INTRODUCTION

An important concept in highway design is that every project is unique. The setting and character of the area, the values of the community, the needs of the highway users, and the challenges and opportunities are unique factors that designers must consider with each highway project. Whether the design to be developed is for a modest safety improvement or 10 miles of newlocation rural freeway, there are no patented solutions. For each potential project, designers are faced with the task of balancing the need for the highway improvement with the need to safely integrate the design into the surrounding natural and human environments.

In order to do this, designers need flexibility. There are a number of options available to State and local highway agency officials to aid in achieving a balanced road design and to resolve design issues. These include the following:

- Use the flexibility within the standards adopted for each State.
- Recognize that design exceptions may be optional where environmental consequences are great.
- Be prepared to reevaluate decisions made in the planning phase.
- Lower the design speed when appropriate.
- Maintain the road's existing horizontal and vertical geometry and cross section and undertake only resurfacing, restoration, and rehabilitation (3R) improvements.
- Consider developing alternative standards for each State, especially for scenic roads.
- Recognize the safety and operational impact of various design features and modifications.

This Guide illustrates the flexibility already available to designers within adopted State standards. These standards, often based on the AASHTO Green Book, allow designers to tailor their designs to the particular situations encountered in each highway project. Often, these standards alone provide enough flexibility to achieve a harmonious design that both meets the objectives of the project and is sensitive to the surrounding environment.

When faced with extreme social, economic, or environmental consequences, it is sometimes necessary for designers to look beyond the "givens" of a highway project and consider other options. The design exception process is one such alternative. In other cases, it may be possible to reevaluate planning decisions or rethink the appropriate design.

For existing roads, sometimes the best option is to maintain the road as is or make only

modest 3R improvements. Since the passage of ISTEA, States also have the ability to develop new standards outside the Green Book criteria for all roads not on the NHS. It is important, however, to recognize that the Green Book criteria are based on sound engineering and should be the primary source for design criteria. When the impact of the proposed action is evaluated and flexible design considerations are appropriate, they should be investigated.

All these options may give designers flexibility to use their expertise and judgment in designing roads that fit into the natural and human environments, while functioning efficiently and operating safely.

The ultimate decision on the use of existing flexibility rests with the State design team and project managers. Each situation must be evaluated to determine the possibilities that are appropriate for that particular project. Managers are encouraged to allow the designers to work with staff members from other disciplines to aid in exploring options, constraints, and flexibilities.

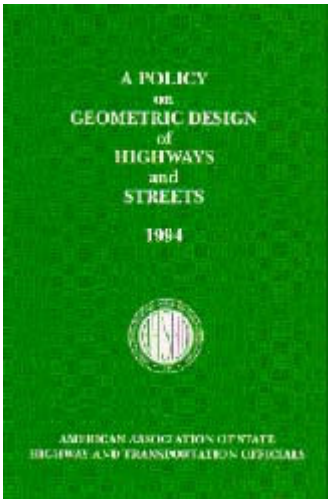
Chapter 2

HIGHWAY DESIGN STANDARDS

THE AASHTO GREEN BOOK

What the Green Book Contains

The reference most often used by designers during the design of a highway project is commonly referred to as the Green Book. Its official title is A Policy *on the Geometric Design of Highways and Streets.* It has been published by the AASHTO, in one form or another, since the late 1930's, with the most recent edition issued in 1994. Although often viewed as dictating a set of national standards, this document is actually a **series of guidelines** on geometric design within which the designer has a range of flexibility. As stated in the forward to this document:



The intent of this policy is to provide guidance to the designer by referencing a recommended range of values for critical dimensions. Sufficient flexibility is permitted to encourage independent designs tailored to particular situations.

In order for the design criteria in the Green Book to become a standard, they must be adopted by a particular State (or may be set by court decision). The FHWY has adopted applicable parts of the Green Book as the national standard for roads on the NHS. These roads comprise all the interstates and some other primary routes. The design of roads other than those on the NHS is subject to the standards of the particular State. The standards adopted by a State are usually based on the Green Book criteria.

What the Green Book Does Not Contain

The Green Book is <u>not</u> a design manual. It provides guidance on the geometric dimensions of the roadway. This includes widths of travel lanes, medians, shoulders, and clear zones; the width and shape of medians; turning radii; and other dimensions. There are many aspects of design that are not directly addressed in the Green Book. A number of these items are as follows:

- Problem definition
- Project definition
- Definition of the termini of the project
- Development of a project concept
- Aesthetic treatment of surfaces
- Design within the appropriate context
- Selection of the appropriate guardrail/bridge rail
- Determination of functional classification
- Determination of the appropriate functional requirements, capacity, and level of service
- Structure design
- Landscape development
- Selection of light fixtures
- Roadside development
- Traffic operations

Some of these items are addressed by reference in the Green Book, including:

1. *The Roadside Design Guide,* AASHTO, 1996.
2. *The Manual on Uniform Traffic Control Devices for Highways and Streets* (MUTCD), FHWA, 1988.
3. *A Guide for Transportation Landscape and Environmental Design,* AASHTO, June 1991.
4. *Guide for the Development of Bicycle Facilities,* AASHTO, August 1991.

An example of a road designed within the appropriate context as a gateway to a beach resort. This is a design aspect the Green Book is not intended to address. (Clearwater, FL)

Many fundamental questions that affect roadway design must be answered before the design

Decisions are made during planning and project development, and it is then that road design starts. Decisions that are made before the design phase include:

- Whether the proposed improvement will be two, four, six, or eight lanes
- Whether the facility will have a median
- Whether roadway junctions will be atgrade intersections or grade separated interchanges.

Design involves the difficult process of merging these previously determined design decisions with the appropriate design criteria used in the Green Book, working within the existing environmental and other important constraints, and using a designer's best judgment and experience to make decisions.

TYPES OE HIGHWAY IMPROVEMENT PROJECTS

There are four basic types of physical improvement projects, some of which must comply with standards and others that do not have to comply. These types of improvement projects are discussed in the following paragraphs.

Four types of highway construction:

1. New Construction
2. Reconstruction
3. 3R
4. Maintenance

New Construction

As its name implies, this action involves the construction of a new highway facility where nothing of its type currently exists. This might take the form of a bypass constructed to carry throughtraffic around an existing town or it might be a new twolane access route linking an existing arterial highway with a State park.

Reconstruction

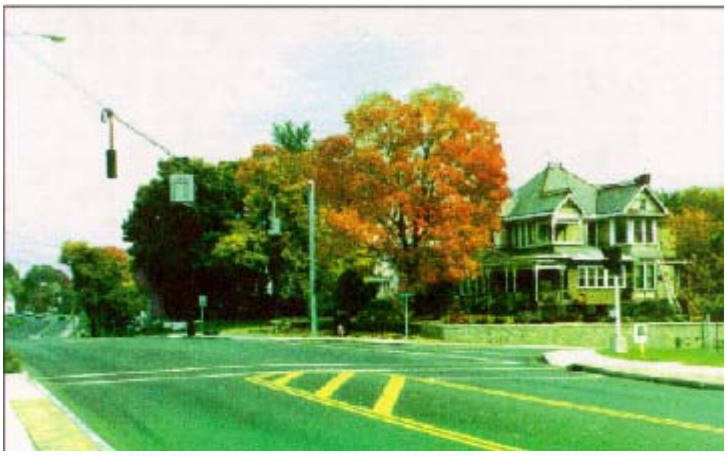
This typically involves a major change to an existing highway within the same general rightofway corridor. In many parts of the country, roads that were originally constructed in the early 20th century as twolane "farmtomarket" roads have been reconstructed over the past few decades into multilane divided arterials to better accommodate the travel demands generated by suburban development. Reconstruction also may involve making substantial modifications to an older highway's horizontal and vertical alinement in order to eliminate safety and accident problems.

Reconstruction can involve a major *change to the roadway appearance.*

Reconstruction of 7th Street. (Phoenix, AZ)

Before reconstruction

After reconstruction.



Resurfacing, Restoration, Rehabilitation (3R)

3R projects focus primarily on the preservation and extension of the service life of existing facilities and on safety enhancements. Under the classification of 3R projects, the types of improvements to existing federalaid highways include: resurfacing, pavement structural and joint repair, minor lane and shoulder widening, minor alterations to vertical grades and horizontal curves, bridge repair, and removal or protection of roadside obstacles.

Transportation Research Board Special Report 214, *Designing Safer Roads, Practices for Resurfacing, Restoration, and Rehabilitation* (1987), documents the result of a study on the cost effectiveness of highway geometric design standards for 3R projects.' Each State was invited to develop and adopt minimum design criteria for nonfreeway 3R projects. The result is that States typically employ design criteria for 3R projects that are lower than those contained in the AASHTO Green Book.

Ongoing maintenance is necessary to keep facilities in good condition.

(Rt. 136, Westport, CT)

Maintenance

Typically, maintenance activities consist of those actions necessary to keep an existing highway facility in good condition. Maintenance activities include repainting lane and edge lines, removing accumulated debris from drainage inlets, repairing surface drainage features, mowing, and removing snow. [1] Transportation Research Board Special Report 214, Designing Safer Roads, Practices for Resurfacing, Restoration, and Rehabilitation (1987)

Design criteria apply only to the first three of these actions: new construction, major reconstruction, and 3R projects. In addition, because 3R projects generally do not involve more than minor changes to roadway alinement and geometry, except to improve safety, FHWA and the State DOTS acknowledge that the AASHTO Green Book criteria do not always have to be adhered to for these projects. Because 3R projects have minimal impact, application of the Green Book design criteria may affect character of a roadway.

As stated in the Green Book, existing roads that do not meet the guidelines for geometric design are not necessarily unsafe and do not necessarily have to be upgraded to meet the design criteria:

The fact that new design values are presented herein does not imply that existing streets and highways are unsafe, nor does it mandate the initiation of improvement projects ...For projects of this type (resurfacing, restoration, or rehabilitation [3R]), where major revisions to horizontal and vertical curvature are not necessary or practical, existing design values may be retained. (p.xliii)

RELATIONSHIP OF THE GREEN BOOK TO STATE AND LOCAL DESIGN MANUALS

As stated earlier, in order for the Green Book to become a standard for a particular State, it must be adopted by that State (or may be set by a court decision). Although all the State DOTS may not specifically use the Green Book as their standard, State highway design manuals do derive from, and explicitly reference, the AASHTO Green Book. Despite this common origin, there are some variations in terms of the degree of adherence to all the contents of the document within the State standards. For example, Table 2.1 presents a comparison of the minimum stopping sight distance values for a range of design speeds, as defined in the 1994 edition of the AASHTO Green Book, compared to the most recent versions of the highway design manuals for California, Oregon, and Virginia.

Minimum Stopping Distance (m)				
Distance Speed (km/h)	**AASHTO** [(1)]	**California DOT** [(2)]	**Oregon DOT** [(3)]	**Virginia DOT** [(4)]
60	74.3-84.6	85	80	80
80	112.8-139.4	130	120	120
100	157-205	190	160	160
120	202.9-285.6	255	210	210
130	N.A. [(5)]	290	N.A.	N.A.

Table 2.1

Example of design criteria differences among several States.

Notes:

[1] *A Policy on Geometric Design of Highways and Streets*, AASHTO, 1994 p. 120, Table III1.

[2] *Interim Selected Metric Values for Geometric Design*, California DOT, December 15, 1993, p. 2, Table 201.1.

[3] *Metric Highway Design Manual*, Oregon DOT, 1994, p. 92, Figure 410.

[4] *Road Design Manual*, Volume 2 (Metric), Virginia DOT, August 1994, p. 27, Table III1.

[5] N.A.=Not Applicable

The AASHTO Green Book provides a range of values for the minimum stopping sight distance, while each of the three States provides only one minimum value. In each instance, the California requirement is highest. Moreover, the California stopping sight distance presents an upper limit design speed of 130 km/h (81 mph), although AASHTO, Oregon, and Virginia standards do not acknowledge using a design speed above 120 km/h (75 mph).

The minimum criteria established for Oregon and Virginia typically fall into the lower to middle portion of the AASHTO range of acceptable values. This situation is encountered in most other States, because in the past most States sought to meet or exceed the minimum values established by AASHTO in their designs, and this is reflected in their standards.

New State and Local Standards

Since the passage of ISTEA in 1991, States have been allowed to develop highway design standards outside of the Green Book criteria. A number of States have either developed or are in the process of developing new standards for roads not on the NHS. Idaho and Maine have implemented such separate design standards, Colorado and Vermont are at various stages of developing separate standards, and South Carolina plans to do so in the near future. These standards will give designers a greater range of flexibility when working on improvement projects to nonNHS roads.

