INTRODUCTION

This course summarizes and highlights the roadway cross-section design process for modern roads and highways. The contents of this document are intended to serve as guidance and not as an absolute standard or rule.

When you complete this course, you should be familiar with the general 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: roadway design; shoulders; rumble strips; curbs; drainage features; traffic barriers; pedestrian/bicycle facilities; and medians.

For this course, Chapter 4 of 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) will be used primarily for fundamental geometric design principles. This text is considered to be the primary guidance for U.S. roadway geometric design.
Geometric design is the assembly of the fundamental three-dimensional features of the highway that are related to its operational quality and safety. Its basic objective is to provide a smooth-flowing, crash-free facility. Geometric roadway design consists of three main parts: cross section (lanes and shoulders, curbs, medians, roadside slopes and ditches, sidewalks); horizontal alignment (tangents and curves); and vertical alignment (grades and vertical curves). Combined, these elements provide a three-dimensional layout for a roadway.

The practice of geometric design will always be a dynamic process with a multitude of considerations: driver age and abilities; vehicle fleet variety and types; construction costs; maintenance requirements; environmental sensitivity; land use; aesthetics; and most importantly, societal values.

Despite this dynamic character, the primary objective of good design will remain as it has always been – to provide a safe, efficient and cost-effective roadway that addresses conflicting needs or concerns.

**DESIGN GUIDELINES**

In today’s environment, applying design standards and criteria to ‘solve’ a problem is not enough. Designers must understand how all elements of the roadway contribute to its safety and operation – horizontal and vertical alignment, cross section, intersections, and interchanges. Each location presents a unique set of design concerns.

**Design Criteria**
- Safety
- Operational quality
- Cost-effectiveness
- Maintenance needs

Designers must be able to understand the basis for their design guidelines to ensure good judgment in their use. Design criteria reflect the research and experience gained over the years which consider local site conditions, needs of space, and other transportation factors. The use of design criteria provides a measure of consistency and quality for roads designed by different individuals. A designer’s ability to make
reasonable, cost-effective, and site-specific choices will be dependent on their understanding of the functional rationale behind the criteria.

Roads are designed in conjunction with design guidelines and standards that are adopted by governmental authorities. Design guidelines take into account speed, vehicle type, road grade (slope), view obstructions, and stopping distance. By applying these guidelines with good engineering judgment, the resulting roadway can be comfortable, safe, and appealing to the eye.

**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 AASHTO's policies for 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**

The cross section is a representation of the roadway showing the position and number of vehicle and bicycle lanes, cross slopes, shoulders, curbs, sidewalks, ditches, and other roadway features (from right-of-way line to right-of-way line). Cross sections also show drainage features, pavement structure and other non-geometric design items. Their design can vary greatly by location and design speed.
TRAVELED WAY

The traveled way is that part of the roadway designed for movement of traffic which does not include shoulders and bicycle lanes. This is generally comprised of two or more lanes. Critical design elements of the traveled way include driver behavior, roadway drainage and skid resistance.

Surface Type Selection Criteria

- Initial cost
- Traffic volume & composition
- Soil characteristics
- Climate
- Maintenance cost
- Pavement performance
- Availability of materials
- Energy conservation
- Service-life cost
The number of lanes needed for a facility is usually determined by the expected traffic volumes at a level of service determined to be appropriate. The number of lanes added to an existing highway represents an increase in the traffic-carrying capability of the facility.

Using projected travel demands, the designer can use analysis procedures in the *Highway Capacity Manual* to determine the appropriate number of travel lanes 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 a predominant 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. Additional lanes at the intersections can be in a variety of configurations to serve traffic needs.

**Cross Slope**

In a tangent (straight) section, the road surface is commonly sloped at 1.5 to 2 percent in order to achieve adequate surface water drainage. Cross slopes of this rate applied in both directions of travel with a crown point in the middle of a roadway are called "normal crown".

For vehicles operating on crowned pavements (cross slopes of 2 percent or less), the effect on steering is barely perceptible. A reasonably steep lateral slope is desirable to minimize water ponding on flat roadway sections due to imperfections or unequal settlement. If a roadway were completely level, it would drain very slowly and create problems with hydroplaning, and/or ice accumulation.

A crucial cross-section design element is the rate of cross slope. In curved sections, the outside edge of the road is superelevated above the centerline. Since the road is sloped down to the inside of the curve, gravity pulls the vehicle down towards the inside of the curve providing some of the centripetal force needed to go around the curve.
On multilane highways, cross-sections with three or more lanes inclined in the same direction desirably should have greater slope (0.5 to 1 percent) across the outside lane than across the two interior lanes.

