor controlling the capacity of an urban roadway. While there may be more flexibility in determining their number of lanes, the need to distribute traffic safely will determine if any expansion of the approach roadway is warranted. Any additional lanes at the intersections can be tailored in a variety of configurations to serve traffic needs.

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.

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.

Hydroplaning

Roadway water is typically channeled through vehicle tire tread pattern and pavement surface roughness. Hydroplaning is the result of exceeding the tire tread and pavement surface drainage capacity. Water accumulates in front of the tire and creates a water wedge with a hydrodynamic force capable of lifting rolling tires.

Hydroplaning Influences

Water depth
Roadway geometrics
Vehicle speed
Tread depth
Tire pressure
Pavement surface condition

Designers can help reduce the potential for hydroplaning through the use of pavement transverse slopes, roughness characteristics, and drainage practices. The *AASHTO Model Drainage Manual* provides additional details about dynamic hydroplaning design.

LANE WIDTH

The selection of a roadway lane width can affect the facility's cost as well as its performance.

Lane Width Influences

Driver comfort
Operational characteristics
Crash probability
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. The *AASHTO Guide for the Development of Bicycle Facilities* provides further details for bicycle requirements.

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". These 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.

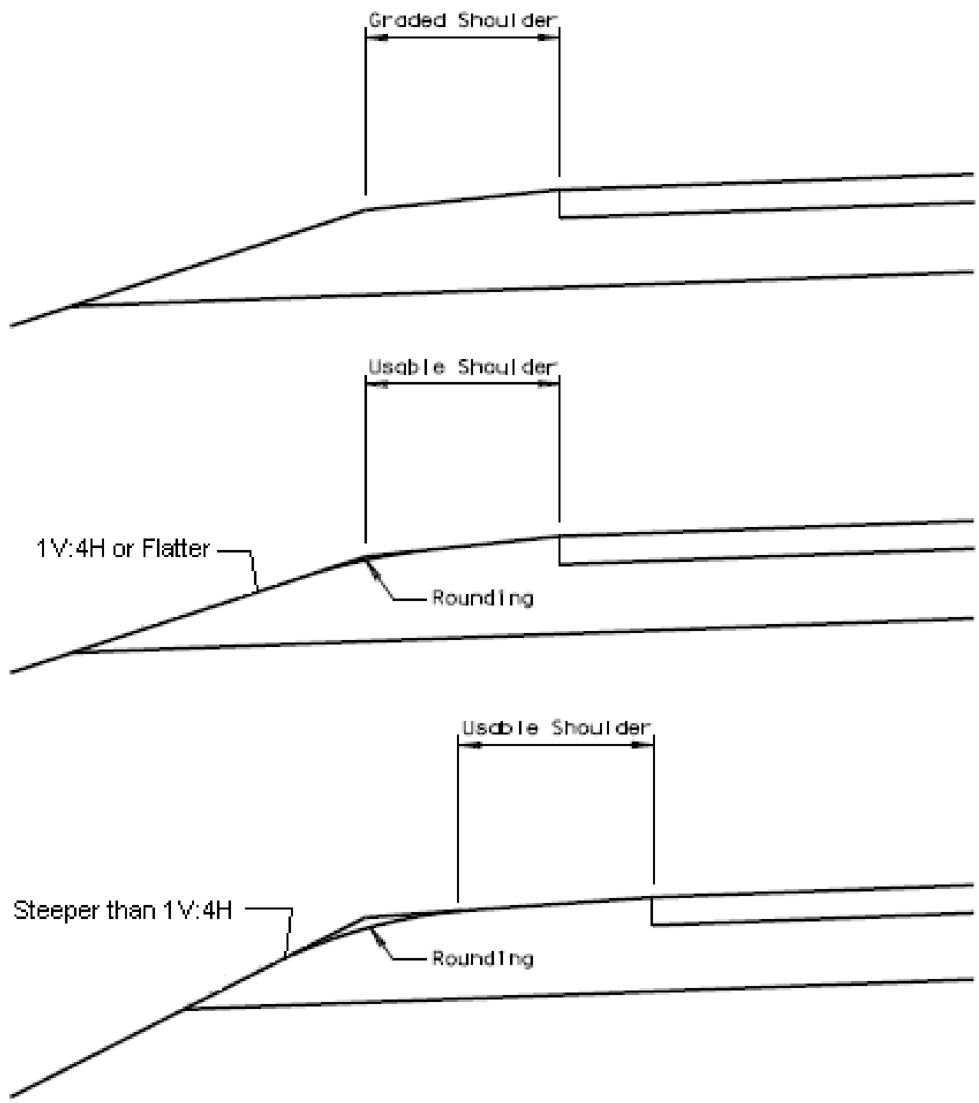
Shoulder surfacing provides better all-weather load support versus soil.

Shoulder Surface Materials

Gravel
Mineral/chemical additives
Shell
Asphaltic/concrete paving
Crushed rock
Bituminous surface treatments

Roadway shoulders are designed for a variety of purposes other than carrying through-traffic, including:

- Area for motorist stops;
- Separate storage space for disabled vehicles, and emergency operations;
- Structural support for roadway paving;
- Improved highway capacity;
- Maintenance operations area (storage, snow/ice removal);
- Space for pedestrians, bikes, bus stops, vehicle encroachment, mail vehicles, and construction detours;
- Space for evasive maneuvers to prevent crashes;
- Sign and guardrail lateral clearance space;
- Minimized surface drainage with discharge points further away from the traveled way;
- Driver ease and reduced stress;
- Improved safety and sight distance;
- Enhanced roadway aesthetics.



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 desirable
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 increase 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
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. Any evidence of shoulder problems may prevent it from being used properly. Regular maintenance is crucial for all types of shoulders to perform as intended.

Over time, unstabilized shoulders consolidate 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.

Advantages of Stabilized Shoulders

- Emergency vehicle refuge
- Drop-off & rutting prevention
- Adequate roadway drainage cross slope
- Maintenance reduction
- Lateral roadway base and surface support

Turf shoulders may be used for areas with suitable climate and soil conditions. These shoulders are good for delineating the traveled way – preventing use as a travel lane. Little maintenance is needed other than mowing to maintain adequate cross slope for proper drainage.

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. Paved shoulders help to prevent erosion, and moisture penetration which enhances the pavement's strength and durability. Edge line pavement markings are typically installed to delineate the edge of traveled way.