The Rhode Island DOT has been particularly innovative in developing new State standards for all State roads. Rhode Island has decided that, because it has historic, scenic, and cultural resources along many of its roads, it would be inappropriate to make major changes to the geometry and alinements that would negatively affect these resources. When possible, the State DOT would prefer to maintain existing facilities by keeping existing alinements and geometries. For new construction, standards based on the AASHTO Green Book would be followed. This new approach will help to preserve the resources along many of Rhode Island's older roads and help engineers maintain the roads in a way that the public feels is appropriate for the communities.

Scenic roads can benefit from new State standards.

(Snickersville Tnpk., VA)

A number of local governments (primarily counties) have also developed their own geometric guidelines in recent years to allow for expanded design flexibility on local roads. In these cases, the local design guidelines are explicitly related to those of their respective State DOT; and/or the AASHTO Green Book.

For example, the *Design Guidelines and Standards for Scenic and Historic Roads,* published in June 1994 by the Prince George's County (Maryland) Department of Public Works and Transportation, was prepared specifically to ensure the adequacy and safety of any new or upgraded roadway within the county in accordance with the guidelines and in order to preserve the scenic and historic values of adjacent areas.

Specific criteria for scenic roads can help minimize impact on valuable resources, such as these rock fences.

(ParisLexington Road, KY)

THE DESIGN EXCEPTION PROCESS

Despite the range of flexibility that exists with respect to virtually all the major road design features, there are situations in which the application of even the minimum criteria would result in unacceptably high costs or major impact on the adjacent environment. For such instances when it is appropriate, the design exception process allows for the use of criteria lower than those specified as minimum acceptable values in the Green Book.

If the highway project is not on the NHS, the State does not need FHWA approval for a design exception. Under the ISTEA, the State can request an exemption from FHWA oversight on nonNHS projects.

For projects on NHS routes, FHWA requires that all exceptions from accepted guidelines and policies be justified and documented in some manner and requires formal approval for 13 specific controlling criteria. The process of justification and documentation, although not required, can be followed by States with exemption from FHWA oversight on nonNHS projects, as well. These criteria are as follows:

1. Design speed
2. Lane width
3. Shoulder width
4. Bridge width
5. Structural capacity
6. Horizontal alinement
7. Vertical alinement
8. Grade
9. Stopping sight distance
10. Cross slope
11. Superelevation
12. Vertical clearance
13. Horizontal clearance (not including clear zone)

For the most part, design exceptions to these 13 criteria can be easily identified and defined. Two

items, horizontal clearance and design speed, warrant further explanation.

Horizontal Clearance

For clear zones, the criteria in the AASHTO *Roadside Design Guide'* should be treated as guidance and not as a national standard requiring a design exception if not numerically met.

Design Speed

Design speed is used to determine individual design elements, such as stopping sight distance and horizontal curvature. Therefore, a design speed exception is an exception to all the various design elements affected by it and should be justified on that basis.

A few points to remember when evaluating design exceptions are as follows:

- Consideration should be given to the effect of the variance on the safety and operation of the facility and its compatibility with adjacent sections of the roadway.
- Consideration should be given to the functional classification of the road, the amount and character of the traffic, the type of project, and the accident history of the road.
- The cost of attaining full standards and any resultant impact on scenic, historic, or other environmental features should also be examined.
- Finally, the following three issues should be considered. What is the degree to which a guideline is being reduced? Will the exception affect other guidelines? Are there any additional features being introduced that would mitigate the deviation?

For preventive maintenance projects, no exceptions are needed for the retention of existing features. [2] Roadside Design Guide, AASHTO, Washington, DC, 1996.

TORT LIABILITY AS IT RELATES TO THE GREEN BOOK

Tort claims against highway agencies have steadily risen since the early 1970's, when the AASHTO first began surveying States for information about tort liability claims. This is partly due to the trend of no longer allowing design immunity (sovereign immunity) for highway agencies in almost all States. There is evidence to believe that the majority of these cases involve allegations of faulty traffic control devices or maintenance. Even though the number of cases alleging design defects is relatively small in comparison, tort liability is still a real concern for highway engineers.

Tort is a legal term that refers to a civil wrong that has been committed, in this case by highway agencies. Negligence is a term used to refer to a classification of tort in which the injury is not intentional, but where there was failure to use due care in the treatment of others compared to what a "reasonable man" would have done. Liability is the responsibility to make restitution to the damaged party through an action or payment determined by the court. Finally, States protected with sovereign immunity for design cannot be sued for decisions regarding design. (Sovereign immunity is now only in existence in a handful of States.)

The AASHTO Green Book, other Stateadopted highway standards, Federal and State regulations

and guidelines, and research publications issued by the Transportation Research Board are often used in tort cases to educate the jury about the standard level of practice for design. In addition, expert witnesses are used, who in turn rely on written text to explain the accepted standard practices for design to the jury.

Designing a highway that is safe and has a minimal impact on its surrounding environment can be a difficult task for engineers. Sometimes a design exception is necessary, as was the case for this project. (Bethel, VT)

This does not mean, however, that adherence to accepted standard practices, such as the AASHTO Green Book guidelines, automatically establishes that reasonable care was exercised. Conversely, deviation from the guidelines, through the use of a design exception, does not automatically establish negligence. The best defense for a design engineer is to present persuasive evidence that the guidelines were not applicable to the circumstances of the project or that the guidelines could not be reasonably met. (It should be noted that an economic defense is not the most effective.) It is highly recommended that designers document their rationales for decisions. If the justification documented by a designer completely describes the physical and environmental factors that make the exception or any design necessary, it is likely that this will be legally persuasive that the correct procedures were followed and ultimately the appropriate decision was made. In addition, it is helpful to have statements by other design experts who concur with the decision in the documentation.

As a result of concerns about litigation, designers may be tempted to be very conservative in their approaches to highway design and avoid innovative and creative approaches to design problems. While it is important for design engineers to do their jobs as thoroughly and carefully as possible, avoiding unique solutions is not the answer. This may undermine design practice and limit growth in the engineering profession. Designers need to remember that their skills, experience, and judgment are still valuable tools that should be applied to solving design problems and that, with reliance on complete and sound documentation, tort liability concerns need not be an impediment to achieving good road design.

Chapter 3

FUNCTIONAL CLASSIFICATION

Refer to Chapter I of the AASHTO Green Book

BACKGROUND

Functional classification is the process by which streets and highways are grouped into classes, or systems, according to the character of traffic service that they are intended to provide. There are three highway functional classifications: arterial, collector, and local roads. All streets and highways are grouped into one of these classes, depending on the character of the traffic (i.e., local or long distance) and the degree of land access that they allow. These classifications are described in Table 3.1.

The Functional Classes:

- Arterial
- Collector
- Local

Each type of road has a specific purpose or function.

Functional System	Services Provided
Arterial	Provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control.

Table 3.1

Functional Classification Systems

Collector	Provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials.
Local	Consists of all roads not defined as arterials or collectors; primarily provides access to land with little or no through movement.

Typically, travelers will use a combination of arterial, collector, and local roads for their trips. Each type of road has a specific purpose or function. Some provide land access to serve each end of the trip. Others provide travel mobility at varying levels, which is needed en route.

There is a basic relationship between functionally classified highway systems in serving traffic mobility and land access, as illustrated in Figure 3.1. Arterials provide a high level of mobility and a greater degree of access control, while local facilities provide a high level of access to adjacent properties but a low level of mobility. Collector roadways provide a balance between mobility and land access.

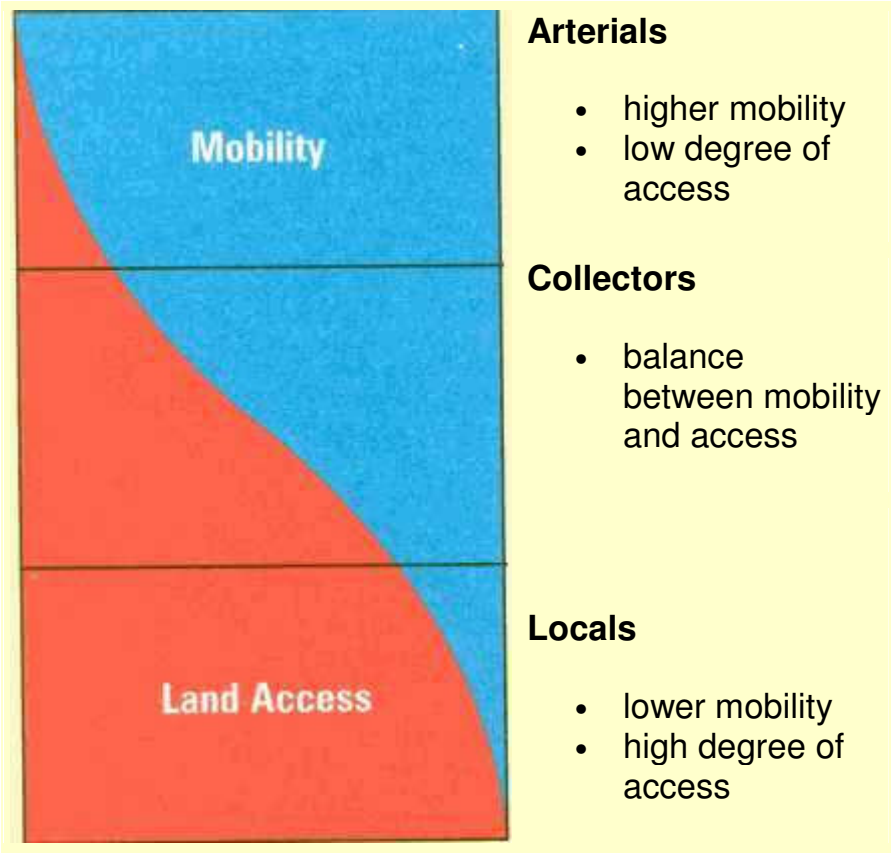


Figure 3.1

Relationship of functionally classified highway systems in serving traffic mobility and land access.

Source: *Safety Effectiveness of Highway Design Features,* Volume I, Access Control, FHWA, 1992

Route 187 in Connecticut was upgraded to provide minimal stops for through traffic, while allowing easy access to development along the road.

The Role of Functional Classification in the Design Process

The AASHTO Green Book explicitly recognizes the relationship between highway functional classification and design criteria. State, county, and city highway design manuals likewise relate design criteria to highway functional classification. The AASHTO Green Book states:

The first step in the design process is to define the function that the facility is to serve. The level of service required to fulfill this function for the anticipated volume and composition of traffic provides a rational and costeffective basis for the selection of design speed and geometric criteria within the range of values available to the designer (for the specified functional classification). The use of functional classification as a design type should appropriately integrate the highway planning and design process. (p. 17)

Once the functional classification of a particular roadway has been established, so has the allowable range of design speed. With the allowable range of design speed defined, the principal limiting design parameters associated with horizontal and vertical alinement are also defined. Similarly, a determination of functional classification establishes the basic roadway cross section in terms of lane width, shoulder width, type and width of median area, and other major design features (see Figure 3.2).

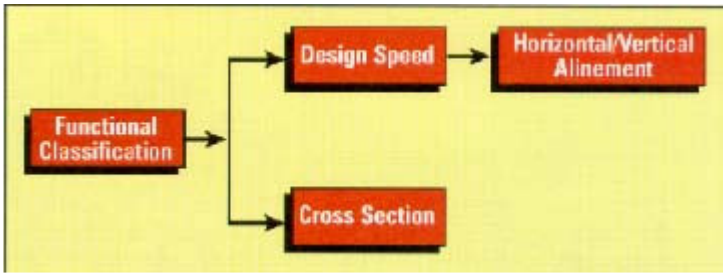


Figure 3.2

The flexibility available to a highway designer is considerably limited once a particular functional classification has been established.

The importance of the functional classification process as it relates to highway design lies in the fact that functional classification decisions are made well before an individual project is selected to move into the design phase. Moreover, such decisions are made on a systemwide basis by city, county, or State DOTS or MPOs as part of their continuing longrange transportation planning functions. Such systematic reassessments are typically undertaken on a relatively infrequent basis. Thus, the functional classification of a particular section of highway may well represent a decision made 10 or more years ago.

Even after the decision has been made to functionally classify a highway section, there is still a degree of **flexibility** in the major controlling factor of design speed. Table 3.2, excerpted from the 1995 edition of the *Roadway Design Manual* of the Virginia DOT, illustrates the manner in which one state has related a range of allowable design speeds to different roadway functional classifications.

Table 3.2

Range of Design Speeds for Various Highway Functional Classes In this example, there are at least three different design speeds for each functional classification.