The cross slope on a tangent alignment should not exceed 3% unless there are at least three lanes in one direction of travel. Cross slope rates greater than 2% are not desirable for paved, high-speed roadways with central crowns. Heavy vehicles with high centers of gravity would have difficulty in maintaining control when traveling at high speeds over steep slopes.

To facilitate roadway drainage for locations with intense rainfall, steeper paved cross slopes (2.5% maximum) and crown line crossover rates (5 percent) may be used. For multi-lane roadways (3 or more lanes in each direction), the maximum cross slope should have a maximum rate of 4 percent.

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

**Skid Resistance**
Since roadway geometrics affect skidding, a level of skid resistance should be provided to accommodate typical braking and steering maneuvers. Vertical and horizontal alignment design should be coordinated to reduce the potential for skidding.

**Main Causes of Poor Skid Resistance**
- Rutting – water accumulation in wheel tracks
- Polishing – pavement surface microtexture reduction
- Bleeding – pavement surface covering
- Dirty pavements – contaminated pavement surfaces

Any corrective measures for skid resistance should have a high initial durability, long term resistance, and minimum resistance decrease for increased speeds.

**Hydroplaning**
Hydroplaning is the result of exceeding the tire tread pattern and pavement
surface roughness. The resulting water wedge produces a hydrodynamic force capable of lifting rolling vehicle tires.

**Hydroplaning Influences**
- Water depth
- Roadway geometry
- Vehicle speed
- Tread depth
- Tire pressure
- Pavement condition

**LANE WIDTH**

The selection of lane width affects the cost and performance of a road (comfort, operational characteristics, crash rate). Narrow lanes cost less to build and maintain, but also reduce the capacity of a road to convey traffic. The effect of lane width is reduced for urban and suburban roads, and low volume roads.

Since drivers increase their speeds with greater lane widths, it may be appropriate to use lesser lane widths that are compatible with the alignment and intended speed at locations with low design speeds and restricted alignments. Standard practice is to provide 12 feet lane widths for capacity, efficiency, heavy vehicles, and high traffic volumes.

**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)

Urban operations are more complex, resulting in greater demands on the width of travel way. Although 12 ft lane widths are considered desirable, lesser widths are commonly used. Lane widths of 11 feet may be used for through-lanes, with parking or auxiliary lanes for intersections and interchanges designed as low as 10 feet in some cases. Indeed, narrower widths are considered desirable with
respect to pedestrian crossing and speed behavior. Lane widths of 9 ft may be used on low-volume roads in rural and residential areas.

**SHOULDER**

Shoulders are one of the most important roadway safety features. The roadway shoulder immediately adjoins the travel way and is designed for a variety of purposes other than carrying through-traffic, including:

- Recoverable area for drivers taking evasive action or experiencing temporary loss of control;
- Storage for disabled or parked vehicles, and emergency operations;
- Law enforcement activities;
- Certain maintenance functions;
- Temporary traveled way during major maintenance and/or reconstruction activities;
- SSD through the inside of a horizontal; curve;
- Safe travel path for bicycles;
- Operational roadway quality and capacity;
- Structural lateral support for roadway pavement.

Shoulder widths can range from 2 ft (minor rural roads) to 12 ft (major roads with stabilized shoulders).
**Graded Width:** edge of traveled way to intersection of shoulder slope and foreslope

**Usable Width:** actual shoulder width that can be used for a vehicle stop. For side slopes of 1V:4H or flatter, the usable width is equivalent to the graded width.
Shoulder Width
Wide, surfaced shoulders are a suitable, all-weather space for stopped vehicles clear of the travel lanes. AASHTO recommends a minimum clearance of 1 foot (2 feet preferable) between a stopped vehicle on the roadway shoulder and the edge of traveled way. At locations with vertical elements or barriers, a minimum offset of 2 feet from the outer edge of shoulder is preferred. For low-volume roadways, a minimum clearance of 4 feet should be maintained between any barriers and the traveled way.

<table>
<thead>
<tr>
<th>Facility</th>
<th>Shoulder Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>High speed, high volume roadways</td>
<td>10 feet normal width</td>
</tr>
<tr>
<td>Low volume highways</td>
<td>2 feet 6 to 8 ft preferable</td>
</tr>
<tr>
<td>High speed, high volume roadways with trucks</td>
<td>10 feet 12 feet preferable</td>
</tr>
<tr>
<td>Bicycles and pedestrians</td>
<td>4 feet no rumble strips</td>
</tr>
</tbody>
</table>

Roadway shoulders should be continuous to foster driver security, and to promote areas for bicycles, and to furnish a refuge for emergency stops.