Shoulder Contrast

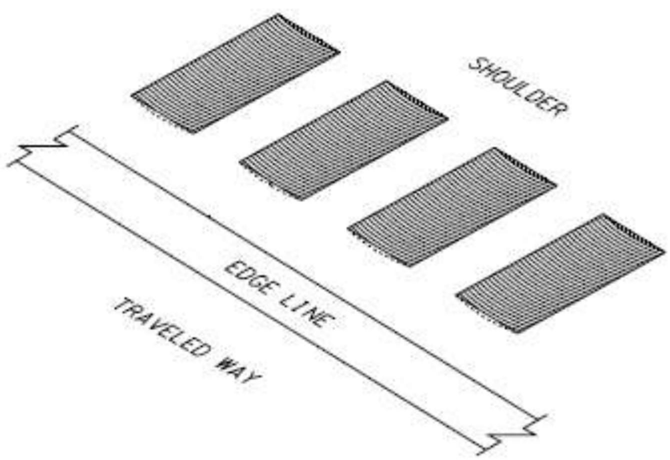
Different colors and textures for shoulders help define the traveled way (night and inclement weather) and discourage using shoulders as through lanes. While suitable contrast with bituminous pavements is difficult – gravel, turf, crushed stone, and bituminous shoulders provide excellent contrast with concrete pavements. Seal coats with light color stone chips may help contrast. Edge line pavement markings can be used to reduce the need for shoulder contrast.

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.

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

Typical 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 are the product of combining rumble strips with pavement markings. These may be installed using raised plastic pavement markers or conventional pavement markings. Rumble stripes provide increased visibility in inclement weather or nighttime conditions.

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.

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, traversable 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 (horizontal, driveways)
- Minimizes contact between obstructions & vehicles (mirrors, doors, truck overhangs, etc.)
- 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.

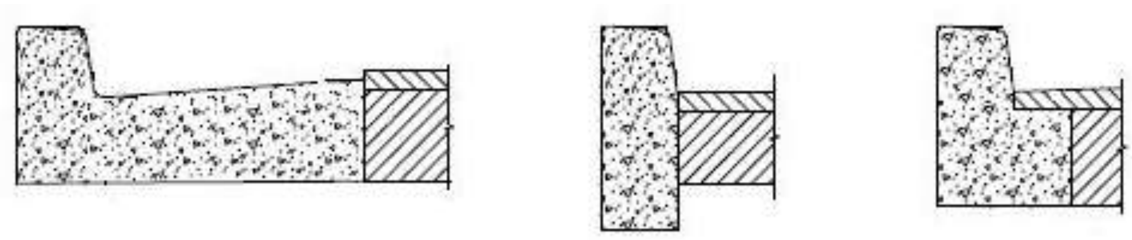
Purposes of Curbs

Drainage control
Roadway edge delineation
Right-of-way reduction
Aesthetics
Delineation of pedestrian walkways
Reduction of maintenance operations
Assistance in orderly 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.

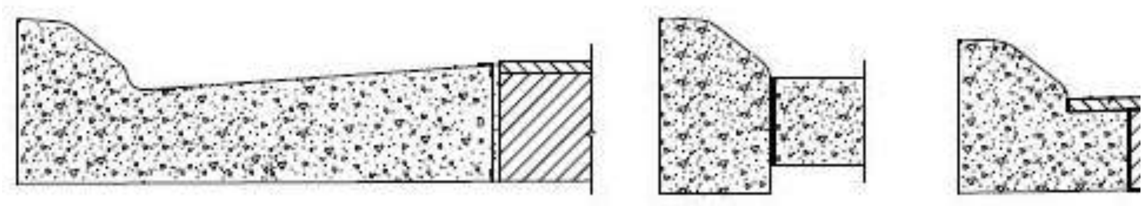
The purpose of **vertical (non-mountable)** curbs is to discourage errant vehicles from leaving the road. These types of curbs are not suitable for high-speed roadways due to vehicle tendencies to overturn or become airborne from curb impact. Vertical curbs (typically range from 6 to 8 inches) can also 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.

Slope of Curb Face	Curb Height	
>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. However, it is preferable to offset these 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).

Although cement concrete curbs are typically used on highways, granite may be preferred over cement ones due to durability in snow and ice areas. However, costs may make granite a less attractive choice.

High visibility treatments may include: *reflectorized markers on curb tops*
reflectorized paints
reflectorized surfaces

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

- Bridges
- Culverts
- Channels
- Curbs
- Gutters
- 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

Rapid runoff rates
Larger volumes of runoff
Costly flood damage
Higher overall costs
Greater restrictions – urban development
Lack of receiving waters
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.

Types of Drainage Channels

- 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 permit 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)** that 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.

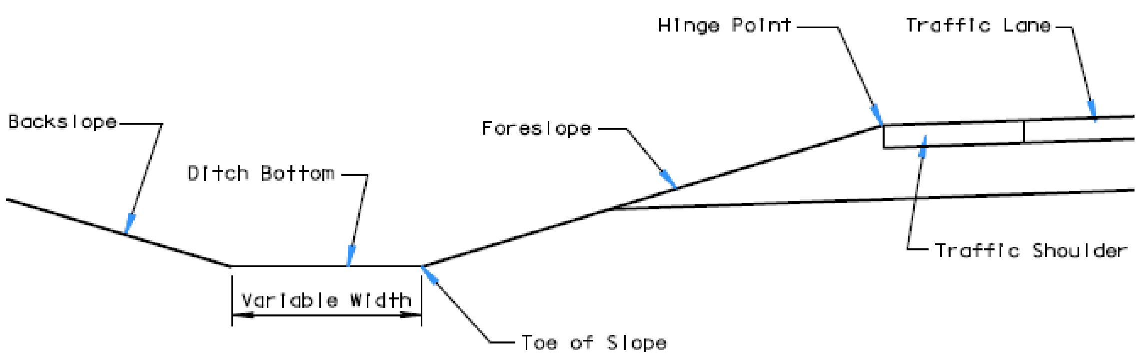
Roadside Channel Lining Criteria

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

Vegetation provides the most economical lining but is not suitable 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 and are 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.

A number of publications are readily available to aid the designer with roadway drainage including:

AASHTO Highway Design Guidelines
AASHTO Model Drainage Manual
AASHTO LRFD Bridge Design Specifications
AASHTO Standard Specifications for Highway Bridges
AASHTO Roadside Design Guide
FHWA Urban Drainage Design Manual
FHWA Design of Stable Channels with Flexible Linings

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 based on the amount of deflection that occurs upon impact by a vehicle.

