Roadway Cross-Sections I

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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.

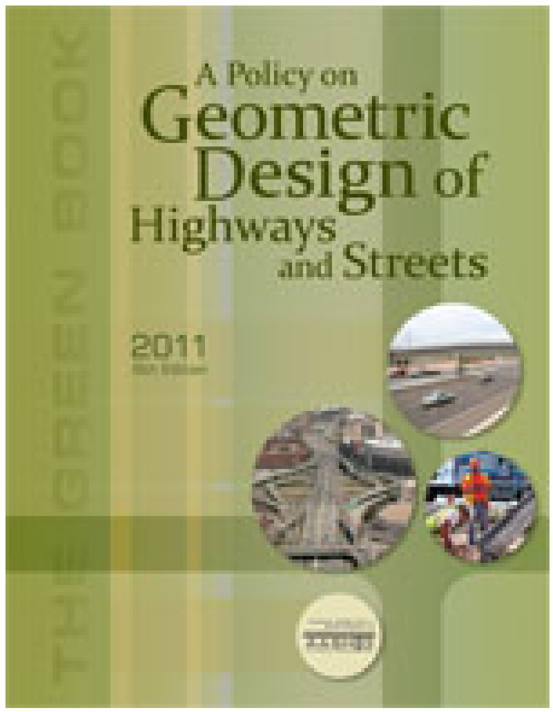
This course is the first of two in this series that focuses on the geometric design of cross-sections for modern roads and highways. Its contents are intended to serve as guidance and not as an absolute standard or rule.

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

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** (Sections 4.1 through 4.10) 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

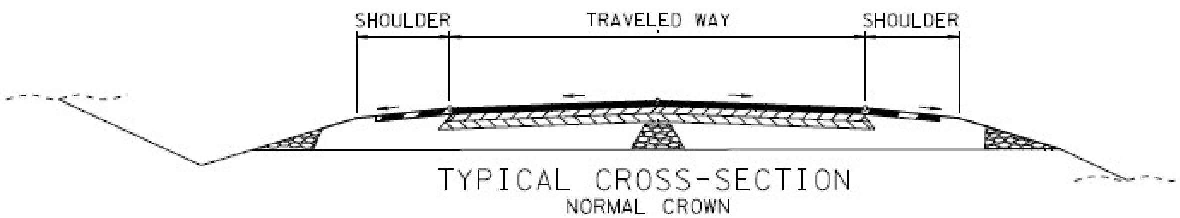
The *American Association of State Highway and Transportation Officials (AASHTO)* publishes and approves information on geometric roadway design for use by individual state transportation agencies. The majority of today's geometric design research is sponsored and directed by AASHTO and the Federal Highway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

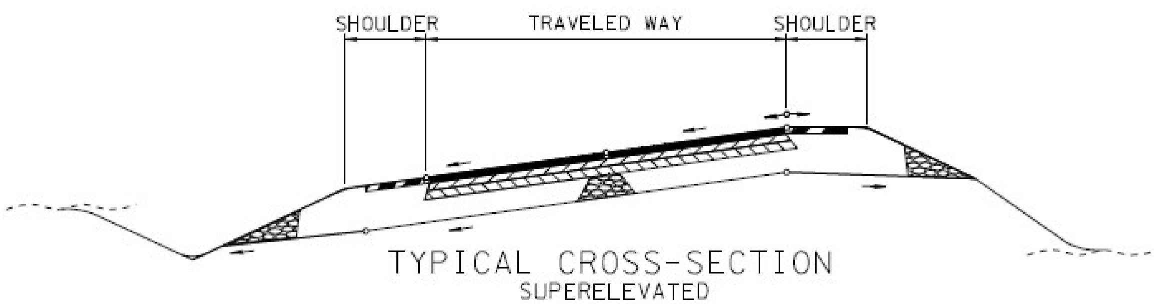
Individual transportation agencies adopt or develop their own design criteria, referencing approved AASHTO policies. Most states usually adopt major portions of the AASHTO design values or adopt the AASHTO policy completely as their design criteria.

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 leftturn 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.