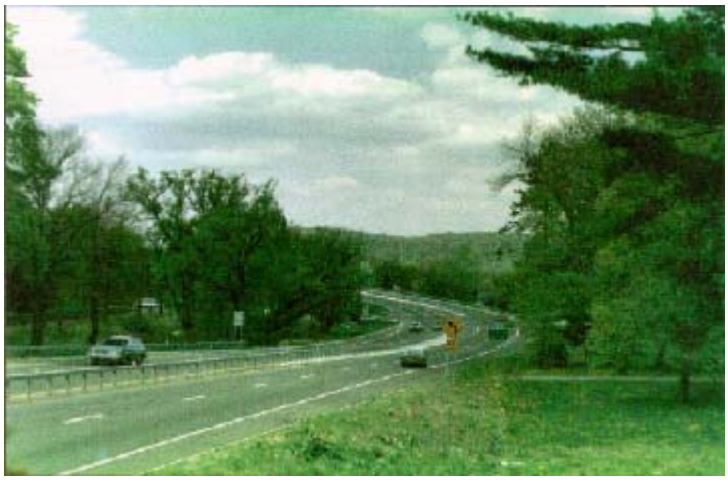
Functional Classification	**20 mph**	**30 mph**	**40 mph**	**50 mph**	**60 mph**	**70 mph**
Rural Principal Arterial				X	X	X
Rural Minor Arterial				X	X	X
Rural Collector	X	X	X			
Rural Local Road	X	X	X			

Source: Roadway Design Manual, Virginia DOT, 1995.
Note: 1 mph = 1.613 km/h

It is important to remember that there are no "cookiecutter" designs for arterial highways or collector streets. Because of the range of geometric design options available, arterials and collectors can vary considerably in appearance, as shown in the following photographs

Representative freeway.
(I476/U.S Rt. 1 Interchange, Montgomery County, PA)

Representative urban arterial
(Windsor, CT)



Representative rural arterial.
(Taconic State Parkway, NY)

Representative rural arterial.

(Rt. 58, CT)
Representative Collectors and Local

Representative collector in a residential area.
(Greenbelt, MD)

Representative urban collector.
(Lambertville, NJ)

Representative rural collector.
(Easton, CT)

Representative local street.
(Montgomery Co., MD)

Current Highway Functional Classifications

The highway system of the United States consists of slightly over 6.3 million km (3.9 million miles) of road.' Of this total, 5.0 million km (3.1 million miles) are located in rural areas, and the remaining 1.3 million km (800,000 miles) are urban streets. Each of these rural and urban streets has been given a specific functional classification, as illustrated in Table 3.3. In terms of jurisdictional responsibility, about 5 percent of the total is administered by the Federal Government, approximately 16 percent is under State control, and the remaining 79 percent is under the control of county and local governments.

Functional System	Percent of Total Mileage	Percent of Total Travel
Interstate	1.2	22.8
Other Freeway/Expressway	.2	6.2
Other Principal Arterial	3.8	24.3

Table 3.3 *Functional System (Rural and Urban) Mileage and Travel*

Minor Arterial	5.7	18.4
Major Collector	11.1	7.8
Minor Collector	7.2	2.1
Collections	2.2	5.3
Local	68.6	13.1
Total	**100**	**100**

The Interstate System represents 1.2 percent of the total road mileage but serves 22.8 percent of the Nation's total travel. (I95, VA) [1] Our Nation's Highways: Selected Facts and Figures, FHWA, Washington, DC, 1995, p. 17-18

ISSUES

The Need To Update Highway Functional Classifications

Traffic service patterns on a roadway and the roadway's function can change over time. If the functional classification system for a specific jurisdiction is not updated on a regular basis, roadways may be designed using inappropriate design standards.

Solution

Clearly, there is a need to reevaluate a locality's functional classification system on a relatively frequent and regular basis to ensure that the functional classification of any particular route accurately reflects the traffic function of the route now and in the foreseeable future. This continuing reassessment process can be viewed as an application of design flexibility even before the decision is made to begin designing a particular project. The decision to change the functional classification should be made based on careful review of changed conditions and sound reasoning.

The Functional Classification Process Is Not an Exact Science

One of the difficulties surrounding the relationship between highway functional classification and design guidelines is that the classification process is not an exact science. The predominant traffic service associated with a particular route cannot be definitely determined without exhaustive surveys of traffic origindestination patterns on each link of the road network. Engineering judgment based on experience must play a role in making design decisions.

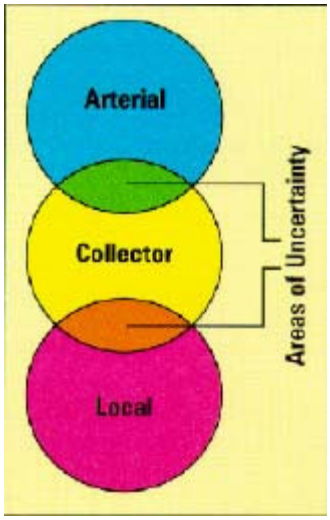


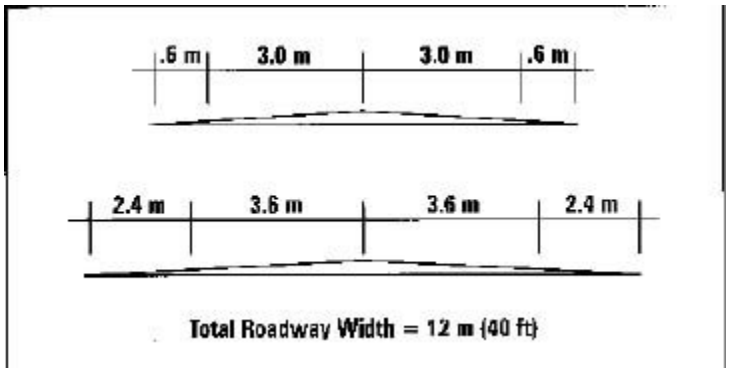
Figure 3.3

Solution

As a result of variances within the highway functional classification system, design guidelines established either in the Green Book or in other State and local government design manuals have overlapping ranges of values. This allows the designer greater flexibility in choosing a road design that is most appropriate within the determined functional classification (see Figure 3.3). For example, the 1994 Green Book indicates that the width of the traveled way for twolane rural collector facilities should be between 6.0 m and 7.2 m (20 ft and 24 ft), depending on traffic volumes, while the shoulder widths on each side of the traveled way should be between 0.6 m and 2.4 m (2 ft and 8 ft). Thus, the total width of the roadway can vary from 7.2 m to 12 m (24 ft to 40 ft), which is a considerable amount (see Figure 3.4). Twolane rural arterials can vary from a total roadway width, including shoulders, of 9 m to 12 m (30 ft to 40 ft). This flexibility allows designers to choose more accurately the specific geometric dimensions that are appropriate for that roadway.

Figure 3.4

The total width of a rural collector can vary from 7.2 m to 12 m, depending on traffic volume.



The Impact of Land Use Changes on Road Functions

Land use is an important determinant of the function of an area's roads. As land use changes because of development, especially at the urban fringe, road functions also change. It is not uncommon for roads that once served as rural local access routes to farmland, and now serve suburban residential subdivisions and commercial land uses, to be reclassified as urban collectors or arterials depending on the intensity of development and the type of traffic generated by the development. Design standards or guidelines must change to meet actual or impending change in traffic character and road function.

Actions taken by a local jurisdiction to control or direct the form and location of growth or to preserve the current physical and scenic characteristics of a highway corridor should also reflect the need for a reexamination of existing functional classification and, perhaps, even a change in jurisdictional responsibility (see Figure 3.5). For example, the construction of a new controlledaccess bypass route might allow for a downward reclassification of what had been the existing arterial route through a community to a collectorlevel facility.

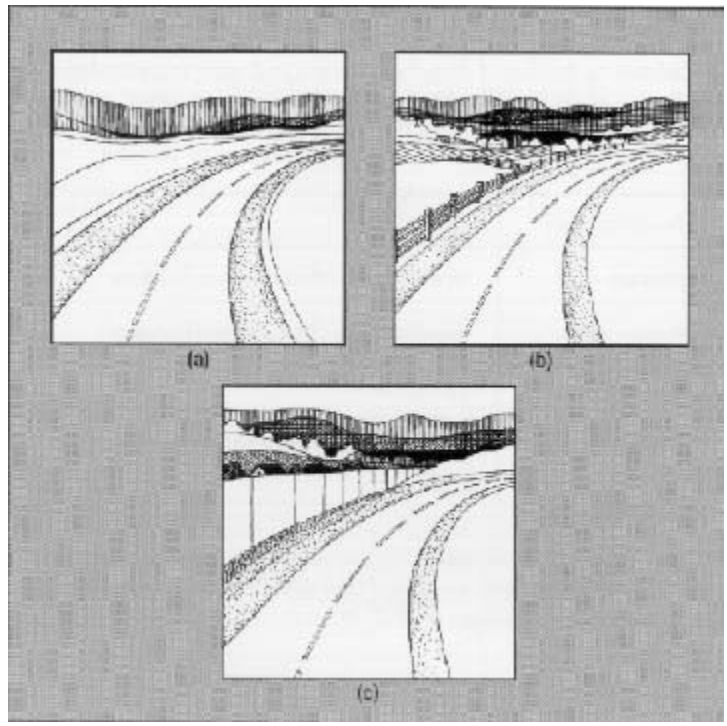


Figure 3.5
Road functions can change over time. These views show changing land use along a rural highway. The first view (a) shows a new road through the country. The second view (b) shows the first residences along the road. The third view (c) shows suburbanization and the need for mitigation.

Solution

One solution to the issue of changing land use is to directly relate the functional classification of the highway system to the "level of development" or, in other words, the design criteria that should be applied. The State of Washington is one jurisdiction that has done this. This relationship is shown in Table 3.4.

Functional Class	Design Criteria
Interstate	New Construction/Reconstruction Standards
Principal Arterial	New Construction/Reconstruction Standards
Minor Arterial	3R Standards
Collector	Maintenance of Structural Integrity and Operational Safety.

Table 3.4 *Relationship of Functional Classification and Design Criteria*

This process allows for improvements to even minor arterialtype routes to be designed using 3R standards, as opposed to applying traditional design criteria for newlocation highway facilities that fall within this functional classification.

Chapter 4

DESIGN CONTROLS

Refer to Chapter II of the AASHTO Green Book

BACKGROUND

In order to design the basic elements of a highwayincluding its alinement and cross sectionthe designer must have an understanding of the basic design controls and criteria associated with the highway. One of the most important, highway functional classification, was discussed in Chapter 3. Other important design controls include, but are not limited to the following:

- The design speed of the facility
- The acceptable degree of congestion (i.e., the designyear peakhour level of service) on the facility
- The physical characteristics of the "design vehicle" (i.e., the largest vehicle that is likely to use the facility with considerable frequency); in virtually all instances, the highway design vehicle is an overtheroad tractortrailer
- The performance of the design vehicle (particularly important in terms of accommodating heavy trucks in mountainous terrain or buses and recreational vehicles in areas subject to high levels of tourist activity)
- The capabilities of the typical driver along the facility (i.e., local residents using lowspeed neighborhood streets versus interstate travelers on rural freeways)
- The existing and designyear traffic demands to be placed on the facility (e.g., daily and peakhour traffic volumes, the mix of passenger cars and trucks on the facility)

Two of the most important of these factors are design speed and peakhour level of service. This chapter will focus on these two important criteria. The peakhour level of service, however, only serves as a controlling factor for a small number of highways. For most highways, after the functional classification and associated design speed for a particular highway facility have been established, the degree of flexibility available to the designer is significantly limited.

Speed limits are not the same as the design speed. They are regulatory limits enforceable by law.

Design Speed

Design speed is defined by the AASHTO Green Book 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.***

Table 4.1

Relationship Between Design Controls and Design Features

	Design Controls			
Design Features	**Functional Classification**	**Traffic Data**	**Terrain Locale**	**Design Speed**
Lane width, rural	X	X		X
Lane width, urban	X		X	
Rural shoulder width, type	X	X		
Urban shoulder width, type	X		X	
Guiderail offset	X	X		
Degree of curve				X
Grades	X		X	X
Bridge clearances (horizontal & vertical)	X	X		
Stopping sight distance				X
Superelevation				X
Widening on curves				X

Rural design speeds	X	X	X	
Urban design speeds	X		X	

Source: Location and Design Manual, Vol. 1, Roadway *Design, Ohio DOT.*

All geometric design elements of the highway are affected in some way by the selected design speed. Some roadway design elements are related directly to and vary appreciably with design speed. These include horizontal curvature, superelevation, sight distance, and gradient (see Table 4.1). Other elements are less related to design speed, such as pavement and shoulder width and clearances to walls and traffic barriers. The design of these features can, however, affect vehicle operating speeds significantly. As a result, more stringent criteria for these features are generally recommended for highways with higher design speeds. Conversely, less stringent criteria for these features may be more appropriate on roadways with lower design speeds.

The selection of a particular design speed is influenced by the following:

- The functional classification of the highway
- The character of the terrain
- The density and character of adjacent land uses
- The traffic volumes expected to use the highway
- The economic and environmental considerations.