Types of Longitudinal Barriers

- Flexible
- Semirigid
- Rigid

Flexible barriers deflect considerably when hit by a vehicle 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, and 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

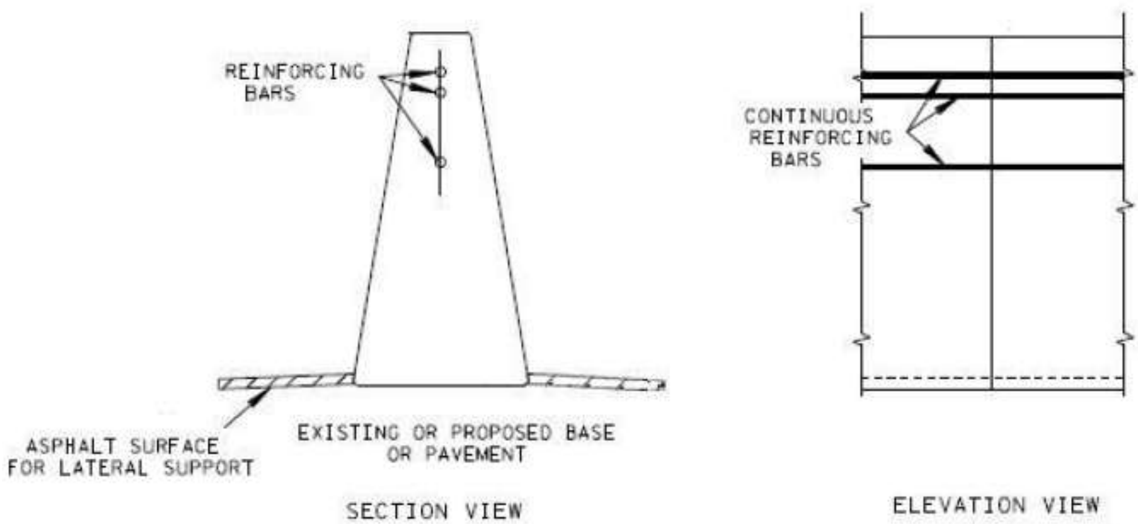
Median barriers are another type of longitudinal system used to prevent vehicles from crossing the median and crashing head-on into oncoming traffic. For roadways with low traffic volumes or wide medians, the likelihood of errant vehicles crossing the median and hitting an opposing vehicle is relatively 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 the median barrier 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 terminal 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/obstacles.

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

Advantages of Converting Flush Medians to Two-Way Left-Turn Lanes

Reduced travel time
Improved capacity
Reduced crash frequency
More flexibility
Public preference

Two-way left-turn lanes increase roadway access instead of controlling it. These are generally used on arterials to provide access for closely spaced, low-volume ramps. The optimum median width for two-way left-turn lanes ranges from *10 to 16 feet.*
Nontraversable medians (raised curbs, concrete median barriers) may be considered for locations where two-way left-turn lanes are unsuitable.

Median design may require tradeoffs by the engineer. For locations with restricted right-of-way, a wide median may not be possible if it requires reducing areas adjacent to the traveled way. A reasonable border width serves as a buffer between private development and the roadway, plus space may be needed for sidewalks, highway signs, utilities, parking, drainage channels/structures, slopes, clear zones, and native plants.

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.

FRONTAGE ROADS

The function of any frontage road depends on the character of the section as well as the type of roadway (major route or local street) it serves. These functions may include:

- Controlling access to the arterial
- Serving as a street for adjoining properties
- Maintaining traffic on each side of the arterial

Frontage roads separate local traffic from high-speed through traffic, and intercept resident/business ramps – preserving highway through character.

While frontage roads are used for all types of roadways – they are used most frequently on freeways to distribute and collect roadway traffic between local streets and freeway interchanges. Frontage roads help preserve roadway capacity and reduce crashes on the arterial streets.

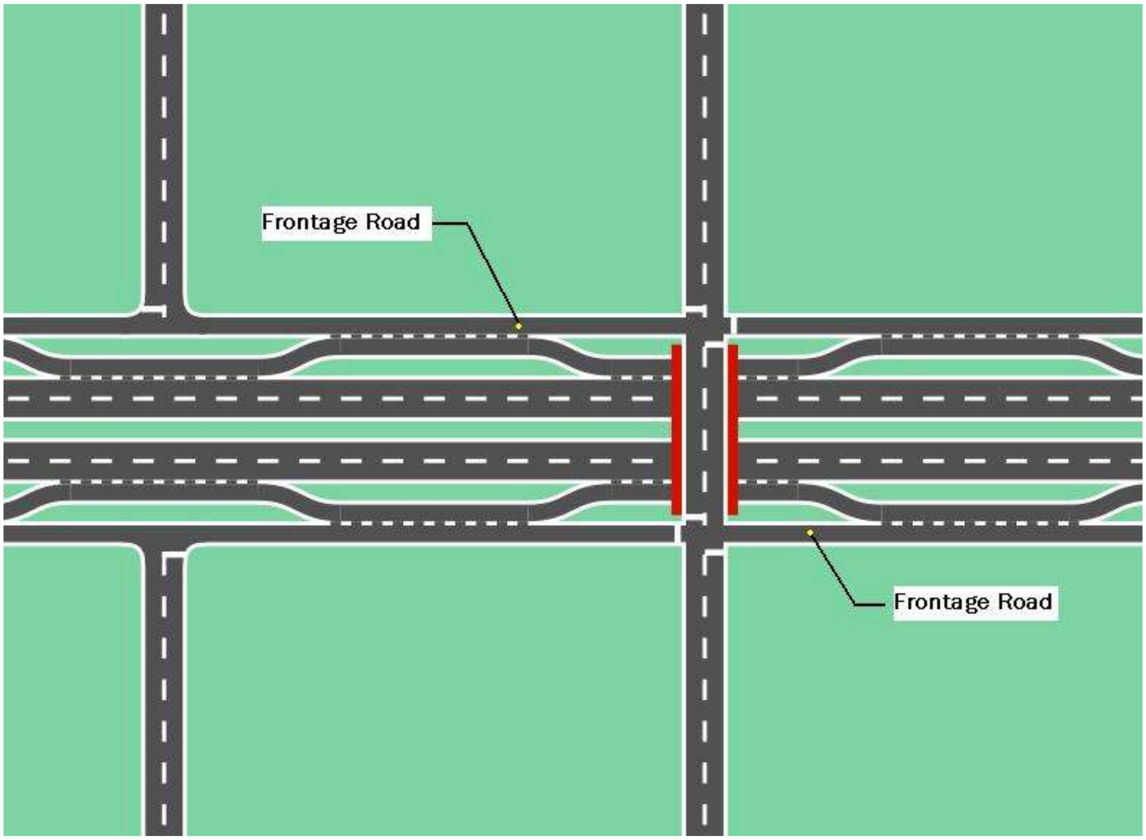
Frontage roads are typically parallel to the main road, may be on one or both sides of the roadway, and may or may not be continuous. Using continuous frontage roads for high-speed arterials with intersections should not be used. Multiple through and turning movements at many closely spaced intersections can increase the potential for vehicle crashes. Frontage roads should be placed a considerable distance (150 ft minimum – urban) from the main line to improve traffic operations.

