



Roadway Geometric Design 3

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INTRODUCTION

This course is the **third** in a series of five volumes that summarizes and highlights the geometric design process for modern roads and highways. Subjects covered include: *traffic barriers; local roads; collector roads; rural and urban arterials; and freeways*. The contents of this document are intended to serve as guidance and not as an absolute standard or rule.

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

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

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

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

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

TRAFFIC BARRIERS

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

Barriers should only be used where the crash severity is less with the barrier than a collision with the hazard behind it. The barriers themselves may be an object that can be struck with a significant crash severity and require continual maintenance.

The potential danger that a roadside hazard might have to roadway users should be assessed based on *size, shape, rigidity, and distance from the traveled way*.

Common Traffic Barrier Locations

Bridge ends

Near steep roadway slopes

Drainage facilities with steep drops

Signs/poles or other roadside hazards

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

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

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

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

Roadside Obstacles Options

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

Roadside Barriers

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

Median Barriers

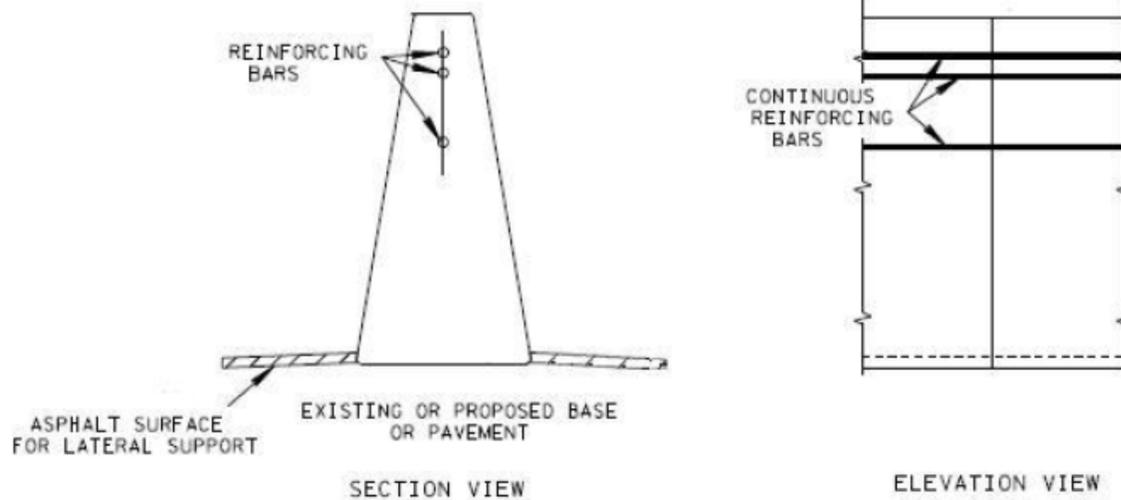
Median barriers are another type of longitudinal system used to prevent vehicles from crossing the median and crashing head-on into oncoming traffic. For roadways with low traffic volumes or wide medians, the likelihood of errant vehicles crossing the median and hitting an opposing vehicle is relatively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

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

Median Barrier Considerations

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

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



Typical Concrete Barrier Wall

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

Bridge Railings

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

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

Crash Cushions

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

Typical Crash Cushion Applications

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

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

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

MEDIANS

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

Principal Median Functions

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

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

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

In rural areas, medians are normally wider than in urban and suburban areas. Medians at unsignalized intersections need to be wide enough for selected design vehicle crossroads and U-turn traffic. In urban and suburban areas, narrow medians work better operationally – wide

medians being used only if large vehicles are anticipated. Wide medians may not be suitable for signalized intersections due to the increased time for crossing vehicles and leading to inefficient signal operation.

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

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

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

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

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

ROADSIDE CONTROL

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

PEDESTRIAN FACILITIES

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

The typical range of values for walking speed varies from 2.5 to 6.0 ft/sec². The MUTCD recommends using a **4.0 ft/sec²** as the walking speed value when calculating pedestrian clearance intervals for signalized intersections.

In order to accommodate pedestrians with visual, hearing, or cognitive impairments, various

types of information (auditory, tactile, and kinesthetic) should be combined to render assistance. Different treatments may include: curb ramps; pedestrian islands; fixed lighting; pedestrian signals; audible signals; etc.