Typically, an arterial highway warrants a higher design speed than a local road; a highway located in level terrain warrants a higher design speed than one in mountainous terrain; a highway in a rural area warrants a higher design speed than one in an urban area; and a highvolume highway warrants a higher design *speed* than one carrying low traffic volumes.

(Left) Lower design speeds are appropriate for city streets.

(Right) Higher volume rural highway facilities should use higher design speeds.

As discussed in Chapter 3, most States and localities have adopted a range of acceptable design speeds for each of the major classes of highways and streets (i.e., freeway, other arterial, collector, and local). Table 4.2 illustrates typical minimum design speeds for various types of highways located in level, rolling, and mountainous terrain.

Freeways	Design Speeds	
Terrain	**Rural**	**Urban**
Flat	70-80	70
Rolling	60-70	60-70
Mountainous	50-60	50-60
Arterial Highways		
Terrain	**Rural**	**Urban**
Flat	60-70	30-60
Rolling	40-60	30-50
Mountainous	30-50	30-50
Collector and Local Roads		
Terrain	**Rural**	**Urban**
Flat	30-50	30-40
Rolling	20-40	20-40
Mountainous	20-30	20-30

Source: Traffic *Engineering Handbook (Fourth Edition),* Institute of Transportation Engineers, Washington, DC, 1992, p. 156.
Note: 1 mile/hr = 1.613 km/hr

Table 4.2 *Typical Minimum Design Speeds for Various Types of Highways (in mph)*

The values presented in Table 4.2 are minimum acceptable design speeds for the various conditions of terrain and traffic volumes associated with new or reconstructed highway facilities. Designers need to balance the advantages of a higher vehicle operating speed gained through the use of a higher design speed against the flexibility lost in design. It may be more important to retain the maximum possible flexibility, so that a contextsensitive roadway that is more in tune with the needs of a community is designed using a lower design speed.

As used here, the term "context sensitive" refers primarily to the land use and environmental conditions adjacent to the highway. For example, for any particular highway other than a freeway or major arterial, as land use density increases, the design speed would typically decrease. The design speed of an urban collector street passing through a residential neighborhood should be appreciably lower than that for a rural highway with the same functional classification. This also recognizes the fact that bicycles and pedestrians would be more likely to use a route located in an urban area.
Similarly, in areas that have significant historic interest or visual quality, a lower design speed may be appropriate in recognition of lower average operating ,speeds and the need to avoid affecting these historic or aesthetic resources.

The Green Book agrees with this philosophy:

Aboveminimum design values should be used where feasible, but in view of the numerous constraints often encountered, practical values should be recognized and used.

Along arterial streets, the controlling factor of design speed applies to a lesser degree than on rural highways or hightype urban facilities, such as freeways or expressways. On many of the arterial streets located in large urban areas, maximum vehicle operating speeds for several hours of the day may be limited to those at which the recurring peak period traffic volumes can be accommodated. Thus, speeds may be governed by the presence of other vehicles traveling en masse both in and across the through travel lanes and by traffic control devices, rather than by the physical characteristics of the street.

During offpeak periods of lowtomoderate traffic demand, vehicle operating speeds are governed by such factors as speed limits, midblock turns, intersection turns, number of driveways and entrances, traffic signal spacing, and signal timing. As a result, when arterial street improvements are being planned, the selection of the appropriate design speed must be balanced against such factors as speed limits, physical and economic constraints, and the probable running speeds that can be attained during offpeak hours.

Although most States have adopted a range of allowable design speeds appropriate for each of the various functional classifications for use in the design of new or reconstructed highway facilities, situations may arise where even the use of the lowest typically acceptable value would result in unacceptably high construction or rightofway costs or unacceptable impact on adjacent properties. In such instances, the design exception process discussed in Chapter 2 can be employed. For example, the reconstruction of a twolane rural arterial route through a relatively flat but environmentally sensitive area might need to employ a design speed of 80 km/h (50 mph) rather than the recommended value for this functional classification of 100 km/h (60 mph) shown in Table 4.2.

PeakHour Level of Service

Once an appropriate design speed has been selected, the other basic defining elements of the highway (i.e., the number of lines and the basic configuration of junctions with other highway facilities) can be determined through application of the concept of acceptable peakhour level of service. Level of service is a grading system for amount of congestion, using the letter A to represent the least amount of congestion and F to refer to the greatest amount. For a comprehensive treatment of this topic, refer to the Highway Capacity Manual'. Table 4.3 presents a brief description of the operating characteristics associated with each level of service.

As congestion approaches capacity, speed decreases.

Level of Service	Description
A	Free flow with low volumes and high speeds.
B	Reasonably free flow, but speeds beginning to be restricted by traffic conditions.
C	In stable flow zone, but most drivers are restricted in the freedom to select their own speeds.
D	Approaching unstable flow; drivers have little freedom to select their own speeds.
E	Unstable flow; may be short stoppages
F	Unacceptable congestion; stop-and-go; forced flow.

Source: Adapted from the AASHTO Green Book. [1] *1995 Highway Capacity Manual (Special Report 209), Transportation Research Board, Washington, DC, Third Edition, updated 1994*

Table 4.3

Level-of-Service Characteristics

The appropriate degree of congestion (that is, the level of service) to be used in planning and designing highway improvements is determined by considering a variety of factors. These factors include the desires of the motorists, adjacent land use type and development intensity, environmental factors, and aesthetic and historic values. The factors must be weighed against the financial resources available to satisfy the motorists' desires.

Table 4.4 presents the relationship between highway type and location and the level of service appropriate for design, suggested by the AASHTO Green Book. Taking into consideration specific traffic and environmental conditions, the responsible highway agency should attempt to provide a reasonable and costeffective level of service.

Table 4.4
Guide for Selection of

	Type of Area and Appropriate Level of Service

Design Levels of Service

Highway Type	Rural Level	Rural Rolling	Rural Mountainous	Urban and Suburban
Freeway	B	B	C	C
Arterial	B	B	C	C
Collector	C	C	D	D
Local	D	D	D	D

While the *Highway Capacity Manual* provides the analytical basis for design calculations and decisions, judgment must be used in the selection of the appropriate level of service for the facility under study. Once a level of service has been selected, all elements of the roadway should be designed consistently to that level.

For example, along recreational routes subject to widely varying traffic demands according to the time of year or in response to environmental or land use considerations, the designer may conclude that the selection of a level of service that is lower than what is usually recommended may be appropriate. The selection of the desired level of service for a facility must be weighed carefully, because the facility's overall adequacy depends on this decision.

ISSUES

Application of Appropriate Design Speed

For some projects, community residents may perceive an imbalance between the scale of improvement deemed appropriate by the highway designers and that viewed as appropriate by the affected community. Much of this conflict can be traced to the design speed for the subject project.

For example, an older twolane rural road with a posted speed limit of 45 mph (72.5 km/h) may be adequate to accommodate current and anticipated future traffic demands, except for a short section containing several sharp curves that has a high incidence of accidents. If this facility were classified as a minor arterial, a State's design criteria might suggest that the reconstruction of the deficient section of roadway utilize a minimum design speed in the range of 60 to 70 mph (96.6 to 112.7 km/h).

If these criteria were followed, the reconstructed section would have a significantly higher design speed (and, hence, a higher operating speed and magnitude of physical impact on its surroundings) than the immediately adjacent sections of highway, resulting in a potentially unsafe condition.

Solution

One approach to avoiding this problem would be to apply a lower uniform design speed over the entire length of the route. This would suggest the application of a design speed of 50 mph (80.5 km/h) to the reconstruction project to preserve the design continuity and character of the route.

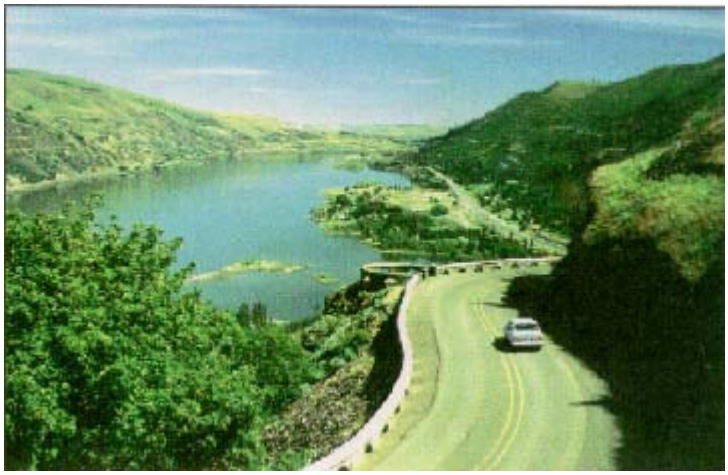
A similar approach was taken during the design of State Route 9A in New York City to better integrate the project into its surroundings. Although this facility is classified as a principal urban arterial street with an allowable design speed under New York State DOT design criteria as high as 60 mph (96.6 km/h), a design speed of only 40 mph (64.4 km/h) was used. The roadway's capacity remains unchanged and the roadway is functioning safely and efficiently.

Note that the design speed must be higher than the posted speed and should also be above the operating speed on a facility, regardless of the posted speed.

Chapter 5

HORIZONTAL AND VERTICAL ALINEMENT

Refer to Chapter III of the AASHTO Green Book

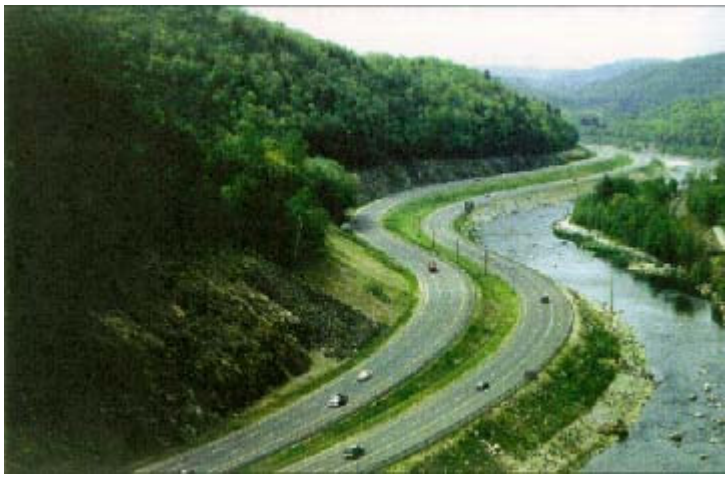


BACKGROUND

One definition of a visually attractive and unobtrusive highway is the degree to which the horizontal and vertical alinements of the route have been integrated into its surrounding natural and human environments. This takes careful planning and design, as noted in the AASHTO Green Book:

Coordination of horizontal alinement and profile should not be left to chance but should begin with preliminary design, during which adjustments can readily be made ...The designer shouldstudy long, continuous stretches of highway in both plan and profile and visualize the whole in three dimensions.

This application of a holistic approach to highway design, where the road is integrated into its surroundings, separates the outstanding project from one that merely satisfies basic engineering design criteria (see Figures 5.1 and 5.2). An excellent description of this holistic design process is contained in the publication Aesthetics in Transportation, from which the following is excerpted: *A general rule for designers is to achieve a "flowing" line, with a smooth and natural appearance in the land, and a sensuous, rhythmic continuity for the driver. This effect results from following the natural contours of the land, using graceful and gradual horizontal and vertical transitions, and relating the alinement to permanent features such as rivers or mountains.*

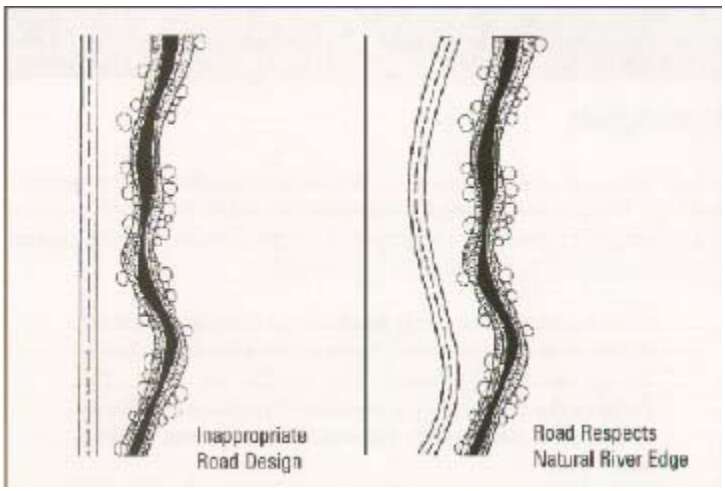


The alinement of Rt.8 gracefully follows the Naugatuck River.

(Naugatuck, CT)

Figure 5.1

Inappropriate road design does not integrate with the natural surroundings. [1] *Aesthetics in Transportation, U.S. DOT,* November 1980, p. 89.