Shoulder Cross-section
Roadway shoulders are crucial for surface water drainage systems. Shoulders carry surface runoff away from the roadway into either open or closed drainage systems. They should be flush with the road’s surface and sloped to drain away from the traveled way. For shoulder locations with curbs, the cross slope should be designed to prevent ponding.

<table>
<thead>
<tr>
<th>Shoulder Surface</th>
<th>Cross Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous/Concrete</td>
<td>2 to 6%</td>
</tr>
<tr>
<td>Gravel/Crushed rock</td>
<td>4 to 6%</td>
</tr>
<tr>
<td>Turf</td>
<td>6 to 8%</td>
</tr>
</tbody>
</table>

The maximum algebraic difference between the traveled way and shoulder grades should range from 6 to 7 percent for tangent sections with normal crown. Superelevated sections should be designed without a significant cross slope break. All or part of the shoulder should be sloped at a rate comparable to the superelevated traveled way.
Shoulder Stability
Roadway shoulders should be sufficiently constructed and maintained to perform their intended functions. Unstabilized shoulders consolidate over time producing a drop-off where the shoulder elevation becomes lower than the traveled way.

Advantages of Paved/Stabilized Shoulders
- Emergency vehicle refuge
- Drop-off & rutting prevention
- Adequate drainage cross slope
- Maintenance reduction
- Lateral roadway support

Turf shoulders may be suitable for collector roads and local streets with favorable climates and soils. If stabilized, these shoulders require minimal maintenance. However, they are often less safe and force pedestrians/bicyclists to share the road with motorists.

Typically, unstabilized shoulders are eventually replaced with some type of stabilized shoulder.

RUMBLE STRIPS
Rumble strips are raised or grooved designs constructed in the roadway lanes or shoulders as part of the edge line or centerline.

Basic Rumble Strip Designs

- Milled-in
- Rolled-in
- Formed
- Raised

The purpose of these strips is to produce a sudden audible sound that causes the vehicle to vibrate and alerts the driver to take corrective action.
Common Uses of Rumble Strips

- Continuous Shoulder Rumble Strip (most common)
  On shoulders to alert drivers of potential roadway departures
- Centerline Rumble Strips
  Two-lane Rural Highways to reduce potential head-on crashes
- Transverse Rumble Strips
  Approaches to intersections, toll plazas, horizontal curves, work zones

While rumble strips are effective in reducing crashes, they may also have concerns regarding noise levels, bicyclists, motorcycles, and roadway maintenance.

ROADSIDE DESIGN

The roadside is a critical feature of the safe highway environment by providing a recovery zone for errant drivers, and mitigating roadside crash severity. The fundamental roadside design elements are clear zones and lateral offsets.

Clear Zones - “...the unobstructed, relatively flat area provided beyond the edge of the traveled way for the recovery of errant vehicles.” AASHTO
A clear recovery area is that area outside of the traveled way that is free of objects or hazards and is sufficiently flat (1V:4H or flatter) for enable driver recovery. Such a recovery area (including shoulders, bicycle lanes, and/or auxiliary lanes) should be clear of obstructions where practical or shielded by crash cushions or barriers.

Research has shown that a width of 30 feet or more (from the edge of traveled way) is adequate for 80% of errant vehicles to recover on high-speed highways. For steeper sloped embankments (greater than 1V:4H), a vehicle could travel farther from the roadway. So, a 30-foot recovery area may not be sufficient. On low-volume/low-speed roads, a 30-ft clear zone may be excessive and unwarranted for design, economic, or environmental reasons.

The AASHTO Roadside Design Guide provides design procedures plus other information on the clear zone concept. These procedures are based on studies of vehicle encroachment frequency, severity of collisions with roadside obstacles, and costs of providing greater clear recovery areas. The optimum solution to roadside design is the balance of engineering judgment with current roadside safety practices.

Lateral Offsets
A lateral offset to vertical obstructions may be necessary (in lieu of a full-width clear zone) for environments with limited right-of-way or constraints. These environments are typically urban with lower operating speeds. They may also have on-street parking, sidewalks, curb & gutter, drainage structures, frequent traffic stops, and fixed roadside objects.

**Advantages of Lateral Offsets**
- Improves travel lane capacity
- Minimizes contact between obstructions & vehicles (mirrors, doors, overhangs, etc.)
- Reduces encroachments from parked/disabled vehicles
- Improves sight distances (horizontal, driveways)
- Avoids lane position impacts & lane encroachments
The AASHTO Roadside Design Guide provides further guidance on using lateral offsets.