One-way frontage roadways are preferred due to their operational and safety advantages. This type of operation may be inconvenient for local traffic. However, the potential for pedestrian/vehicular conflicts is greatly reduced, as well as the needed width for both roadway and right-of-way. The roadway capacity is also maintained for freeways and frontage roads.

Two-way frontage roads are suitable for suburban/rural locations with irregular access points, or where one-way operation would create driver inconvenience. These may also be used where there are no parallel roads within a reasonable distance of the frontage roadway.

Connecting ramps are crucial to frontage road design. Simple openings or slip ramps are typically used for one-way frontage roads and slow-moving arterials.

These should not be used for freeway - two-way frontage road connectors due to increased crash potential. For high-speed roadways (freeways, arterials), the connections need to be designed to allow for speed changes and vehicle storage.



Typical Frontage Road Example

OUTER SEPARATIONS

Outer separations are buffer areas between through-traffic roadways and local frontage road traffic. These separations also provide shoulder space and ramp connection area for the through roadways. *As the outer separation widths increase - the influence from local traffic on through traffic decreases.* Wide separations are suitable for landscape treatment and aesthetics. Suitable widths are also advantageous for intersections to minimize vehicular and pedestrian conflicts.

The cross-section of an outer separation depends on:

- **width**
- **type of arterial**
- **frontage road type**

The *AASHTO "Green Book"* provides a number of typical cross-sections for these types of outer separations.

NOISE CONTROL

Traffic noise is typically the resulting sound from vehicle engines, aerodynamics, exhaust, tire interaction with the roadway surface, etc. Designers should make every effort to minimize sound radiation along noise-sensitive areas. They should also review any noise ordinances or restrictions that could limit the types of equipment permitted or the hours of work. Coordination with local agencies is essential during the planning and design process for successful implementation. Location and design methods can be used to help reduce roadway traffic noise.

A standard method of sound measurement involves using the **A-scale** on a standard sound level meter to read effective decibels (dBA). Since these results are measured on a **logarithmic scale**, 10 dBA increases appear as half of the original noise level (i.e. 50 dBA noise level sounds half as loud as 60 dBA). Doubling the noise level results in only a 3 dBA increase (i.e. a single vehicle produces a noise level of 60 dBA, two vehicles at the same point produce 63 dBA, four vehicles 66dBA, etc.).

Sound decreases with distance at approximately *3 to 4.5 dBA* for each doubling of distance from the roadway.

Similar traffic noise produces different reactions depending on the environment. Area development typically affects the annoyance level – higher noise levels are tolerated in industrial areas versus residential ones.

Noise levels may also be an important consideration when choosing a roadway's design speed. Studies have shown that greatly reduced noise levels result in drivers underestimating their speeds and driving 4 to 6 mph faster. Drivers are likely to become desensitized to their own speeds due to reduced noise levels.

Design Procedures

In order to analyze the effects of roadway noise, the criteria for noise impacts must be established. Next, noise-sensitive areas (schools, churches, motels, parks, hospitals, residential areas, nursing homes, libraries, etc.) need to be identified. Existing noise levels can then be measured and roadway-generated noise levels predicted by current noise prediction methods. The prediction will typically produce the worst hourly traffic noise for the design year. Major factors include traffic characteristics, topography, and roadway characteristics.

Traffic Characteristics: Speed Volume Composition

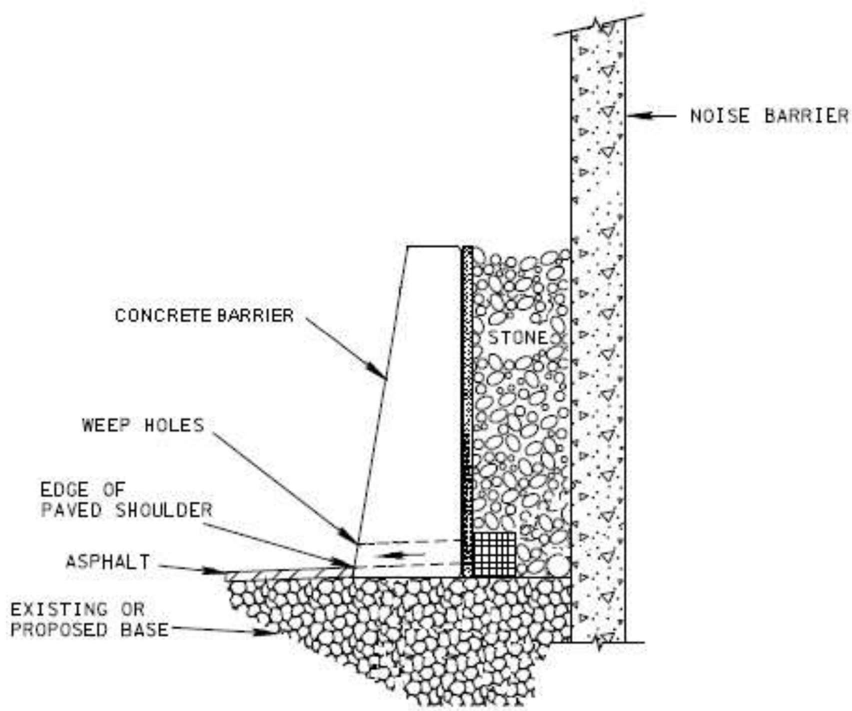
Topography: Vegetation Distance Barriers

Roadway Characteristics: Configuration Pavement type Grades Facility types

The FHWA provides noise-abatement criteria and design noise levels according to land usage. AASHTO states that traffic noise impacts occur only for the following cases:

- Predicted noise levels approach or exceed noise-abatement criteria
- Predicted noise levels exceed predicted levels but are within noise-abatement criteria

Both of these specific situations should be analyzed to successfully assess the traffic noise impact for future projects.