Sidewalks

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

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

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

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

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

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

Advantages of Buffer Areas

- Increased pedestrian distance from moving traffic

- Aesthetics of the facility
- Reduced width of hard surface space
- Space for snow storage

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

Grade-Separated Pedestrian Crossings

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

Grade-Separated Pedestrian Crossing Factors

Pedestrian volume

Intersection capacity

Traffic volume

Conditions favoring usage

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

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

Possible Grade-Separated Crossing Locations

Moderate to high pedestrian demand to cross roadway

Large numbers of children regularly crossing high-speed/high-volume roads

Unacceptable number of pedestrian conflicts with traffic

Documented collisions or close calls with pedestrians and vehicles

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

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

Possible Overpass Locations (with screens)

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

Curb Ramps

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

Curb Ramp Design Factors

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

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

Minimum curb ramp width 4 feet

Maximum curb ramp grade 8.33%

Sidewalk cross slopes 2% maximum

Top level landing area 4 ft x 4 ft

(no obstructions, 2% maximum cross slope)

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

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

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

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

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

Curb Ramp Guidelines

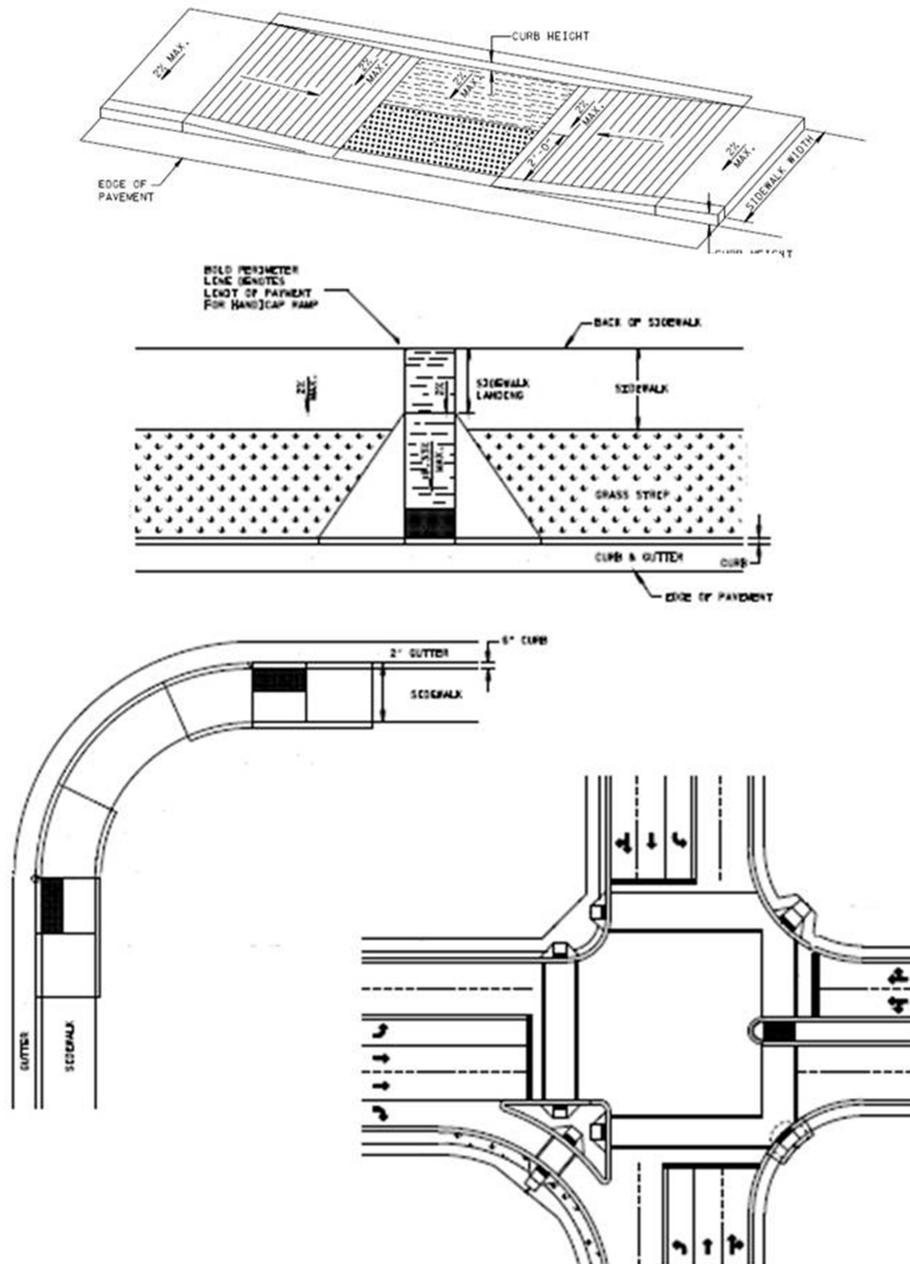
Curb ramps should not project into the traveled way