**CURBS**

Roadway curbs influence driver behavior, roadway utility, and safety. They can affect trajectories of impacting vehicles and a driver’s ability to control the striking vehicle. Vertical and sloping curb designs may include curb and gutter combination sections.

**Purposes of Curbs**
- Drainage control
- Roadway edge delineation
- Right-of-way reduction
- Aesthetics
- Delineation of pedestrian walkways
- Reduction of maintenance operations
- Orderly roadside development

**SLOPING CURBS (Mountable)**

Sloping curbs are designed for vehicles to cross and are considered “mountable”.

- 4-inch Sloping Curb: High-speed facilities with drainage issues, restricted right-of-way, access control
- 6-inch Sloping Curb: High-speed urban/suburban roads with frequent access and intersections
These curbs may be used for median edges, island channelization, or shoulder outside edges.

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

Vertical curbs range from 6 to 8 inches in height and discourage vehicles from leaving the roadway. These curbs should not be used for high-speed roads since impacting vehicles could overturn or become airborne.

VERTICAL CURBS (Non-mountable)

Curbs combined with a gutter section (typically 1 to 6 feet wide) may form the main roadway drainage system. It is usually impractical to expect design 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. Sloping curbs may be placed at the edge of the traveled way for urban low-speed locations but it is preferable to offset these 1 to 2 feet. Vertical curbs should not be used along high-speed roadways. If used intermittently along streets, they should be offset 2 feet from the edge of traveled way. For medians or islands, vertical curbs should be offset a minimum of 1 foot (preferably 2 feet) from the traveled way.
DRAINAGE CHANNELS AND SIDESLOPES

Drainage design is an integral part of any roadway’s geometric design. It should consider potential property impacts, possible flooding issues, design traffic needs, governmental regulations, and funding. Modern drainage facilities should be used to intercept and remove surface runoff from roadways.

Types of Roadway Drainage Facilities

- Bridges
- Culverts
- Channels
- Curbs
- Gutters
- Drains

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

Drainage Channels

The purpose of drainage channels is to control surface water by designing for adequate capacity, and providing a smooth transition for stormwater. The most efficient channel cross-section from a hydraulic standpoint contains steep sides. Slope stability limitations, as well as construction and maintenance restrictions,
may require a need for flatter slopes.

An important roadside design consideration is slope combinations for potential errant vehicle trajectories. The transversal of drainage channels (4 to 8 feet wide) produces the same level of severity regardless of slope. Utilizing suitable slope combinations can result in channel cross-sections that can be safely traversed.

Flat foreslopes (1V:4H or less) provide flexibility in backslope design for vehicle transversal and recovery distance. Using a 10-ft shoulder with a 1V:4H or flatter shoulder produces a roadside channel completely visible to the driver. This type of channel increases driver comfort, provides a sense of openness, and encourages the use of shoulders for emergencies.

Intercepting channels (typically flat cross-section) should contain adequate capacity and follow natural contours when possible to avoid disturbing the existing ground surface.

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

Flumes (either open channels or culverts) transport water from intercepting channels down cut slopes and discharge it. Culverts or closed flumes are preferable for use to prevent erosion or settlement.

**Sideslopes**
Sideslopes are adjacent to the shoulder and located between the shoulder and right-of-way boundary. They can limit the chances of loss of control for vehicles leaving the roadway, provide adequate space for recovery, and assist roadway stability.
Regions of the Roadside

Hinge Point (top of slope) - contributes to loss of vehicle control
- vehicles may become airborne at this point

Foreslope - provides area for recovery maneuver or speed reduction before impact

Toe of Slope - usually within clear zone and impacted by vehicle

Data has shown that rounding of the hinge point may increase general roadside safety. Rounded transitions decrease the probability of airborne vehicles, reduce further encroachment, and provide more vehicle control.

Foreslopes

Steeper than 1V:4H Not desirable – limits backslope options
1V:3H or steeper For locations where flatter slopes are not permitted
May need roadside barrier

Backslopes

1V:3H or flatter Normally used – accommodates equipment
Steeper than 1V:3H Evaluate for soil stability & crash severity
Steeper than 1V:2H Retaining walls may be required (space constrictions)
1V:2H or flatter Where required by soil characteristics

For roadways with wide roadsides (flat, smooth, and clear of obstructions), many potential crashes may be prevented by providing adequate area for recovery.
Embankment Slope

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

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 the grass to root into the soil – even with adequate water. Slopes of 1V:3H or flatter are also easily maintained.

Rock cuts depend on the material and often involve bench construction in the slopes. Slopes can range from 2V:1H (typical) to 6V:1H (good-quality rock).