Noise Barrier Example

Noise Reduction Design

Designers should ensure that the placement of any proposed noise barriers do not intensify the severity of any potential crashes. The barriers should allow for sign placement and lateral offsets to hazards outside the traveled way, where practical. Sufficient sight distance is also a crucial design factor for noise barriers. A barrier should be installed anywhere with stopping sight distances below minimum AASHTO values (i.e. inside curve locations).

For gore areas, noise barriers should begin or end a **minimum of 200 feet** from the theoretical nose.

Any potential noise attenuation should be built into the design process as early as possible. This will prevent costly revisions later in the project cycle. Typical traffic noise solutions involve using solid materials to block the line of sight between the source and its receptors. A popular method for noise reduction is to design a roadway that takes advantage of its terrain to form a natural sound barrier. Depressed roadway sections (below ground level) have the same effect as barriers. For elevated roadways, their embankments may block the line of sight to receptors and reduce potential noise.

Special sound barriers (concrete, wood, metal, masonry walls, etc.) may be needed for certain noise-sensitive areas. The use of earth berms has been shown to be aesthetically pleasing by blending in with the natural landscape. These berms may be used alone or in combination with walls or screens to meet their intended purpose.

Buffer plantings (trees, shrubs, or ground cover) provide significant aesthetic effects and some noise reduction but are inefficient sound shields due to air flow.

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.

Driveways

Driveways are low-volume intersections whose operational effects are directly related to the functional classification of the road which they access. Although these ramps are important access points for residential and commercial use, their location or number can adversely impact traffic operations.

Driveways that may be used for either right or left turns increase through traffic interference and are unsuited for arterials. Eliminating left turns for drives on major streets can worsen traffic operations by forcing traffic to travel farther, etc. to reach their destination. Right turn only driveways are preferred for roadways with curbed medians, flush medians, or median barriers.

Driveway Design Objectives

Operation & efficiency of intersecting roadways
Reasonable property access
Sight distance for vehicles, pedestrians & sidewalk users
ADA requirements for pedestrians with disabilities
Bicycle lanes or paths
Public transportation locations

Several state and local governments have developed driveway regulations to maintain efficiency. These regulations may control location, design, right-of-way, signing, lighting, drainage, sight distance, curbs, and parking. Appropriate driveway designs should accommodate the anticipated types and volumes of vehicles.

Vertical profiles for driveways should allow efficient operations for entering or exiting vehicles. These alignments should minimize dragging, accommodate disabled pedestrians, supply adequate drainage structures, and prevent potential ponding.

For further information on driveway design, consult the *TRB Access Management Manual* and the *NCHRP Guide for Geometric Design of Driveways*.

Mailboxes

Mailboxes and newspaper tubes constitute a risk (either directly or indirectly) to motorists. They should be located to provide maximum convenience to the user while limiting any potential for crashes.

Mailbox & Newspaper Tube Risk Factors

Placement
Roadway cross-section
Sight distance
Traffic volume
Impact resistance

The crash potential involving carriers and motorists is impacted by carriers stopping and continuing travel on the roadway.

Mailboxes should be installed only on the right side of the roadway in the direction of travel – exception may be made for one-way streets where they can be used on the left side. Placement along high-speed, high-volume roads should not be used – if possible. Placement considerations should include minimum walking distance by the user, available stopping sight distance within the roadway, and corner sight distance.

Vehicles stopped at mailboxes should be clear of the traveled way and roadway traffic. Greater clearances for high traffic volumes. This may be remedied by placing mailboxes outside a wide usable shoulder or turnout.

Roadway Type	Shoulder/Turnout Width in Front of Mailbox
Rural Highway	8 feet
High-volume, high-speed	10 feet (12 feet some conditions)

Shoulders or turnouts less than 8 feet may not be practical for low-volume, low-speed roads. It is recommended that the mailbox face be placed 8 to 12 inches outside the shoulder/turnout to provide space to open the mailbox door.

For additional guidance regarding mailboxes, please refer to the *AASHTO Roadside Design Guide.*

Fencing

Fencing is used by various highway agencies to delineate access control for roadways and reduce the potential of right-of-way encroachment. Fencing is usually installed along the right-of-way line.

Full access-controlled highways may be fenced in any area except:

- precipitous slopes
- natural barriers
- where not required for access control

Highway agencies typically have control of the type and location of access control fence. For areas where fence is not needed for access control, it will be the property of the landowner. The type of fence should be the most cost-effective that is best suited to the land usage.

TUNNELS

Roadway development may at times require tunnels to transport traffic either under/through natural obstacles or to minimize highway impacts on a community.

Tunnel Construction Warrants

Areas where land acquisition costs may exceed tunnel costs
Narrow right-of-way locations with minimal expansion areas
Long, narrow terrain ridges with environmental or economic concerns
Long or serial intersection areas with non-standard street patterns
Existing or proposed parks and natural reserves
Transportation facilities - railroads, airports, etc.

Major Categories of Tunnels

Mining Methods
- Hard rock
- Soft ground

Cut-and-Cover Methods
- Trench
- Cut-and-cover

Tunnel classifications are determined by their method of construction. Tunnels built by mining methods leave overlying rock and soil intact. This method is further divided into the types of proposed excavated material *(hard rock or soft ground).* Hard rock tunneling is typically the cheaper option due to structural demands and construction costs. Tunnels needing immediate and heavy support will usually require costly soft ground tactics *(shields, compressed air).*

Tunnels built by cut-and-cover methods are constructed from the surface. The trench type uses pre-fabricated sections that are sunk, joined, and backfilled at the site. For favorable environmental and construction conditions, the trench method may be the most economical method. Cut-and-cover tunnels are the most common type for urban shallow tunnels. For this method, an open cut is excavated, the tunnel is built, and then backfilled. For ideal conditions, cut-and-cover tunnels are the most inexpensive method for shallow depth tunnels – but any surface disruption or utility problems can make this very difficult and expensive.

Design Considerations

Tunnel lengths need to be as short as practical in order to keep down costs and to enhance user comfort. The horizontal alignment is a crucial design element. *Tangent designs help to minimize length, improve operating efficiency, and provide adequate sight distance.* Using curved tunnels may limit stopping sight distance. Therefore, it is important to thoroughly analyze sight distances for tunnel designs.

Vertical alignments are also important for tunnel design by addressing driver comfort. Many factors need to be considered in order to balance user needs (lights, ventilation, etc.) with roadway costs (construction, operation, maintenance and others).