Ramp area should be protected

Curb area should be used at sites with parking lanes

Locations should be coordinated with crosswalk lines

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



Curb Ramp Examples

(Ref: TDOT, Standard Roadway Drawings)

BICYCLE FACILITIES

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

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

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

Basic Types of Bicycle Facilities

Shared lane: typical travel lane shared by both bicycles & vehicles

Wide outside lane: outside travel lane (14 ft minimum)

for both bicycles & vehicles

Bicycle lane: part of roadway exclusively designated (striping or signing)

for bicycles, etc.

Shoulder: roadway paving to the right of traveled way for usage

Multiuse path: physically separated facility for bicycles, etc.

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

Paved roadway shoulders

Wider outside traffic lanes (14 ft min.) – if no shoulders

Bicycle-friendly drainage grates

Manhole covers at grade

Smooth, clean riding surface

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

The main differentiation between bikes and other vehicles is that the bicycle and rider are

considered together as a system. Driver characteristics for motor vehicles are important but the driver-vehicle interface is rarely considered.

Typical bicyclist requirements: 3 feet lateral space 7.5 feet height

Required track width: 0.7 feet @ 7 mph or greater

2.5 feet @ 3 mph or greater

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

ON-STREET PARKING

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

Considerations For On-Street Parking

Specific function of street

Traffic operations (existing and proposed)

Roadway width

Adjacent land use

Traffic volume

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

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

(separate maneuvering space) – 20 feet

Minimum width of a parking lane – 8 feet

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

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

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

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

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

A 36 ft roadway cross-section consisting of two 11 ft travel lanes and a single 7 ft parking lane on each side is frequently used for urban residential collectors with passenger vehicle traffic.

Local Streets

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

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

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

Two methods are commonly used to address this problem:

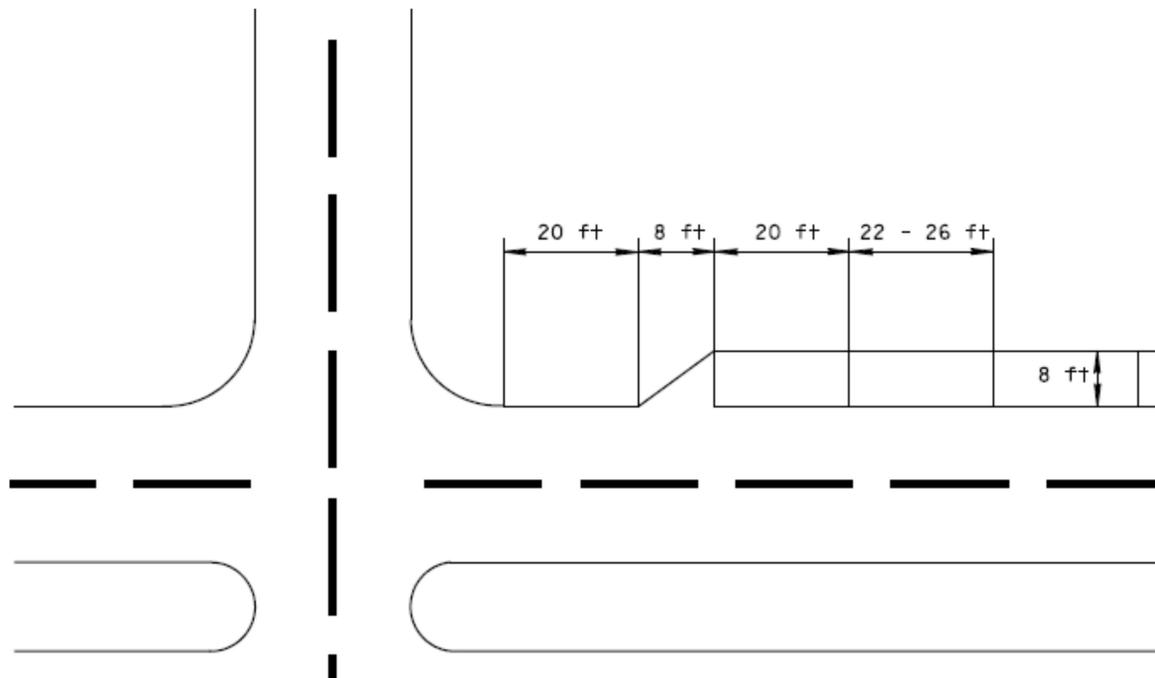
- End the parking lane a minimum of 20 feet prior to the intersection
- Prohibit parking at a specified distance to create a short turn lane.