TRAFFIC BARRIERS

The purpose of any roadside barrier (guardrails, concrete barriers, and attenuation devices) is to reduce the severity of crashes involving vehicles that leave the roadway. Determining their need (including location and type) are critical factors in roadway design. The barriers themselves may be an object that can be struck with a significant crash severity and require continual maintenance.

General Rule of Thumb for Treatment of Obstacles

- Eliminate the obstacle.
- Redesign the obstacle to be safely traversed.
- Relocate the obstacle to where it is less likely to be struck.
- Make the obstacle breakaway.
- Provide for redirection (longitudinal barrier) or severity reduction (impact attenuators).
- Delineate the obstacle.

The AASHTO Roadside Design Guide contains warrants and design guidelines for determining the need for barriers, the selection and the design of the barrier (length of the barrier, design of end treatments, etc.).

Barrier types range from concrete median barriers, guardrail, to cable systems, and more flexible types. Each type has its unique performance characteristics
and applicability - depending on the design circumstances.

The classes of traffic barriers include:

- Longitudinal barriers
- Crash cushions

**Longitudinal Barriers**
Longitudinal barriers are placed along roadsides and in medians to redirect errant vehicles. The difference between the types of these barriers is the amount of deflection that occurs after being impacted. They are divided into the following types: **flexible; semirigid;** and **rigid**.

Flexible barriers undergo substantial dynamic deflection when struck and produce lower impact force on the vehicle. The purpose of this system is to contain the vehicle instead of redirecting it. Flexible systems also require more lateral clearance due to impact deflection.

Semirigid barriers break posts near the point of impact to distribute the impact force by beam action to adjacent posts. Longitudinal deflection is controlled within acceptable limits and redirects the errant vehicle along the traffic flow.

Rigid systems do not deflect generally when struck. The barrier bears little or no damage by dissipating the energy through vehicle movement and body deformation. Rigid barriers are best suited for locations with shallow impact angles.

**Median Barriers**
Median barriers are used to prevent vehicles from crossing into opposing traffic. For low-traffic facilities or wide median roadways, the likelihood of a vehicle crossing the median and colliding with an opposing vehicle is relatively low. Although median barriers reduce cross-median collisions, they may increase the overall crash frequency due to the decreased space available for return-to-road maneuvers.
Typical Concrete Barrier Wall

**Types of Median Barriers**
- Double-faced steel w-beam (strong posts)
- Box-beam barrier (weak posts)
- Concrete barrier
- Cable barrier (light steel posts)

**Bridge Railings**
Bridge railings are intended to redirect impacting vehicles and minimize railing penetration. These barriers also prevent falls and keep vehicles, pedestrians and bicyclists on the structure. Bridge railings differ from other barriers by their foundations – they are structural extensions of the bridge.

**Crash Cushions**
Crash cushions decelerate errant vehicles to a safe stop after head-on collisions or redirect vehicles away from an obstruction. These may be used for bridge ends or to shield rigid objects – bridge piers, sign supports, abutments, or retaining wall ends.
MEDIANS

The median of the divided highway cross section separates the opposing traffic lanes (including shoulders). The width and design characteristics are among the most important safety features of high-speed highways in both urban and rural areas. Medians provide the following safety-related functions:

- Separate high-speed opposing traffic
- Provide clear recovery area
- Provide an emergency stopping area
- Provide space for speed changes and storage
- Lessen headlight glare
- Provide space for future width

Median widths are dependent on the roadway type and location. The general range of median widths is from 4 ft (urban areas) to 80 ft or more (rural areas). The wider medians are safer but more costly - requiring more right-of-way, construction, and maintenance. These costs increase as the width increases.

In rural areas, medians are normally wider than in urban and suburban areas. For rural unsignalized locations, the median should be as wide as practical to allow design vehicles to safely maneuver. In urban and suburban areas, narrow medians work better operationally – wide medians being used only if large vehicles are anticipated.

**Types of Medians**

**Depressed**: preferable for better drainage and snow removal
adequate for sideslopes of 1V:4H (1V:6H desirable)

**Raised**: desirable for regulating left-turn movements
frequently used for landscaping → potential obstructions
Flush: typically for urban arterials
crowned type used to eliminate ponding
may be converted to 2-way left turn lanes (10 to 16 ft width)

Median design requires tradeoffs by the engineer. In 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 more**, 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**

Frontage roads preserve the character of the highway and prevent impacts of road development. These roads are used most frequently on freeways to distribute and collect roadway traffic between local streets and freeway interchanges.

A minimum spacing of 150 feet between arterial and frontage roads is recommended in urban areas to lengthen the spacing between successive intersections along the crossroads.