Design criteria for tunnels is similar to those for grade separated facilities including:

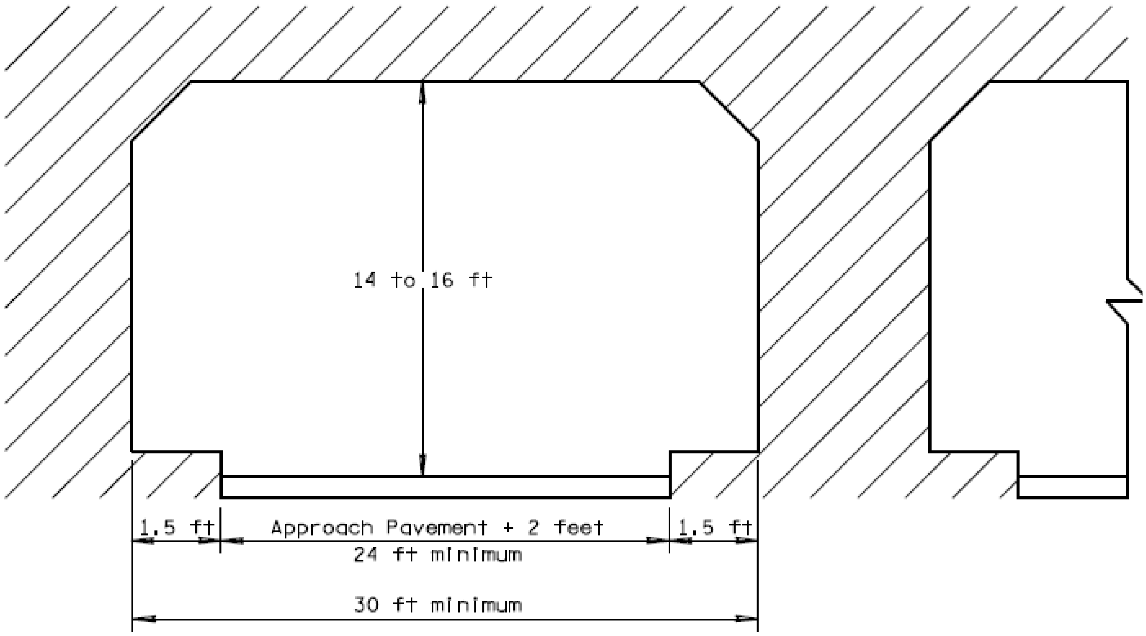
- Alignment
- Profile
- Clearances (vertical and horizontal

The main difference is that minimum values are generally used for tunnels because of economic and right-of-way issues.

Additional lateral space (shoulders) is needed on tunnels to prevent major delays caused by stalled vehicles. Construction costs may prevent the use of shoulders in long tunnels. Determining shoulder widths within tunnels should be based on analysis of all factors pertaining to design. For tunnel locations without shoulders, arrangements should be made with emergency services to remove disabled vehicles.

Two-Lane Tunnel Dimensions

Minimum roadway width between curbs	approach pavement + 2 feet (24 ft minimum)
Curb or sidewalk width	1.5 ft minimum
Total clearance width between walls	30 feet
Minimum vertical clearance	16 ft freeways (14 ft other highways)



The preferred two-lane tunnel cross-section contains two 12-ft lanes, 10-ft right shoulder, 5-ft left shoulder, and a 2.5-ft curb/sidewalk (on each side) with vertical clearances of 16 feet for freeways (14 feet for other roadways).

Although pedestrians are prohibited from freeway tunnels, raised sidewalks (2.5-ft wide) may be used beyond the shoulder space for emergency/maintenance walking access, or as a buffer between vehicles and tunnel walls/lighting fixtures.

PEDESTRIAN FACILITIES

Due to roadway interactions between pedestrians and motorized traffic, it is critical to integrate these 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 area. 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
- 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.

For more information regarding pedestrian facilities, refer to *Public Rights-of-Way Accessibility Guidelines*, and *AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities.*

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 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% max. 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.

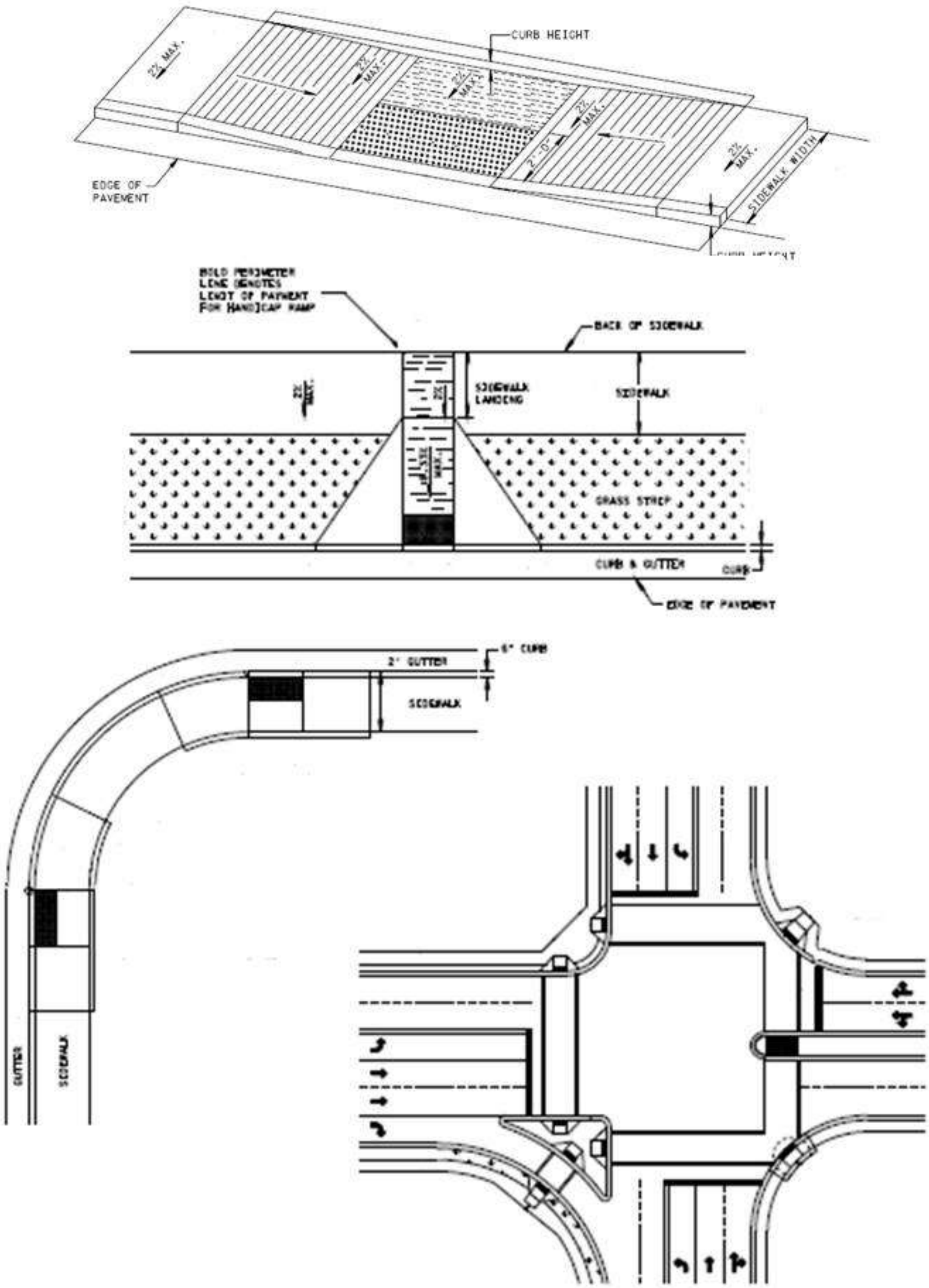
Combination curb ramps merge aspects of both perpendicular and parallel ramps. A sloped section ascends to a lower landing (lower than full curb height) and then from the landing to the sidewalk. This design prevents water and debris accumulation.