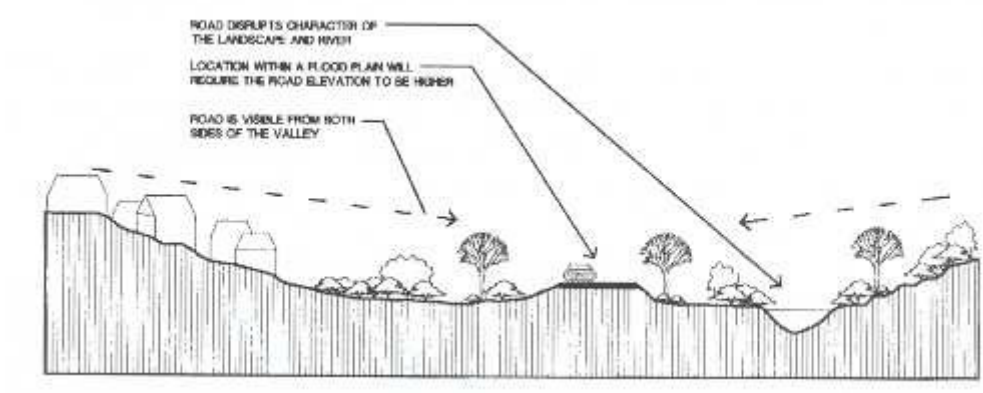
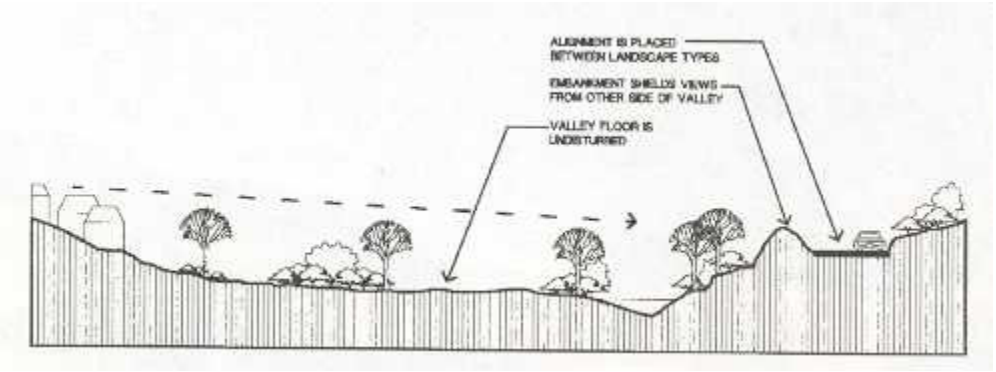


Figure 5.2

The alinement of a new facility plays an important role in minimizing impacts on the surroundings. In this example, the character of the landscape was disrupted.

In this alternative, the valley is undisturbed and the road is partially shielded from view.



HORIZONTAL AND VERTICAL ALINEMENT CONSIDERATIONS

The greatest opportunities for influencing the horizontal and vertical alinements of a highway occur during the planning and preliminary engineering phases associated with a newlocation facility. The designs of such facilities have the most dramatic effects on the natural and human environments through which they pass.

Preservation of unique rock formations enhances the view along this highway. (State Route 313, Moab, UT)

The more typical design problem faced by today's highway engineers is the improvement of an **existing highway or street.** In many instances, the basic alinements may have been established well over 100 years ago. Regardless, the same basic design principles with respect to horizontal and vertical alinements can, however, be applied to both new and existing facilities.

Important points to consider regarding horizontal and vertical alinements are that they should be consistent with the topography, preserve developed properties along the road, and incorporate community values. The superior alinements are ones that follow the natural contours of the land and do not affect aesthetic, scenic, historic, and cultural resources along the way. Construction costs may be reduced in many instances when less earthwork is needed, and resources and development are preserved. It is not always possible, however, to avoid having an impact on both the natural and human environments. That is why the superior alinements incorporate input received by the community through a participatory design process.

When possible, the alinement should be designed to enhance attractive scenic views, such as rivers, rock formations, parks, historic sites, and outstanding buildings. The designation of certain highways as scenic byways recognizes the importance of preserving such features along our Nation's roadways.

Equally important as the consideration of the horizontal alinement is that of the facility's vertical alinement. A number of factors influence the vertical alinement of a highway, including

the following:

- Natural terrain
- Minimum stopping sight distance for the selected design speed
- The number of trucks and other heavy vehicles in the traffic stream
- The basic roadway crosssection; i.e., two lanes versus multiple lanes
- Natural environmental factors, such as wetlands and historic, cultural, and community resources

COMBINATION OF HORIZONTAL AND VERTICAL ALINEMENT

The interrelationship of horizontal and vertical alinement is best addressed in the route location and preliminary design phases of a project. At this stage, appropriate tradeoffs and balances between design speed and the character of the roadtraffic volume, topography, and existing developmentcan be made. A mistake often made by inexperienced engineers is designing the horizontal alinement first and then trying to superimpose the design onto a vertical profile. Because they must be complementary, horizontal and vertical geometries must be designed concurrently. Uncoordinated horizontal and vertical geometries can ruin the best parts and accentuate the weak points of each element. Excellence in the combination of their designs increases efficiency, and safety, encourages uniform speed, and improves appearancealmost always without additional cost.

One tool to assist in coordinating horizontal and vertical geometries is the use of computeraided design (CAD). CAD enables highway designers to quickly assess the interrelationships between horizontal and vertical alinement, particularly in areas of difficult terrain.

Proper consideration of these basic design considerations will help to ensure that both newlocation facilities and improvements to existing highways fit harmoniously into their surroundings.

Good integration of horizontal andvertical alinement on a reconstructed twolane rural highway.

(State Route 89 near Lake Tahoe, CA)

ISSUES

There are numerous examples around this country of excellence in integration of the

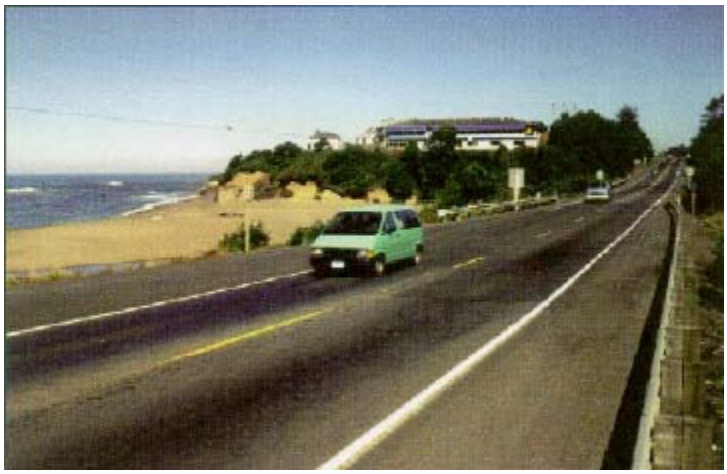
horizontal and vertical alinements of highways into their surroundings. Unfortunately, there are also examples of new or widened highways that have scarred a rural landscape or disrupted an established community. While these past actions cannot easily or inexpensively be rectified, future problems can be avoided by applying the principles outlined above and the creative approaches detailed below.

Avoiding Impact on Adjacent Natural and Human Environments

Particularly during the era of Interstate construction from the 1950's to the 1980's, a number of instances of new highway construction had a devastating impact on communities and areas of environmental sensitivity. It is readily acknowledged that there will be some degree of physical impact on the surroundings associated with the construction of any new location highway or major reconstruction or widening of an existing highway facility. However, from the perspective of horizontal and vertical alinement, much of this impact can and should be alleviated.

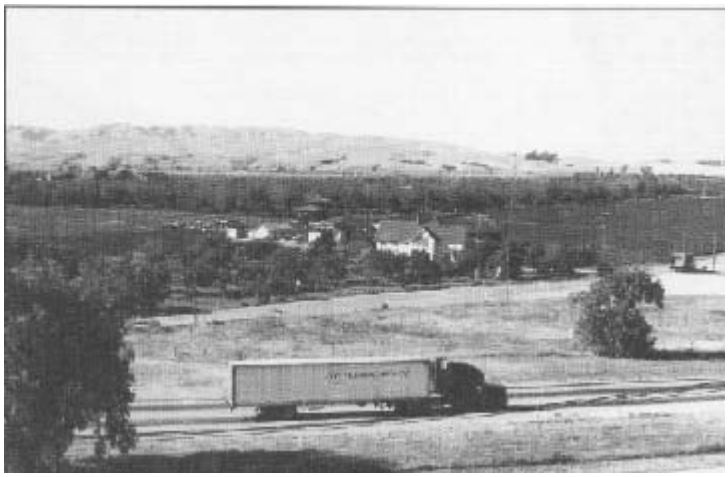
Solution

Impact on the surrounding environment can be minimized by careful attention to detail during the route location and preliminary design phases and a willingness of all concerned parties to work together toward a common goal. For example, minor adjustments to the originally proposed horizontal and vertical alinements (combined with the use of short sections of retaining wall) along the Lincoln Beach Parkway (U.S. Route 101) in Oregon eliminated the need to acquire any of the adjacent homes and businesses.



Minor alinement changes can avoid impacts on adjacent properties. (U.S. Route 101, Lincoln Co., OR)

Similarly, a minor horizontal alinement shift at the beginning of the project allowed for the Hollister Bypass (SR 156) in San Benito County, CA, to avoid affecting a number of historic properties.



Impact on the historic Mitchell Fruit Farm was avoided as a result of a minor shift in the horizontal alinement of the Hollister Bypass.

(San Benito, CA)

The use of a "cutandcover" design, whereby the roadway is placed below the existing ground level and covered over with a park, building, or other public space can help to avoid negative impact. Lake Place Park in Duluth, MN and other public parks were the result of cutandcover tunnels that not only saved historic properties but also gave pedestrians improved access to Lake Superior.

Designers employed several cutandcover tunnels along I35 to avoid impacting an historic district and to reconnect the downtown to the waterfront.

(Duluth, MN)

In many cases, there is a potential for designing a divided highway with independent horizontal and vertical alinements for each direction of traffic.

Separate profiles and varied median widths on divided roadways are options for designers to minimize impact on the environment.

(Rt 395, Inyo National Forest, CA)

Each side of the highway can have a different alinement to better integrate the roadway into its surroundings.

(I15, MT)

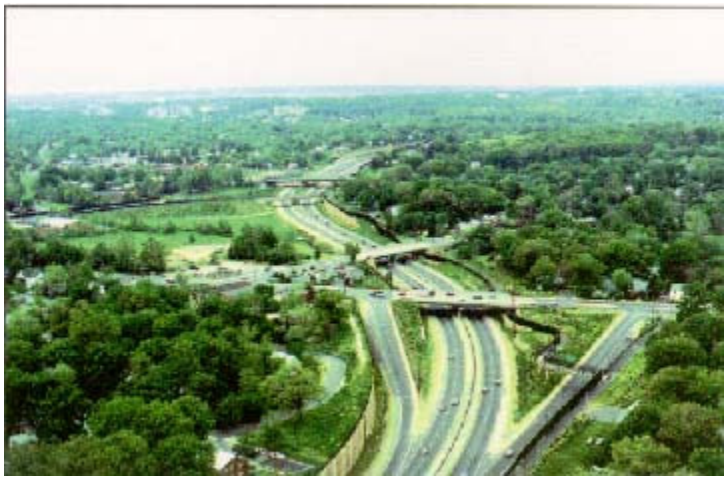
Coordination Between Horizontal and Vertical Alinement

When horizontal and vertical alinements are designed separately from one another, unnecessarily large cuts and fills may be required, resulting in very dramatic and often visually undesirable changes to the natural landscape.

Solution

One of the ways to ensure the most effective coordination of horizontal and vertical alinement is through the use of a multidisciplinary design team during the planning and engineering phases of a project. On such projects as 166 in Fairfax and Arlington Counties in Virginia, the combined expertise of landscape architects, urban designers, structural engineers, and historic preservationists, in addition to civil engineers and highway designers, has resulted in superior highway improvement projects.

The concept of using a multidisciplinary design team is not new; it was pioneered in the early 1900's during the planning and design of the Bronx River Parkway in Westchester County, NY After a period of use primarily on largescale or controversial projects, this approach has come back into more general application as a way to achieve community consensus.



A multidisciplinary design team can help minimize the impact an urban freeway has on a community.

(I66, VA)

Chapter 6

CROSS-SECTION ELEMENTS

Refer to Chapter IV of the AASHTO Green Book

BACKGROUND

The cross section of a road includes some or all of the following elements:

- **Traveled way** (the portion of the roadway provided for the movement of vehicles, exclusive of shoulders)
- **Roadway** (the portion of a highway, including shoulders, provided for vehicular use)
- **Median** area (the physical or painted separation provided on divided highways between two adjacent roadways)
- **Bicycle and pedestrian facilities**
- **Utility and landscape areas**
- **Drainage channels and side slopes**
- **Clear zone width** (i.e., the distance from the edge of the traveled way to either a fixed obstacle or nontraversable slope)

Considered as a single unit, all these crosssection elements define the highway rightofway. The rightofway can be described generally as the publicly owned parcel of land that encompasses all the various crosssection elements (see Figures 6.1 and 6.2).