Negative Aspects of On-Street Parking

Decreased through-traffic capacity

Disrupted traffic flow

Increased crash potential



Parking Lane Transition at Intersection

LOCAL ROADS

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

LOCAL RURAL ROADS

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

Design Speed determines various geometric design features that are to be used for a roadway (see Table 5-1, “Green Book”). Above-minimal design criteria should be used, where practical. *Low* design speeds are typically suited for rolling or mountainous terrains with winding alignments. *High* design

speeds are more applicable to level terrains or favorable environmental conditions. *Intermediate* speeds can be used where conditions are a combination of those for low/high design speeds.

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

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

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

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

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

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

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

LOCAL URBAN STREETS

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

Major Local Urban Design Controls

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

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

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

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

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

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

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

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

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

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

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

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

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

Vertical Clearance

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

* Allow for future resurfacing

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

COLLECTOR ROADS

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

RURAL COLLECTORS

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

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

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

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

URBAN COLLECTORS

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

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

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

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

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

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

Types of Collector Medians

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

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

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

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

ARTERIALS

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

RURAL ARTERIALS

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

Rural Principal Arterial

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

Rural Minor Arterial

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

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

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

(Ref: AASHTO Table 7-1)

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

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

Minimum Sight Distances for Arterials

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

(Ref: AASHTO Table 7-1)

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

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

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

Two crucial aspects of rural arterial roadside design are **clear zones** and **lateral offsets**. Although unobstructed roadsides are preferred, AASHTO's *Roadside Design Guide* provides appropriate treatment guidance for fixed objects or non-traversable slopes within the clear zone. Lateral offsets to vertical

obstructions help accommodate operating and parked vehicles. A minimum lateral offset of 4 feet (from edge of traveled way) should be used on roadways without curbs and shoulders less than 4 feet wide. Overpasses should be designed so that piers/supports have a lateral offset not less than the approach roadway.