Frontage roads are typically parallel to the freeway

- Either one or both sides
- Continuous or non-continuous

Arterial and frontage road connections are a crucial element of design. For slow-
moving traffic and one-way frontage roads, simple openings may be adequate. On high-speed roadways, ramps should be designed for speed changes and storage.

Frontage road design is also impacted by its intended type of service – it can assume the character of a major route or a local street.

**OUTER SEPARATIONS**

The “outer separation” is the buffer area between through traffic on a roadway and local traffic on a frontage road. The wider the separation, the lesser the influence on through traffic. Wide separations are particularly advantageous at intersections with cross streets to minimize vehicular and pedestrian conflicts.
The cross-section of an outer separation is dependent on: width
- type of arterial
- frontage road type

The AASHTO “Green Book” provides a number of typical applications for these type of separations.

### NOISE CONTROL

Traffic noise can have many sources – vehicle engines, aerodynamics, exhaust, surface interaction, etc. Designers should make every reasonable effort to minimize noise into sensitive areas along roadways.

A typical method of noise measurement involves using a standard sound level meter to read decibels (dBA). Since these results are measured on a logarithmic scale, 10 dBA increases appear as half of the original noise level (example: 60 dBA noise level sounds half as loud as 70 dBA). Doubling the noise level results in only a 3 dBA increase (example: a single vehicle produces a noise level of 50 dBA, two vehicles at the same point produce 53 dBA, four vehicles 56dBA, etc.).

Noise decreases approximately 3 to 4.5 dBA for each doubling of distance from the roadway.

### Design Procedures

The initial step for noise control design is to define the noise impact criteria. Once defined, noise-sensitive locations (residences, schools, churches, parks, hospitals, etc.) can 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 according to land usage. AASHTO states that traffic noise impacts occur only when:

- Predicted noise levels approach/exceed noise-abatement criteria
- Predicted noise levels exceed existing 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 Reduction Design

Noise barriers are being used more and more for both new and existing roadways. Efforts should be made to prevent any new barrier from increasing the severity of any future crashes. Sight distances as well as setback distances should be checked for application.

A popular method for noise reduction is to design a roadway that takes advantage of its terrain to form a natural sound barrier. A depressed roadway cross-section has the same effect as building barriers to reduce noise levels. Elevated roadways may block sight lines and reduce noise level impacts to receptors.

Different types of noise walls (concrete, wood, metal, masonry, etc.) are effective sound barriers. Earth berms are more aesthetically pleasing and can be graded to blend into its surroundings. Plantings (trees, shrubs, or ground cover) may prove to be aesthetic but not very efficient in shielding sound.
ROADSIDE CONTROL

Unregulated roadside development and/or driveways produce lower roadway capacity, increased conflicts, and early obsolescence. For highways without access control, their efficiency and safety is dependent on the number and type of roadside interference (vehicle movements, roadside development, access points, etc.).

Driveways

The design and location of proposed driveways should be treated in the same manner as low-volume intersections. Driveways are directly linked to available right-of-way, land usage, zoning control, and roadway functional classification.

**Driveway Design Objectives**

- Operation & efficiency of intersecting roadways
- Reasonable property access
- Sight distance for vehicles & pedestrians
- ADA requirements for pedestrians
- Bicycle lanes/paths
- Public transportation locations

Important features of driveway design include: adequate widths, throat dimensions, design vehicles, and traffic volumes. The *NCHRP’s Guide for Geometric Design of Driveways* provides driveway design guidance for grades, widths, channelization, cross slopes, etc.

Mailboxes

Mailboxes and/or newspaper tubes may be a roadside hazard depending on: placement; roadway cross-section; sight distance; traffic volume; and support impact resistance.

Crash potential involving carriers and motorists occurs when carriers decelerate for a stop and then continues traveling along the roadway.

A crucial concern is the mailbox location in relation to roadway traffic. The higher
the traffic volume/speed, the greater the clearance from the traveled way should be.

<table>
<thead>
<tr>
<th>Roadway Type</th>
<th>Shoulder/Turnout Width in Front of Mailbox</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural Highway</td>
<td>8 feet</td>
</tr>
<tr>
<td>High-volume, high-speed</td>
<td>10 feet (12 feet for some conditions)</td>
</tr>
</tbody>
</table>

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.

**Fencing**

Highway fencing is used to delineate access control for the roadway and reduce right-of-way encroachment. Fencing is usually located near the right-of-way line.

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

- precipitous slopes
- natural barriers
- where not required

**TUNNELS**

Tunnels typically carry roadways either under/through a natural obstacle or minimize roadway impacts on a community.