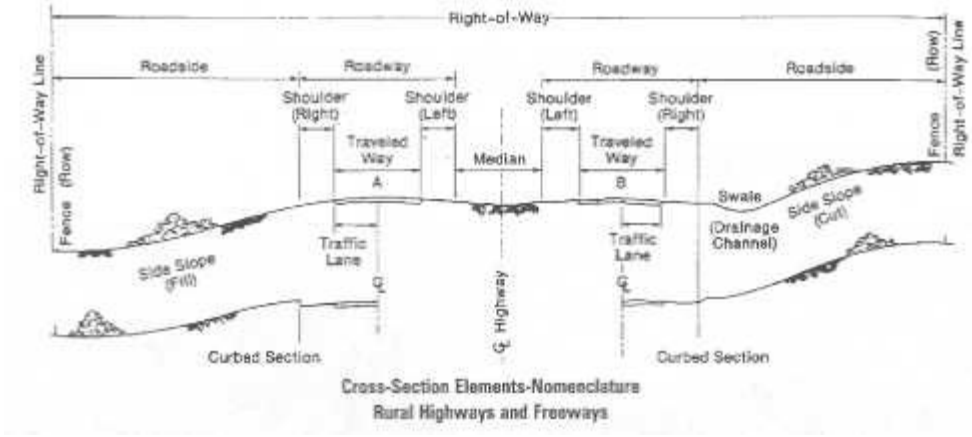


Figure 6.1

Twolane rural highway crosssection design features and terms.

Some decisions about cross section are made during project development, such as the capacity and number of lanes for the facility. Other decisions, such as functional classification, are made earlier in the process. Within these parameters, the Green Book guidelines recommend a range of values for the dimensions to use for crosssectional elements. Deciding which of the elements to include and selecting the appropriate dimensions within these ranges is the role of the designer.

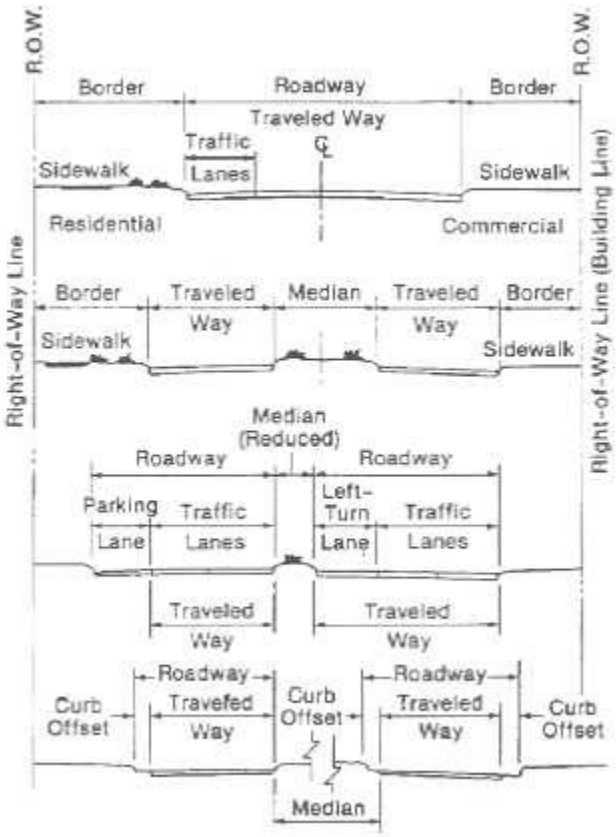


Figure 6.2

Urban highway crosssection design features and terms.

In selecting the appropriate crosssection elements and dimensions, designers need to consider a number of factors, including the following:

- Volume and composition (percent trucks, buses, and recreational vehicles) of the vehicular traffic expected to use the facility
- The likelihood that bicyclists and pedestrians will use the route
- Climatic conditions (e.g., the need to provide storage space for plowed snow)
- The presence of natural or humanmade obstructions adjacent to the roadway (e.g., rock cliffs, large trees, wetlands, buildings, power lines)
- Type and intensity of development along the section of the highway facility that is being designed
- Safety of the users

The most appropriate design for a highway improvement is the one that balances the mobility needs of the people using the facility (motorists, pedestrians, or bicyclists) with the physical constraints of the corridor within which the facility is located.

The likelihood of pedestrian and bicycle traffic is one factor to consider when designing the cross section of a facility.

CROSSSECTION ELEMENTS

Travel Lanes

The number of lanes needed for a facility is usually determined during the concept stage of project development. It is usually the number of lanes necessary to accommodate the expected traffic volumes at a level of service determined to be appropriate for the facility (see Chapter 4 for a discussion of level of service). The number of lanes can only be added in integer units, i.e., a twolane highway can be widened to three or four lanes. Each additional lane represents an increase in the trafficcarrying capability of the facility.

Knowing future projected travel demands, the designer, using the analysis procedures in the Highway Capacity Manual, can provide input into the decisionmaking process during project development to determine the appropriate number of travel lanes for the level of service desired. Community input also plays a part in this decision. A community may decide through public involvement that a lower level of service is acceptable for the situation than the level of service normally provided for new construction projects.

In urban and suburban areas, signalized intersections are usually the predominant factor

controlling the capacity of the highway or street. There may be more latitude in determining the number of lanes for these types of facilities. For example, a twolane facility approaching an intersection can be expanded to four lanes (one left turn lane, two through lanes, one rightturn lane) at the intersection itself and then returned to two lanes beyond the intersection. The need to distribute traffic safely will determine the need for any expansion of the approach roadway. The added lanes at the intersection can be in a variety of configurations to serve the travel desires of the traffic.

Lane Width

The width of travel lanes is limited by the physical dimensions of automobiles and trucks to a range between 2.7 and 3.6 m (9 and 12 ft). Generally, as the design speed of a highway increases, so must the lane width to allow for the lateral movement of vehicles within the lane. However, constricted rightofway and other design restrictions can have an impact on this decision. Chapter IV of the Green Book recognizes the need for flexibility in these cases:

Although lane widths of 3.6 m are desirable on both rural and urban facilities, there are circumstances that necessitate the use of lanes less than 3.6 m wide. In urban areas where rightofway and existing development become stringent controls, the use of 3.3 m lanes is acceptable. Lanes 3.0 m wide are acceptable on lowspeed facilities. Lanes 2.7 m wide are appropriate on lowvolume roads in rural and residential areas.

A landscaped median.

(I35E, St. Paul, MN)

Medians

An important consideration in the design of any multilane highway is whether to provide a median and, if one is provided, what the dimensions should be. The primary functions of highway medians are to:

- Separate opposing traffic flows
- Provide a recovery area for outofcontrol vehicles
- Allow space for speed changes and leftturning and Uturning vehicles

- Minimize headlight glare
- Provide width for future lanes (particularly in suburban areas)
- Provide a space for landscape planting that is in keeping with safety needs and improves the aesthetics of the facility
- Provide a space for barriers.

Depending on agency practice and specific location requirements, medians may be depressed, raised, or flush with the surface of the traveled way. Medians should have a dimension that is in balance with the other elements of the total highway cross section. The general range of median widths is from 1.2 m (4 ft), usually in urban areas, to 24 m (80 ft) or more, in rural areas. An offset of at least a 500 mm (1.5 ft) should be provided between any vertical element located within the median, such as a curb or barrier, and the edge of the adjacent traveled lane.

The design and width of medians again require tradeoffs for designers. In locations where the total available rightofway is restricted, a wide median may not be desirable if it requires narrowing the areas adjacent to the outside edge of the traveled way. A reasonable border width is required to serve as a buffer between private development along the road and the edge of the traveled way, and space may be needed for sidewalks, highway signs, utilities, parking, drainage channels and structures, proper slopes and clear zones, and any retained native plant material. On the other hand, wider medians provide more space for plant material, offer a refuge for pedestrians at intersections, and help soften the look of the roadway. Including and designing medians requires public input to find the design that meets the needs of the community.

Twoway leftturn lanes improve safety and efficiency for vehicular traffic but do not afford a safe refuge for pedestrians.

The use of twoway leftturn lanes on urban streets in densely developed suburban commercial areas has increased as an alternative to raised medians with leftturn or Uturn bays. Although not as aesthetically pleasing as raised, planted medians, continuous leftturn lanes can improve capacity. Twoway leftturn lanes generally are not recommended in residential areas because they do not afford a safe refuge for pedestrians. Also, the number of driveways can create unsafe vehicle maneuvers.

Shoulders increase safety and highway capacity and provide a place for pedestrians and bicyclists when no sidewalks are provided.

(Rt. 197, MD)

Shoulders

Although the physical dimensions of automobiles and trucks limit the basic width of travel lanes, the treatment of that portion of the highway to the right of the actual traveled way, that is, the "roadway edge," provides the designer with a greater degree of flexibility. This is true in both urban and rural areas, although different design elements are more appropriate in each location.

Shoulder widths typically vary from as little as 0.6 m (2 ft) on minor rural roads, where there is no surfacing, to about 3.6 m (12 ft) on major highways, where the entire shoulder may be stabilized or paved.

The treatment of shoulders is important from a number of perspectives, including safety, the capacity of the highway section, impact on the surrounding environment, and both the initial capital outlay and ongoing maintenance and operating costs. The shoulder design should balance these factors. For example, a designer must consider the impact of the shoulder width and other roadside elements on the surrounding environment and, at the same time, how these dimensions will affect capacity. Even with a maximum lane width of 3.6 m (12 ft), the absence of a shoulder or the presence of an obstruction at the edge of the travel lane can result in a reduction in capacity of as much as 30 percent, compared to an area where shoulder or clear zone exists that is a minimum 1.8 m (6 ft) wide. On the other hand, significant environmental, scenic, or historic resources may be adversely affected by a widened shoulder.

Another consideration is the accommodation of pedestrians and nonmotorized vehicles. In many parts of the country, highway shoulders provide a separate traveled way for pedestrians, bicyclists, and others (when no sidewalks are provided).

(a)

(b)

Various shoulder treatments:
(a) Gravel

(b) Paved

(c) Concrete

(c)

(d)

(c) Concrete

(d) Grass with sidewalk

In addition to the dimensions of shoulders, designers have choices to make about the materials used. Shoulders may be surfaced for either their full or partial widths. Some of the commonly used materials include gravel, shell, crushed rock, mineral or chemical additives, bituminous surface treatments, and various forms of asphaltic or concrete pavements.

In a number of States, particularly in the southern part of the country where snow removal is not an issue, grass or turf surfaces have been provided on top of compacted earth embankments. The advantages of grass shoulders are that they provide both a natural storm water detention system and are aesthetically pleasing. The disadvantages can be that they are often less safe than paved shoulders and force pedestrians and bicyclists to share the road with motorists, if no offstreet facility is provided.

Shoulders represent an important element in roadway drainage systems by carrying surface runoff away from the travel lanes into either open or closed drainage systems. A variety of design treatments have been used to accommodate roadway drainage across shoulder areas. In rural and suburban areas, the most common technique allows surface runoff to cross over the shoulder and go directly into drainage ditches running parallel to the roadway edge.

In rural areas where significant physical and/or environmental constraints exist, more "urban" style solutions have been used. For example, along an older section of Maryland State Route 51, passing through the Green Ridge State Forest in Allegany County, steep, narrow cuts along the existing alinement severely limited the total roadway width. Asphalt curbing and a closed drainage system were constructed in conjunction with a recent pavement rehabilitation project. This allowed for a modest widening of the travelway and elimination of an area of steep and narrow ditches, without the need to engage in major earthwork.

Use of paved shoulder, asphalt curbing, and closed drainage system along a rural minor arterial.

Clear Zones

An important consideration in defining the appropriate cross section for a particular highway facility is the width of the clear zone. As defined in Chapter IV of the AASHTO Green Book, the clear zone is ***"...the unobstructed, relatively flat area provided beyond the edge of the traveled way for the recovery of errant vehicles."***

The width of the clear zone is influenced by several factors, the most important of which are traffic volume, design speed of the highway, and slope of the embankments. The AASHTO Roadside Design Guide' is a primary reference for determining clear zone widths for freeways, rural arterials, and highspeed rural collectors based on these factors. For lowspeed rural collectors and rural local roads, the AASHTO Green Book suggests providing a minimum clear zone width of 3.0 m (IO ft). For urban arterials, collectors, and local streets with curbs, the space available for clear zones is typically restricted. [1] Roadside Design Guide, AASHTO, Washington, DC, January 1996.