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

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.

BUS TURNOUTS

Bus turnouts are designed to separate buses from roadway traffic. Their intent is to provide safe access in the most efficient way possible.

Freeways

The purpose of bus turnouts is to provide adequate space (away from the traveled way) for bus deceleration, standing, and acceleration.

Bus Turnout Design Elements

- Separation from traveled way
- Passenger platforms
- Ramps
- Stairs
- Railings
- Signs
- Markings

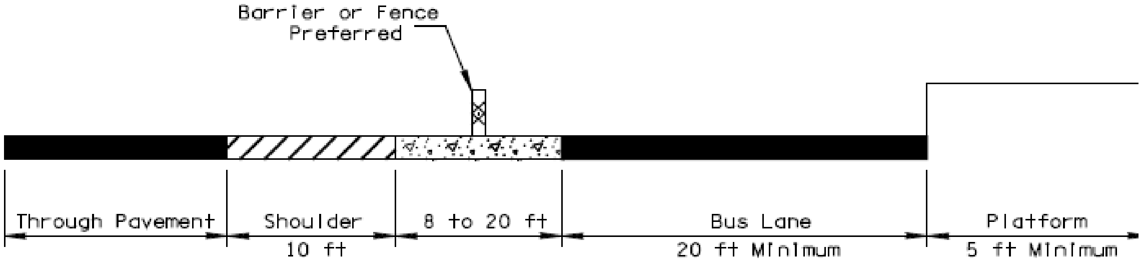
Speed-change lanes should have sufficient length for buses to enter or exit the roadway at average running speed without passenger discomfort. *Acceleration* lanes need to have above-minimum lengths to allow for lower accelerations of loaded buses. Different pavement colors and textures may be used to discourage through-traffic encroaching/entering the bus stop.

Freeway Bus Turnout Dimensions

Bus standing area/speed-change lanes width (including shoulders) *20 ft*

Dividing area between outer shoulder edge and edge of bus turnout lane *20 ft or more (4 ft minimum)*

Pedestrian loading platform width *5 ft minimum (6 – 10 ft preferred)*



Typical Bus Turnout

Arterials

Bus turnouts can substantially reduce the amount of interference between buses and other arterial traffic. In many cases, sufficient right-of-way may not be available to allow turnouts in the arterial border area. Turnouts should be provided whenever practical.

Effective Bus Turnout Characteristics

- Deceleration lane or taper for easy entrance to loading area
- Adequate standing space for maximum number of vehicles expected at one time
- Merging lane for easy reentry to roadway

A minimum deceleration lane taper of *approximately 5:1* (longitudinal to transverse) is intended to encourage buses to decelerate clear of roadway traffic before stopping. It is desirable to provide a length that permits deceleration from highway speeds.

Loading Area: 50 ft length per bus
10 ft wide (12 feet desirable)
3:1 maximum reentry taper

Two-Bus Loading Area: 180 ft minimum total length (midblock location)
150 ft near-side location
130 ft far-side location
10 ft loading area width

Turnout lengths should be increased by 13 to 16 feet for loading area widths of 12 feet.

For additional information on bus turnouts, please refer to *AASHTO Guide for Design of High-Occupancy Vehicle (HOV) Facilities* and *Guidelines for the Location and Design of Bus Stops.*

Park-and-Ride Facilities

Park-and-ride facilities are parking areas with connections to public transit that allow commuters to change mode of travel for continuing their journey. These facilities differ from typical parking lots by their various activities. Park-and-rides need to be close to residential areas to minimize single occupant travel but far enough from the city's center to prevent land costs from being prohibitive. Location factors can also include acquisition costs, terrain, connector road capacity, and surrounding land usage.

Location Considerations

Visible to attract commuters
Adjacent to streets and roadways
Prior to traffic bottlenecks
Close to residential areas

Parking lot size depends on existing parking lot characteristics, design volume, and available land. Each park-and-ride should contain a separate parking area with drop-off facilities near station entrances, and parking for passenger pickup. User conflicts may be minimized by considering bus loading/unloading, taxi service, bicycle parking, and parking for disabled individuals (see *ADA Accessibility Guidelines – ADAAG*).

Park-and-Ride Dimensions

Bus roadway width: 20 ft minimum (to allow passing)
Parking spaces: 9 ft x 20 ft (full-size cars)
8 ft x 15 ft (subcompact cars)
Sidewalks: 5 feet wide (minimum)
Loading areas: 12 feet wide
Parking area grades: 1% minimum
2% desirable
5% maximum
Entrances & exits: one for every 500 parking spaces
Curb return radii: 30 ft minimum

Access points should be located with minimal disruption to through traffic – a minimum of 300 feet from other intersections. These points need to have sufficient sight distance for entering and exiting vehicles (300 ft minimum corner sight distance). Access to lots should be avoided on crest vertical curves.