**Tunnel Construction Warrants**

- Narrow right-of-way locations
- Terrain ridges with environmental or economic concerns
- Intersection areas with non-standard street patterns
- Parks, natural reserves
- Railroads, airports, travel facilities
- Locations where land acquisition costs may exceed tunnel costs
The type of tunnel is determined by its construction method: **mining** or **cut-and-cover**. Tunnels constructed by mining methods do not remove overlying rock or soil. Soft-ground tunneling is more expensive than hard-rock tunneling since the rock normally has less structural demands and construction costs.

Tunnels built by the cut-and-cover method consist of excavating an open cut, constructing the tunnel, and backfilling over the completed facility. This method is the most common and most economical option.

**Design Considerations**

Since tunnels are the most expensive roadway structures, its horizontal alignment is a key design consideration – to be short as practical. Sight distances should also be analyzed.

Vertical alignment is another crucial design concern. Proposed grades based on driver comfort should be balanced with economic factors (construction, operation, and maintenance expenses).

Forks, and exit/entrance ramps should not be used within tunnels, if possible.

**Two-Lane Tunnels**

<table>
<thead>
<tr>
<th></th>
<th>Approach Pavement + 2 Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum roadway width between curbs</td>
<td>24 ft minimum</td>
</tr>
<tr>
<td>Curb or sidewalk width</td>
<td>1.5 ft minimum</td>
</tr>
<tr>
<td>Total clearance width between walls</td>
<td>30 feet</td>
</tr>
<tr>
<td>Minimum vertical clearance</td>
<td>16 ft freeways</td>
</tr>
<tr>
<td></td>
<td>14 ft other highways</td>
</tr>
</tbody>
</table>
The preferred section for two-lane tunnels 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-ft for freeways and 14-ft for other roadways.

Raised sidewalks (2.5-ft wide) may be used beyond the shoulder space to provide emergency/maintenance walking access, or as a buffer space between vehicles and tunnel walls.

PEDESTRIAN FACILITIES

Sidewalks
The safe and efficient accommodation of pedestrians along the traveled way is equally important as the provisions for vehicles. By separating pedestrians and vehicles, sidewalks increase pedestrian safety and help vehicular capacity. Sidewalks are typically an integral part of the transportation system in central business districts. Data suggests that providing sidewalks along highways in rural and suburban areas results in a reduction in pedestrian accidents.

Early consideration of pedestrian needs during the project development process may also streamline compliance with accessibility requirements of the Americans
with Disabilities Act Accessibility Guidelines (ADAAG). Intersections designed with proper curb ramps, sidewalks, crosswalks, pedestrian signals, and refuge islands can also aid in furnishing a pedestrian-friendly environment.

Sidewalks are typically placed along roadways without shoulders – even at locations with light pedestrian traffic. For sidewalk locations along high-speed roads, buffer areas may be utilized to distance the sidewalk from the traveled way.

Sidewalks should be wide enough for the volume and type of expected pedestrian traffic. Typical residential sidewalks vary in width from 4 to 8 ft. The Americans with Disabilities Act Accessibility Guidelines require passing sections for sidewalks with widths less than 5 ft spaced every 200 ft. An optional planted strip may be provided between the sidewalk and the curb (2 ft minimum width) to allow for maintenance activities. At locations with sidewalks adjacent to the curb, the width should be 2 feet wider than the minimum width required.

**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 possibility of requiring additional right-of-way.

The wider the sidewalk, the more room there is for street furniture, trees, utilities, and pedestrians plus it is easier to maneuver around these fixed objects. It is important not to overlook the need to maintain as unobstructed a pathway as possible.

**Grade-Separated Pedestrian Crossings**
A grade-separated pedestrian facility (either over or under the roadway) permits pedestrian and vehicle crossings at different levels without interference. These structures may be used at locations where pedestrian/traffic volumes, intersection capacity, etc. encourage their construction. Governmental regulations and codes can provide additional design guidance when considering these facilities.
AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities provides more specific information for these structures.

Pedestrian walkways should be a minimum of 8 feet wide. Wider walkways may be used for tunnels, high pedestrian traffic areas, and overpasses with a tunnel effect (from screens).

Vandalism is a legitimate concern for pedestrian/vehicle overpass structures – where individuals drop objects onto oncoming traffic. While there is no universal deterrent, options have been developed to deal with this problem, including:

- Solid plastic enclosures
- Screens

**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 sidewalks and streets at pedestrian crossings. Basic curve types have been developed for use according to intersection geometric characteristics.