Curbs

Used primarily in urban and suburban environments, curbs can serve some or all of the following functions:

- Drainage control
- Roadway edge delineation
- Rightofway reduction
- Aesthetics
- Delineation of pedestrian walkways
- Reduction of maintenance operations
- Assistance in roadside development.

There are basically two types of curbs: barrier and mountable. Flexibility in the use of either type is a handy tool for a highway designer when defining the cross section of an improvement project. Barriertype curbs are not, however, recommended for projects with

design speeds above 65 km/h (40 mph).

Curbs can be constructed from a variety of materials, including concrete, asphalt, and cut stone. Figure 6.3 illustrates a variety of commonly used barrier and mountable curbs.

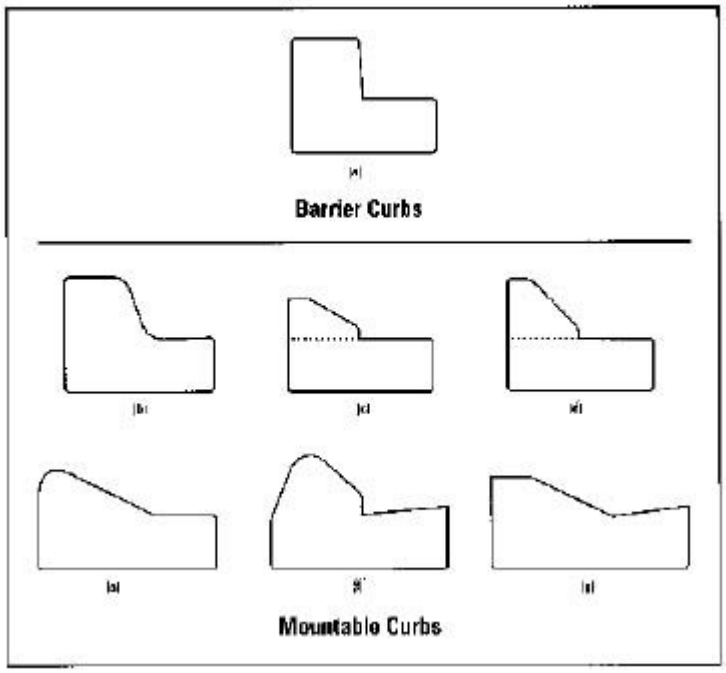
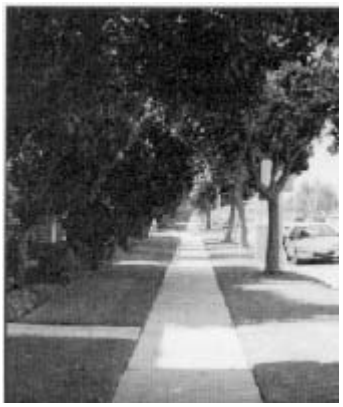


Figure 6.3 *Examples of barrier and mountable curbs.*

Sidewalks and Pedestrian Paths

The safe and efficient accommodation of pedestrians along the traveled way is equally important as the provisions for vehicles. Too often, pedestrians are a secondary consideration in the design of roadways, particularly in suburban areas. Although sidewalks are an integral part of city streets, they are much more rare in rural areas and provided only sporadically in suburban areas, despite data that suggest that providing sidewalks along highways in rural and suburban areas results in a reduction in pedestrian accidents.



Sidewalks can be located next to a planted strip or flush with the roadside edge.

When considering the placement of sidewalks, designers have several options. The sidewalk

area, such as a planted strip (usually of grass or plant material), located between the sidewalk and roadside. The pros and cons of each option should be weighed and considered by the designer, using input from the community. For example, a planted strip has these advantages:

- Pedestrians are kept at a greater distance from moving vehicles and thus are safer (in urban areas with onstreet parking, parked cars help to act as a shield for pedestrians from moving traffic, so a buffer space may not be necessary to address that concern).
- Planted strips tends to add to the aesthetics of the facility and help reduce the apparent width of hard surface space.
- Planted strips provide a space for snow storage.

Buffers, or planted strips, may have the disadvantage of requiring additional rightofway that may negatively affect restricted rightofway corridors.

Another important consideration, and one in which the designer is given some flexibility, is in the width of the sidewalk and planted strip. Typically, sidewalks in residential or lowdensity commercial areas vary in width from 1.2 to 2.4 m (4 to 8 ft). The Americans with Disabilities Act Accessibility Guidelines of August 1992 set the minimum passing width on a sidewalk at 1.525 m (5 ft) at least every 61 m (200 ft). If a planted strip is provided between the sidewalk and the curb, it should be at least 0.6 m (2 ft) wide to allow for maintenance activities. This planted strip also provides space for street lights, fire hydrants, street hardware, and landscaping.

The wider the sidewalk, the more room there is for street furniture, trees, utilities, and pedestrians. (Alexandria, VA)

Sidewalks can also provide space for street furniture and necessary traffic poles and signals; however, additional width should be added to sidewalks to accommodate these fixtures. The wider the sidewalk, the greater the number of pedestrians that can be accommodated and the less difficult it is for them to maneuver around these fixed objects. When considering the placement of objects inside sidewalks, it is important not to overlook the need to maintain as unobstructed a pathway as possible. For instance, locating utility poles to the sides and not in the center, of sidewalks is important. This detail facilitates the movements of people with disabilities as well.

Adding sidewalks to a facility where none previously existed can be beneficial to a community. When the Lincoln Beach Parkway section of the Pacific Coast Highway (U.S. Route 101) was reconstructed in the early 1990's, sidewalks were added along both sides of the facility. Not only did this result in a more aesthetically pleasing alternative to the shoulder section for the two travel lanes that previously existed, but the sidewalks made it safer for residents to walk between their homes and local commercial facilities. Residents can now interact with each other much more easily, which has fostered a higher level of community spirit.

Sidewalks can be built with a variety of shapes and materials.

(San Antonio, TX)

Pedestrian barriers can provide safety by separating pedestrian and vehicular traffic.

(Annapolis, MD)

Street trees and light fixtures are carefully lined to one side of the sidewalk to provide the widest possible space for pedestrians.

Accommodating Bicycles

Bicycles are recognized by many as a viable mode of transportation in the United States, both for commuting and recreation. Transportation designers should consider the needs of these users in the design of facilities. Basically, there are five types of bicycle facilities:

- **Shared lane** - a "standardwidth" travel lane that both bicycles and motor vehicles share
- **Wide outside lane** - an outside travel lane with a width of at least 4.2 m (14 ft) to accommodate both bicyclists and motorized vehicles
- **Bicycle lane** - a portion of the roadway designated by striping, signing, and/or pavement markings for preferential or exclusive use by bicycles and/or other nonmotorized vehicles
- **Shoulder** - a paved portion of the roadway to the right of the traveled way designed to serve bicyclists, pedestrians and others
- **Multiuse path** - a facility that is physically separated from the roadway and intended for use by bicyclists, pedestrians, and others

A multiuse path.

There are three primary factors to consider when designing facilities to accommodate bicycles and other nonmotorized vehicles:

1. What type of bicyclist is the route most likely to serve, i.e., advanced bicyclists, basic bicyclists, or children?

   Advanced bicyclists are the experienced riders who make up the majority of the current users of collector and arterial streets, wish to operate at maximum speed with minimum delays, and require sufficient space on the roadway shoulder to be treated as vehicles. Designated bicycle lanes along a roadway give riders an even greater degree of comfort along arterial and collector streets. Basic bicyclists and children generally prefer the most comfortable, although sometimes circuitous, access to destinations, using lowspeed, lowtrafficvolume streets or a separate, multiuse path.

2. What type of roadway project is involved, i.e., new construction, major reconstruction, or minor rehabilitation?

   Recommended design treatments are most easily implemented when new construction or major reconstruction is planned. Although retrofit and/or enhancement projects may be relatively limited in scope, opportunities to make at least minor improvements to better accommodate the needs of pedestrians and bicycles should be investigated. Marginal roadway improvements undertaken as part of 3R projects, such as widening the pavement area 0.3 to 0.6 m (1 to 2 ft) will enhance the roadway for bicycle use.

3. What are the current and future traffic operations and design characteristics of the route that will affect the choice of bicycle design treatments?

The shoulders on SR 313 were specifically designed to accommodate bicycle traffic.

(Moab, UT)

Six factors are recognized by transportation planners and engineers as having the greatest effect on bicycle use:

- **Traffic volume-**higher traffic volumes represent greater potential risk for bicycles.
- **Average motor vehicle operating speed**-operating speed is more important than the posted speed limit; motor vehicle operating speed can negatively affect the bicyclist's comfort unless mitigated by special design treatments.
- **Traffic mix-**the presence of trucks, buses, and other large vehicles can increase risk

and have a negative impact on the comfort of bicyclists.

- **Onstreet parking**-additional width is needed for bicycle lanes on roads that have onstreet parking.
- **Sight distance**-this must be sufficient to allow a motor vehicle operator to either change lane position or slow to the bicyclist's speed when overtaking the bicycle, primarily on rural highways.
- **Number of intersections**-the number and frequency of intersections should be considered when assessing the use of bike lanes. Intersections pose special challenges to bicycle and motor vehicle operators and require special treatments.

East Capitol Street accommodates two travel lanes, onstreet parking, and a designated bike lane in each direction.

(Washington, DC)

The highway landscape is an important part of its overall appearance.

(Papago Freeway, Phoenix, AZ)

Landscape Design and Selection of Plant Material

Landscape design is an important element in the design of all highway facilities and should be considered early in the process, so that it is in keeping with the character or theme of the highway and its environment. The AASHTO Green Book mentions three objectives of landscape design:

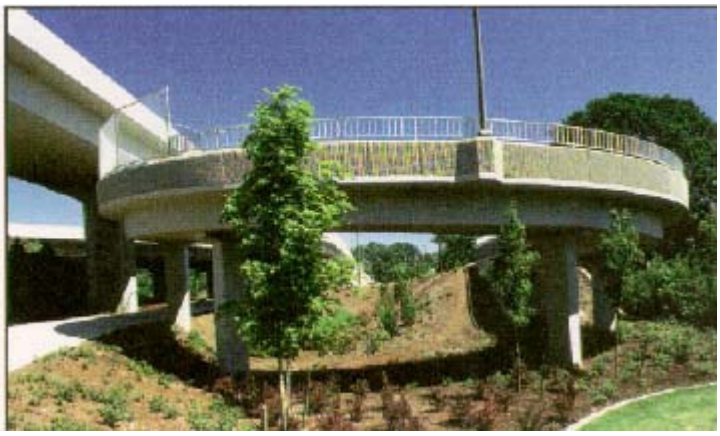
- To provide vegetation that will be an aid to aesthetics and safety
- To provide vegetation that will aid in lowering construction and maintenance costs
- To provide vegetation that creates interest, usefulness, and beauty for the pleasure and satisfaction of the traveling public

Landscape designs for urban highways and streets plays an additional role in mitigating the

many nuisances associated with urban traffic and can help a roadway achieve a better "fit" with its surroundings.

Landscape treatment is most successfully integrated into a project when considered early in the design.

(OR)



Trees

An important aspect of roadside landscape design is the treatment of trees. Singlevehicle collisions with trees account for nearly 25 percent of all fixedobject fatal accidents annually and result in the deaths of approximately 3,000 people each year. This problem is most apparent on roads that have existing trees, where designers do not have direct control over placement. For landscape projects, where the type and location of trees and other vegetation can be carefully chosen, the potential risks can be minimized.

Integrating trees into the design of a facility has many advantages. Trees provide a visual "edge" to the roadway that helps guide motorists. Trees also add to the aesthetic quality of a highway. In urban and suburban areas, trees soften the edges of arterial and collector streets. If sight distance is a concern, taller trees with lower branches that are trimmed or lowgrowing (shorter than I m [3 ft]) herbaceous and woody plants can be another option along both the roadway edge and in raised medians.

Trees add to the visual appeal of this urban street and can be placed in both medians and along roadway edges.

Trees make a difference. Compare the left side of this roadway with the right side, where the trees have been removed.

(Rt 30, Maui, HI)

It is important to select the appropriate species of tree for the highway environment. In particular, trees need to be chosen that can survive poor air quality, infertile and compacted soils, and extreme temperature fluctuations. Remember that maintenance, particularly during the first year after installation, is essential to the longterm health and viability of trees and other plants. Utilize the skills and knowledge of the city or town urban forester or arborist, the local agricultural extension service, or a landscape architect to identify the plant material that will be best suited for the location.