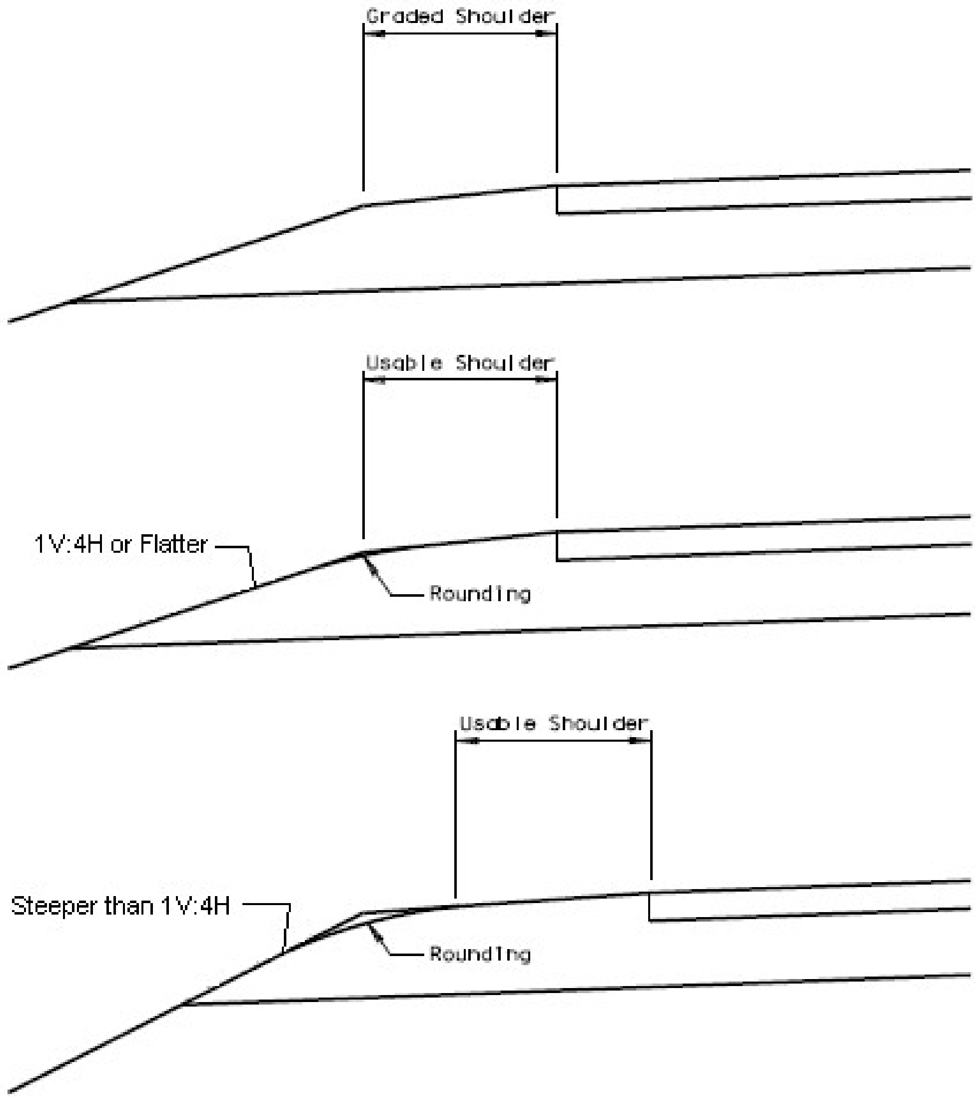
Shoulder surfacing provides better all-weather load support versus soil.

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 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 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

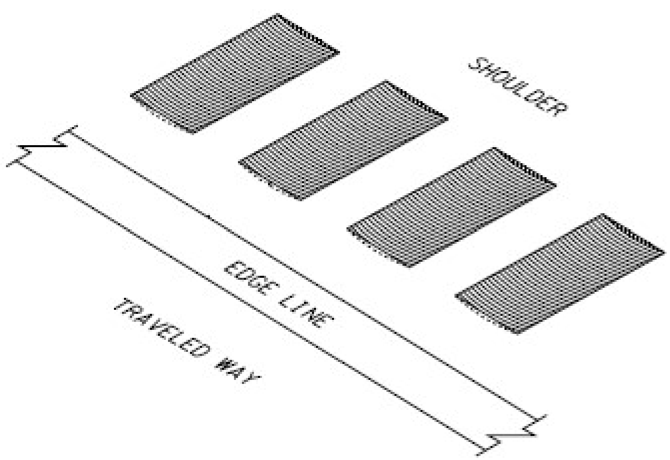
Different colors and textures for shoulders help define the traveled way (night and inclement weather) and discourage using shoulders as through lanes. While suitable contrast with bituminous pavements is difficult – gravel, turf, crushed stone, and bituminous shoulders provide excellent contrast with 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, 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 (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.

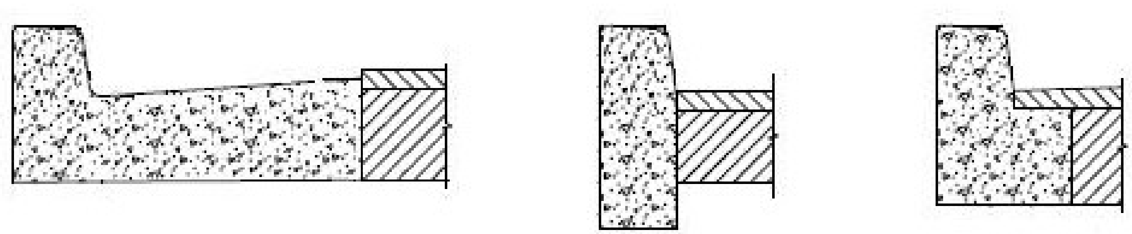
Purposes of Curbs

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.