Divided Arterials

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

Advantages of Dividing Multilane Arterials

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

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

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

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

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

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

Cases for Attaining Superelevation

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

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

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

Multilane Divided Arterials

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

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

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

URBAN ARTERIALS

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

Urban Principal Arterial

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

Urban Minor Arterial

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

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

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

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

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

Table 7-4. Maximum Grades for Urban Arterials

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

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

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

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

Lateral Offset Benefits

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

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

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

Traffic control devices – traffic signals, pavement markings, advance signs

Regulatory measures – turning movement restriction, curbside parking prohibition

Directional lane usage – one-way, reverse-flow operation

FREEWAYS

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

Freeway Elements

Roadways

Medians

Grade separations at crossroads

Ramps to/from traveled way

Frontage roads

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

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

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

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

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

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

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

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

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

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

RURAL FREEWAYS

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

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

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

URBAN FREEWAYS

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

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

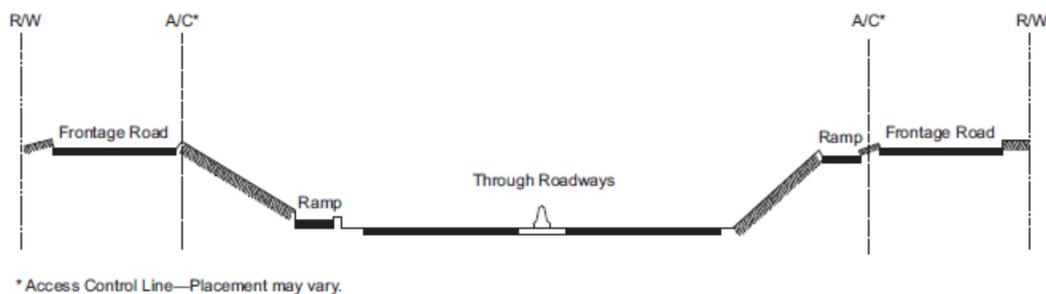


Figure 8-3. Typical Cross Section for Depressed Freeways

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

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

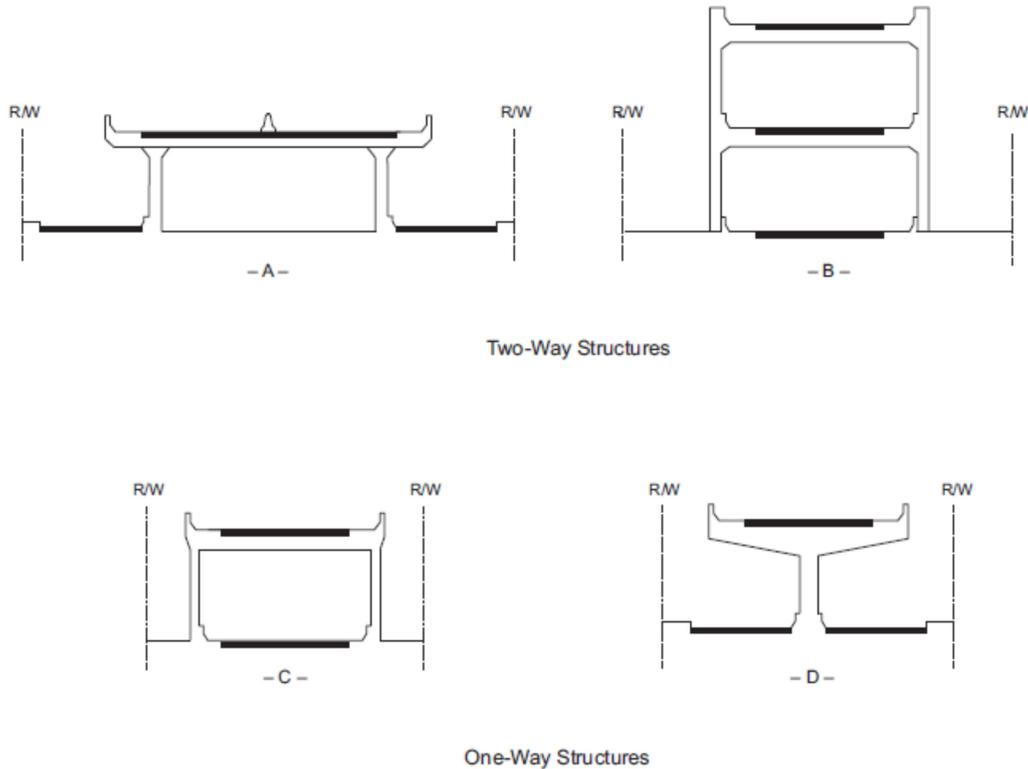


Figure 8-7. Typical Cross Sections for Elevated Freeways on Structures without Ramps