**Curb Ramp Design Considerations**
- 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
  (with no obstructions, 2% maximum cross slope)

Curb ramp locations should be closely integrated with the pedestrian crosswalk by having the curb ramp bottom within the crosswalk’s parallel boundaries, and perpendicular to the curb face. These ramps are typically placed within the corner radius or beyond the radius on the tangent section.
Curb Ramp Examples
BICYCLE FACILITIES

Due to the bicycle's popularity as a mode of transportation, their needs should be considered when designing roadways. 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)

The basic types of bicycle facilities include:

- 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.

Transportation planners and designers list these factors that have a great impact on bicycle lanes: traffic volume; average operating speed; traffic mix; on-street parking; sight distance; and number of intersections.

BUS TURNOUTS

Bus turnouts separate buses from roadway traffic and should provide safe access in the most efficient way possible.

Freeways
The purpose of a freeway bus turnout is to provide a place (away from the traveled way) for bus deceleration, standing, and acceleration.
Bus Turnout Design Elements

- Passenger platforms
- Ramps
- Stairs
- Railings
- Signs
- Markings

Speed change lanes: sufficient length for entrance or exit from the highway without passenger discomfort

Acceleration lanes: above-minimum lengths for lower acceleration buses

Widths for the bus standing area and speed-change lanes (including shoulders) should be 20 feet to permit passing. The distance between the outer edge of shoulder and the edge of bus turnout lane should be preferably 20 feet of more (a minimum of 4 feet). Pedestrian loading platforms should be a minimum of 5 feet wide (6 to 10 feet desired).

Arterials

Bus turnouts on arterials can drastically reduce the amount of interference between buses and other traffic. In many cases, sufficient right-of-way is unavailable to permit turnouts in the border area for arterials.
**Effective Bus Turnout Characteristics**

- Deceleration lane for easy entrance to loading area
- Adequate standing space for maximum number of vehicles
- Merging lane for easy reentry to roadway

A deceleration lane taper of approximately 5:1 (longitudinal to transverse) is desired to encourage the bus operator to decelerate clear of roadway traffic before stopping.

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 wide

*For loading area widths of 12 ft, turnout lengths should be increased by 13 to 16 feet.

**Park-and-Ride Facilities**

The design of the park-and-ride facilities depends on design volume, available land, and local parking lots. Separated parking areas should contain a drop-off area near the station entrance, and short-term parking for passenger pickup. Vehicle and pedestrian conflicts can be minimized by addressing loading/unloading needs, taxi services, bicyclists, and ADA requirements.

**Location**

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

Bus roadway widths should be a minimum of 20 feet to allow passing.
Self-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  

Access to lots should be at least 300 feet from other intersections with sufficient sight distance for entering/exiting vehicles. The location for these access points should not be on crest vertical curves and should have a minimum of 300 feet corner sight distance.

Shelters should be placed at principal loading areas to accommodate off-peak passenger volumes (minimum). In order to size these shelters, AASHTO suggests using the anticipated number of patrons multiplied by a factor of 3 to 5 ft². These shelters can be expanded and accessorized relatively easily.

The two predominant bus-loading areas designs are:

Parallel  
Sawtooth  

The sawtooth arrangement is very popular due to its ease of bypassing standing buses.
ON-STREET PARKING

The basic function of a roadway system is the safe and efficient movement of vehicles. Various segments within this system may also provide on-street parking locations.

The designer should consider on-street parking compatibility with existing land usage. For freeways, access-controlled facilities, and most rural roadways where stopping/parking is for emergencies only, on-street parking may not be desirable. It may be appropriate to prohibit parking on urban and rural arterials unless these communities are located directly on these routes.

Some commonly used types of on-street parking are parallel parking, and angle parking (normal and back-in/head-out). The type to use should be based on the following factors: specific road function; street width; adjacent land use; and traffic volume/operations.

Back-in/head-out diagonal parking is a popular option due to its improved visibility and simplicity of maneuvering.

Parallel Parking
Minimum width of a parking lane – 8 feet
Desirable – 10 to 12 feet (sufficient for delivery vehicles and bicyclists)

Land access and mobility demands are equally important for urban collector streets.

Urban Collector Streets
Parking lane width- 8 feet (for wide variety of traffic & land usage)
- 10 to 12 feet (desirable through-travel lane width to accommodate urban transit)
- 7 feet (for residential neighborhoods with passenger vehicles)

A 36 ft cross-section consisting of two 11 ft travel lanes and a single 7 ft parking lane on each side is a common example.
Local Streets
A 26 ft wide urban roadway with a single through lane and parking on both sides is typically used for local streets. Two-way movement can usually be accommodated in areas with intermittent parking on both sides of the roadway.

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.

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.

Parking Lane Transition at Intersection
REFERENCES

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

Flexibility in Highway Design.