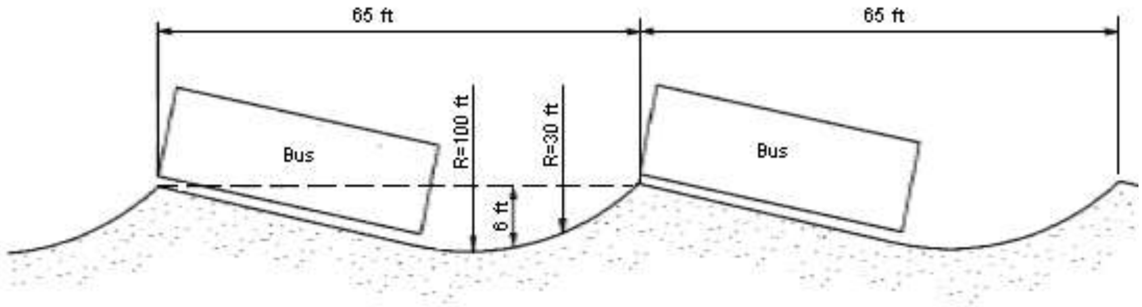
Shelters should be installed at main passenger loading areas to protect transit patrons. These need to be large enough for off-peak passenger volumes but may be larger where practical. It is not critical to accommodate the ultimate passenger demand at initial construction due to ease of future shelter expansion.

$$\text{Shelter size} = (\text{Anticipated number of patrons}) \times (3 \text{ to } 5\ ft^2)$$

Bus-loading designs depend on the anticipated bus traffic. The two predominant bus-loading areas designs are:

Parallel
Sawtooth

Sawtooth arrangements (typically preferred) are easier for buses to bypass standing buses. Useful for sites where two buses are expected at the same time.



Typical Sawtooth Bus Loading Design

Parallel designs allow loading two buses (95 ft length) – 45 ft for each additional space. The loading area should have a minimum width of 24 feet for passing.

For additional guidance, please see *AASHTO Guide for Design of High-Occupancy Vehicle (HOV) Facilities*, *TCRP Report 19, Guidelines for the Location and Design of Bus Stops*, and *AASHTO Guide for the Design of Park-and-Ride Facilities*.

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 (sufficient for 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).

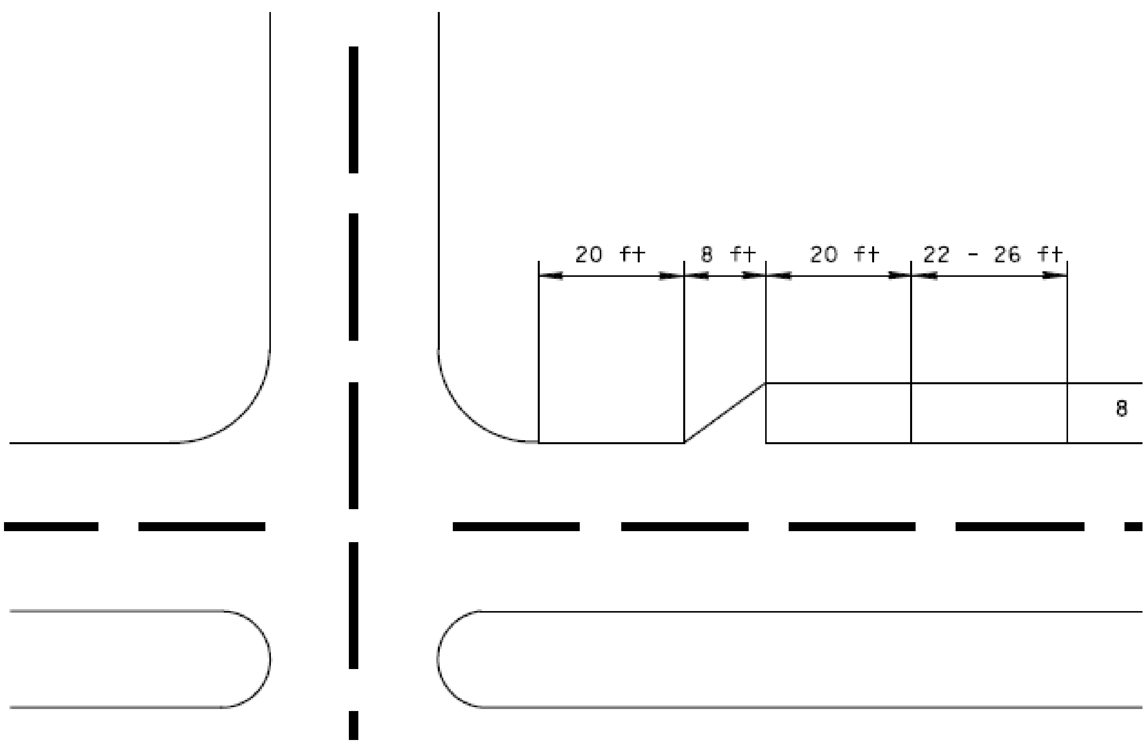
For areas with a significant number of pedestrian crossings, the relationship between parking lanes and intersections should be considered. At sites where parking lanes are carried to the intersection, vehicles may use the parking lane as a right-turn lane resulting in operational inefficiencies or crashes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

<u>Negative Aspects of On-Street Parking</u>

Decreased through-traffic capacity
Disrupted traffic flow
Increased crash potential



Parking Lane Transition at Intersection

SUMMARY

The AASHTO "Green Book" defines a **roadway cross-section** as *"a vertical section of the ground and roadway at right angles to the centerline of the roadway, including all elements of a highway or street from right-of-way line".* Along with the vertical alignment (grades and vertical curves) and horizontal alignment (tangents and curves), the roadway cross-section (lanes and shoulders, curbs, medians, roadside slopes and ditches, sidewalks) helps provide a three-dimensional roadway model. Its ultimate goal is to provide a safe, smooth-flowing facility that is crash-free.

This course focused on the geometric design of cross-sections for modern roads and highways. The participant should now be familiar with the general concepts for designing roadway cross-sections. The course objective was to provide an in-depth look at the principles to be considered when selecting and designing a roadway cross-sections.

Course topics covered include:

Design guidelines	*Traveled way*
Lane width	*Shoulders*
Rumble strips	*Roadside design*
Curbs	*Drainage channels*
Traffic barriers	*Medians*
Frontage roads	*Outer separations*
Noise control	*Roadside control*
Tunnels	*Pedestrian facilities*
Bicycle facilities	*Bus turnouts*
On-street parking	*Sideslopes*

A Policy on Geometric Design of Highways and Streets (also known as the "Green Book") published by the American Association of State Highway and Transportation Officials (AASHTO) is considered to be the primary guidance for U.S. roadway design. For this course, **Chapter 4 - Cross-Section Elements** was used exclusively for fundamental roadway geometric design principles.

REFERENCES

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Note: All equations contained within this course are from this text unless noted otherwise.

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