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

Typical Elevated Freeway Dimensions

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

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

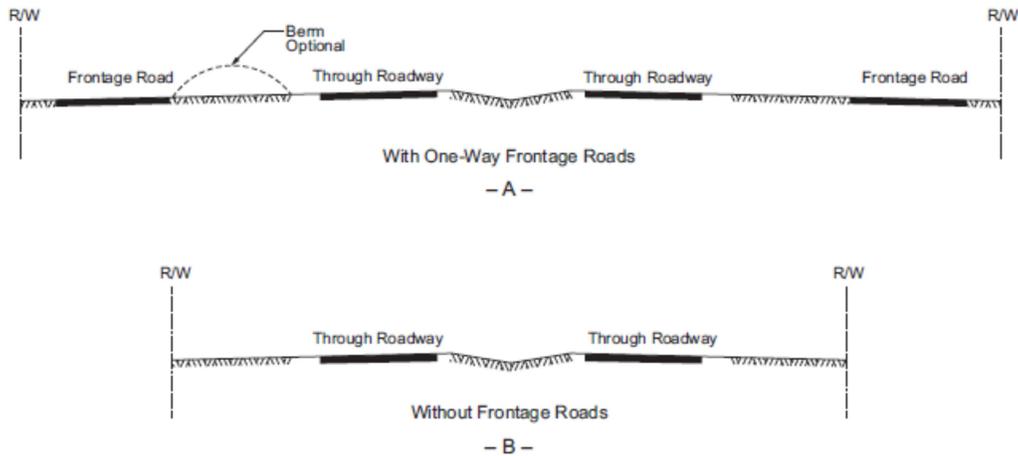


Figure 8-12. Typical Cross Sections for Ground-Level Freeways

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

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

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

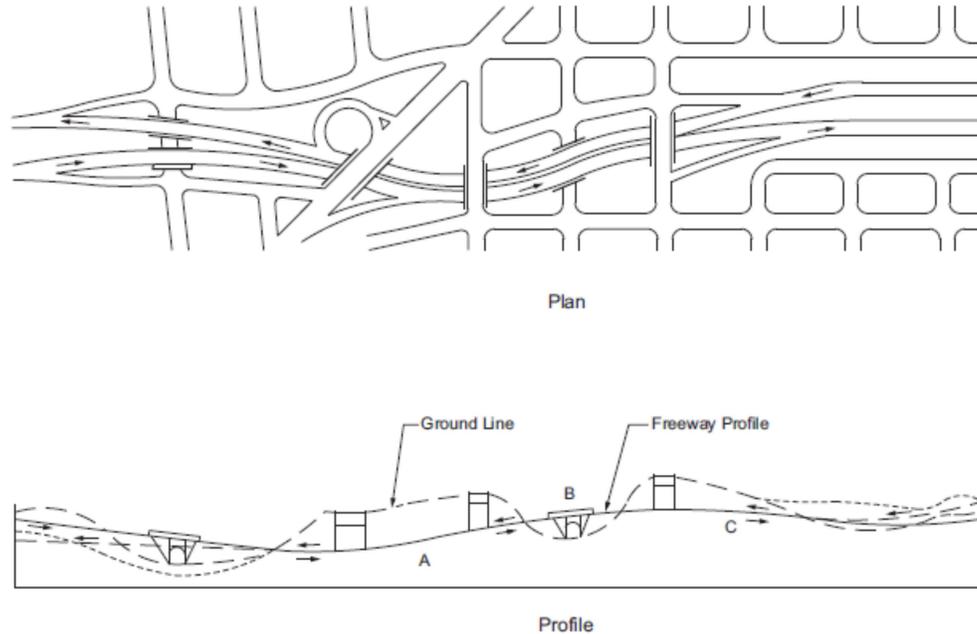


Figure 8-14. Profile Control—Combination-Type Freeway in Rolling Terrain

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

Combination-types are appropriate for level terrains where

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

and – *continuous viaduct construction is not practical.*

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

REFERENCES

A Policy on Geometric Design of Highways and Streets, 6th Edition.

AASHTO. Washington, D.C. 2011.

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

Civil Engineering Reference Manual, 8th Edition.

Michael R. Lindeburg. Professional Publications, Inc. Belmont, CA 2001.

Design of Stable Channels with Flexible Linings, 3rd Edition.

FHWA. Washington, D.C. 2005.

Flexibility in Highway Design.

Federal Highway Administration. Washington, D.C. 1997.

Guide for the Design of High-Occupancy Vehicle (HOV) Facilities, 3rd Edition.

AASHTO. Washington, D.C. 2004.

Guide for the Design of Park-and-Ride Facilities, 2nd Edition.

AASHTO. Washington, D.C. 2004.

Guide for the Planning, Design, and Operation of Pedestrian Facilities.

AASHTO. Washington, D.C. 2004.

Handbook of Simplified Practice for Traffic Studies.

Center for Transportation Research & Education – Iowa State University.

Ames, Iowa. 2002.

Manual on Uniform Traffic Control Devices, 2009 Edition.

Federal Highway Administration. Washington, D.C. 2009.

Mini-Roundabouts Technical Summary.

FHWA. Washington, D.C. 2010.

NCHRP Report 672 Roundabouts: An Informational Guide, 2nd Edition.

FHWA. Washington, D.C. 2010.

Roadside Design Guide, 4th Edition.

AASHTO. Washington, D.C. 2011.

Roundabouts: An Informational Guide.

FHWA. Washington, D.C. 2000.

Standard Roadway Drawings.

Tennessee Department of Transportation.

TCRP Report 19 Guidelines for the Location and Design of Bus Stops.

Transportation Research Board. Washington, D.C. 1996.

Traffic Engineering Handbook, 5th Edition.

Institute of Transportation Engineers. Washington, D.C. 1999.

Traffic Engineering Handbook, 6th Edition.

Institute of Transportation Engineers. Washington, D.C. 2009.

Urban Drainage Design Manual, 3rd Edition.

FHWA. Washington, D.C. 2009.