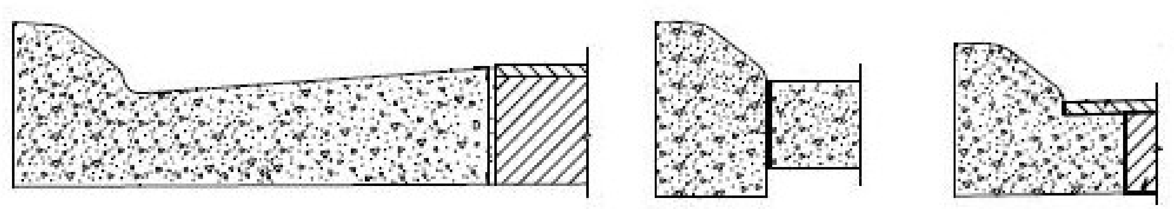
The purpose of **vertical (non-mountable)** curbs is to discourage errant vehicles from leaving the road. These types of curbs are not suitable for high-speed roadways due to vehicle tendencies to overturn or become airborne from curb impact. Vertical curbs (typically range from 6 to 8 inches) can also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

- 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.

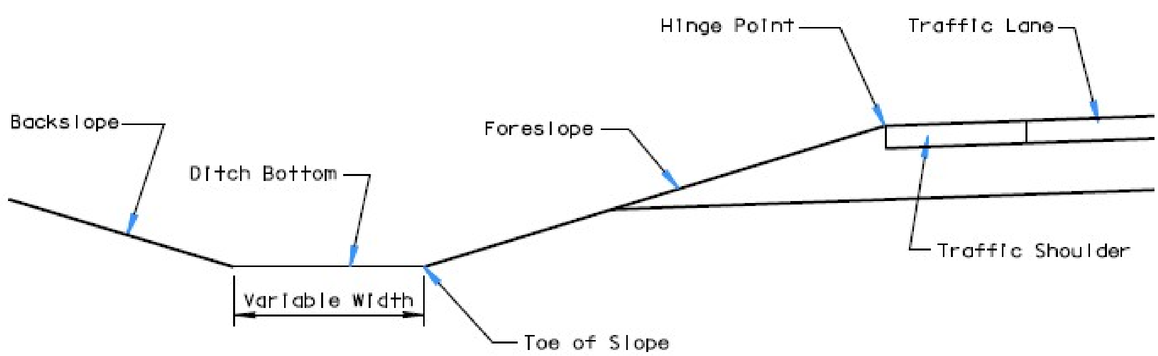
Roadside Channel Lining Criteria

- 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

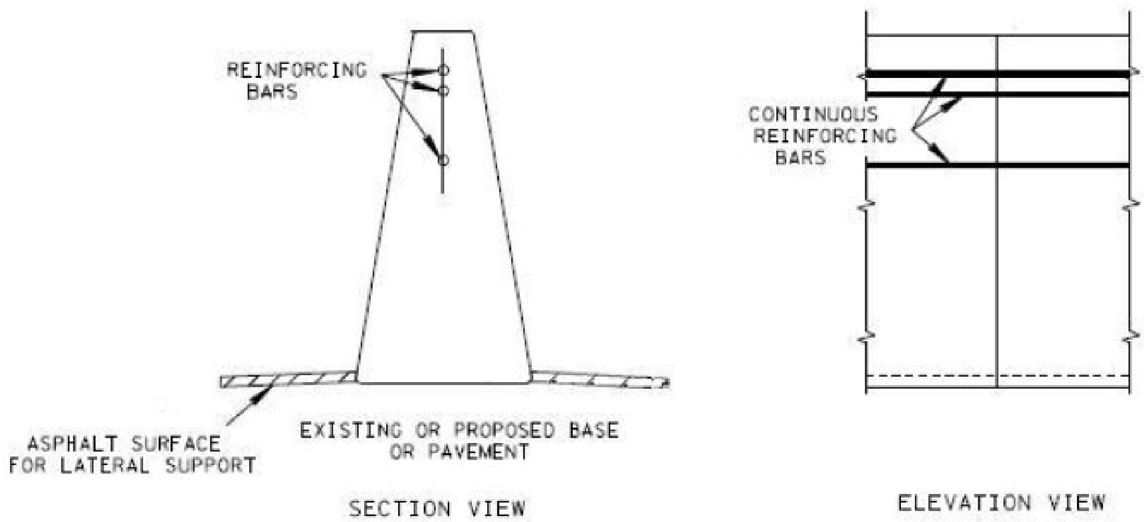
Median barriers are another type of longitudinal system used to prevent vehicles from crossing the median and crashing head-on into oncoming traffic. For roadways with low traffic volumes or wide medians, the likelihood of errant vehicles crossing the median and hitting an opposing vehicle is relatively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

<u>Typical Crash Cushion Applications</u>

- 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.

SUMMARY

This course focused on the geometric design of cross-sections for modern roads and highways. 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.

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 roadway cross-sections.

Course topics covered include:

Design guidelines
Traveled way
Lane width
Shoulders
Rumble strips
Roadside design
Curbs
Drainage channels
Traffic barriers

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 (Sections 4.1 through 4.10)** was used exclusively for fundamental roadway geometric design principles.

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.**

REFERENCES

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

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