In addition to selecting a type of tree for its hardiness, the size and placement of trees is

another important consideration. Generally, a tree with a trunk diameter greater than 100 mm (4 in) measured 100 mm (4 in) above the ground line is considered a "fixed object" along the roadway. Because most trees grow larger than this, their placement along the roadway needs to be carefully considered. Factors that affect this decision include the design speed, traffic volume, roadway cross section, and placement of guardrail. Trees should not be placed in the clear zone for any new construction or major reconstruction, nor should they be considered safe because they are placed just outside the clear zone. The safe placement of trees to prevent errant drivers from hitting them should be made in conjunction with a highway designer who is knowledgeable about safety. However, the decision to create a clear zone that requires the removal of existing trees is an issue that should be presented to the public and addressed by the multidisciplinary team early on.

Trees are an important aspect of community identity and carry a great deal of emotional ties with the residents. If communities consider existing trees a valuable resource, alternatives to complete eradication should be pursued. These include installation of traffic barriers, lowering of the design speed, or even complete redesign of the facility to incorporate the trees. It is not unusual for a community to value one specific tree and desire to preserve it. In general, transportation designers must balance safety with other community values when considering facility design and tree preservation.

Utilities

One element of crosssection design that is often overlooked is the accommodation of public utilities. Overhead utilities typically include electric, telephone, and cable television. For new construction in urban areas, electric, telephone, and other telecommunication lines are now often placed underground.

Motor vehicle collisions with utility poles result in approximately 10 percent of all fixedobject fatal crashes in the United States annually. Utility poles also have a negative affect on the aesthetics of a roadway. It is important, therefore, whether designing in rural or urban locations, to consider accommodating utilities early in the design process.

The most desirable design solution, in terms of safety for overhead utilities, is to locate the utility poles where they are least likely to be struck by a vehicle. (The same is true for sign and luminaire supports.) The 1996 AASHTO *Roadside Design Guide*notes the following options for the location and design of utilities:

- Bury power and telephone lines underground
- Increase lateral pole offset
- Increase pole spacing
- Combine pole usage with multiple utilities
- Use a breakaway pole design
- Use traffic barriers to shield poles

Burying power and telephone lines, although the safest and most aesthetically pleasing option, is also the most expensive. For example, during the reconstruction of 1.66 km (1.03

miles) of Carson Street in the city of Torrance, CA, all the existing overhead utilities were placed underground at a cost of about $2.3 million, or approximately 37 percent of the total project cost. Because of these tradeoffs, the design and location of utilities requires public input and should be considered early in the design of each project.

Traffic Barriers

The options available to designers for traffic barriers include deciding whether or not to include them in the design and, if they are included, deciding which type to choose. The purpose of the barrier, as stated in the AASHTO Green Book, is to ***"minimize the severity of potential accidents involving vehicles leaving the traveled way where the consequences of errant vehicles striking a barrier are less than leaving the roadway."*** In addition to preventing collisions with fixed objects along the roadside, traffic barriers are themselves obstacles and have some degree of accident potential. The use of traffic barriers should consider these tradeoffs.

A wide variety of traffic barriers is available for installation along highways and streets, including both longitudinal barriers and crash cushions. Longitudinal barriers (such as guardrails and median barriers) are designed primarily to redirect errant vehicles and keep them from going beyond the edge of the roadway. Crash cushions primarily serve to decelerate errant vehicles to a complete stop (such as impact attenuators at freeway exit gore areas) .

The design of the traffic barrier is an important detail that contributes to the overall look or theme of roadway design; therefore, in addition to safety, the selection of an appropriate barrier design should include aesthetic considerations. In addition, all traffic barriers should meet crashtesting guidelines for the type of roadway being designed. Crashtesting guidelines have different levels, depending on the facility and the type of vehicles that will use the facility. For example, on parkways with restricted truck traffic, many aesthetic barriers have been designed and crash tested. The criteria used for these types of barriers are less stringent than the criteria for facilities with truck traffic. Because aesthetic considerations are usually a factor on parkways, many of these barriers are designed to add to the visual quality of the road. Even for roads that are not parkways, however, there are still many barrier designs that meet the criteria for facilities with truck traffic. Given these options, designers must balance their decisions based on safety, cost, and aesthetics.

Weathering steel is a lowcost option for designers who are trying to "blend" a barrier into the surrounding environment.

(NM 65, Montezuma, NM)

(a)

(b)

(c)

(d)

A sample of available traffic barrier designs includes:

a. A threestrand cable barrier system allowing deflections on impact of up to 4.6 m (15 ft)
b. Various steel beam barriers allowing deflections on impact of up to 1.2 m (4 ft)
c. Steelbacked timber barriers that allow deflections on impact of up to 2.4 m (8 ft)
d. New Jersey shaped concrete barriers
e. Stone masonry walls consisting of a reinforced concrete core faced with stone masonry.

(e)

An indepth discussion of the factors associated with the decision to install traffic barriers and guidance on the selection of a particular barrier design is presented in the AASHTO *Roadside Design Guide.*

A concern among some States when selecting a barrier design is cost. Aesthetic barriers might have a higher upfront cost than standard steel barriers and may be more expensive to maintain. One solution to this concern is to be consistent in the type of aesthetic barrier used throughout a State. For instance, a State might want to limit the type of barriers used to only two, an inexpensive barrier for highways where aesthetics are not a major concern and an aesthetic type for highways where visual quality is important. In this way, States can cut back on the cost to maintain multiple barrier designs.

Weathering steel guardrails are an example of an inexpensive barrier that may be considered acceptable in certain surroundings. For many States, weathering steel has been a good solution, because its rustic color helps the guardrail blend into the environment. Weathering steel has, however, had durability problems in a few areas.

These HO V lanes are restricted to buses, vanpools, and carpools carrying three or more occupants. (I84, CT)

Accommodating Transit

Highways operate as truly multimodal transportation facilities, particularly in large urban areas. Accommodating public transit and other highoccupancy vehicles (HOVs) is an important consideration. On one end of the scale, this may involve including sidewalks to allow local residents to walk to and from bus stops. As higher levels of vehicle traffic and transit usage are expected, bus turnouts may need to be considered. At the higher end of the scale, such as on major urban freeways, dedicated bus lanes and/or HOV lanes may need to be incorporated into the design. The management of the local public transit operator should be consulted during the planning stage, if possible, so that these facilities can be incorporated into the design from the beginning.

ISSUES

Some of the challenging aspects of highway design have to do with crosssection elements. Decisions that designers need to make may include the number of lanes proposed for the

improvement, the width of travel lanes and shoulder areas, the type of drainage proposed, or the desirability of including sidewalks or bicycle/pedestrian paths as part of the project.

Restricted RightofWay

Many roads currently exist that were not built to today's standards. These roads may be located in restricted rightofway corridors that have scenic or historic resources adjacent to the roadway. It is necessary to try to avoid impacting these resources when considering highway improvements.

Solution

One option, as has been discussed previously, is to reconsider the functional classification and design speed of a particular section of highway, because these decisions go a long way toward defining the basic design parameters that can be used in connection with an improvement of the facility. Lowering the design speed or changing the functional classification results in a lowering of the minimum width dimensions for the crosssectional elements.

Another option is to maintain the road as is or as a 3R project. Design criteria established by States are generally lower for 3R projects than for reconstruction projects. A third option is to seek design exceptions. Whichever alternative is chosen, the designer should try to maintain consistency in the roadway cross section. If only a small stretch of highway is located within restricted rightofway, it would be unsafe to narrow that stretch while maintaining a much higher roadway width before and after it.

A successful resolution of the design of a highway cross section was found during the planning and design for the State Route 9A project along the Hudson River in Manhattan. The existing atgrade "interim" facility had two 3.6m (12ft) lanes in each direction, separated by a 4.6m (15ft) flush median with a Jersey barrier.

The preferred alternative, which is now under construction, replaces a rather unattractive urban street, with a six to eightlane divided urban boulevard that has a landscaped median. The new design incorporates extensive landscaping and separate bikeways and pedestrian walkways. The width of the travel lanes was reduced from 3.6 m (12 ft) on the existing surface street to 3.4 meters (11 ft) on the new urban boulevard. This cross section accommodates traffic demands and dramatically enhances the physical environment of the project area. More information about this project is in the case study section of this Guide.

The Design of CrossSection Details

Some highway facilities may be designed with the greatest concern to fit into their surrounding environments, but if the details are not carefully thought out, they can still leave the impression of an unappealing roadway.

Solution

The design of all elements of the highway cross section adds greatly to its appearance. Design details include the design and width of the median and traffic barriers and the selection of plant material. All these elements contribute to the theme of the roadway and should be considered as a unit. The best method for achieving a unified look is to work with a multidisciplinary design team from the beginning of the project development process through the last detail of the design.

Details are some of the first elements users of a facility will notice. For example, designers may go through a lot of trouble to preserve vegetation along the roadway because of its importance to the community and its scenic qualities, but if designers use concrete barriers as shields in front of this vegetation, that one element may catch the users' attention.

Another option that aids designers in the details of crosssection elements is the use of computerimaging technology. The series of figures on the following page illustrates the application of various combinations of basic design elements to define a number of widening options for a portion of State Highway 23 in Rockville, MN. These options include the use of different median types and widths and incorporate different levels of rightofway acquisition.

The Minnesota DOT has found the use of such computerimaging techniques to be particularly useful in illustrating the impact of alternative design concepts on existing facilities for project area residents and businesses. Minnesota DOT has made this approach a standard element in all major project planning and preliminary engineering assignments.

With the increasing need to ensure meaningful and continuous public involvement on all such projects, the use of computer imaging to illustrate design alternatives to communities will help to alleviate potential conflicts and misunderstandings and lead to the best design decisions.

Computer visualization showing proposed design concepts of SH 23 in Rockville, MN.

Existing conditions.

Proposed continuous left turn lane design.

Proposed continuous left and rightturn lane design.

Proposed channelized and raised median design.

Chapter 8

INTERSECTIONS

Refer to Chapter XI of the AASHTO Green Book

BACKGROUND

At grade intersections are one of the most critical and most complicated elements in highway design. The efficiency, safety, speed, cost of operation, and capacity of the highway system depend on the design of its intersections. Design criteria that are used to create the most efficient roadways are easily thwarted when that roadway meets up with intersecting traffic vying for the same limited roadway space. In urban and suburban areas in particular, the capacity of signalized intersections can effectively define the capacity of the highway system. Add the need safely to accommodate bicyclists and pedestrians with varying degrees of mobility, and the need to handle left and right turns, and the challenge faced by designers becomes even more complicated. *Page*

The Basics of Intersection Design

As stated in the AASHTO Green Book, the main objective of intersection design is to:

...reduce the severity of potential conflicts between motor vehicles, buses, trucks, bicycles, pedestrians, and facilities, while facilitating the convenience, ease, and comfort of people traversing the intersections.(p. 627)

A "T" intersection.

(Wethersfield, CT)

Intersection design can vary widely in terms of size, shape, number of travel lanes, and number of turn lanes. Basically, there are three types of atgrade intersections, determined by the number of intersecting legs, topography, traffic patterns, and the desired type of operation. Each roadway radiating from an intersection is called a "leg." Most intersections have four legs, which is generally accepted as the maximum recommended number for safety and capacity reasons. The three basic intersection types are:

- "T"intersection (three approach legs)
- Fourleg intersection
- Multileg intersection (five or more approach legs).

INTERSECTION DESIGN ELEMENTS

As is the case with other aspects of the highway design process, designers can use a wide range of intersection design elements in combination to provide both operational quality and safety. These include:

- Traffic islands to separate conflicting vehicle movements
- Street closures or realinements to simplify the number and orientation of traffic movements through an intersection
- Separate left and rightturn lanes to remove slowmoving or stopped vehicles from through traffic lanes
- Medians and channelized islands to provide refuge for pedestrians and bicyclists out of the vehicular traveled way.

The following paragraphs summarize of primary intersection design guidelines.

Angle of Intersection

Crossing roadways should intersect at 90 degrees, if possible, and at no less than 75 degrees. Skew angles of 60 degrees or less may need geometric countermeasures, such as reconstruction, or traffic control, such as signalization.

Horizontal and Vertical Alinement

The alinement before and through an intersection must promote driver awareness, operate well under frequent braking, and be easy to drive, so that the navigational task is not too difficult. The Green Book has recommended values for the minimum stopping sight distance needed based on the design speed of the approach roads. The design of intersections should also incorporate provisions for intersection sight distance.

Plant materials in medians enhance an intersection's appearance.

Medians

Medians, either raised or painted, provide a physical separation between opposing traffic flows. They also provide a refuge area for pedestrians to wait at crossing locations. Medians are a standard form of channelization at rural roadways and urban street intersections carrying four or more lanes. There are two principal functions of medians specifically located at intersections:

- Separating opposing traffic flows
- Providing storage for vehicles making left and Uturns and vehicles crossing traffic and shielding pedestrians

Another important benefit of a median in an urban area is that it offers a green space for trees and lowgrowing plant material. Careful consideration is needed, however, to select the proper location and type of plantings. Particularly in narrow medians, plantings can create maintenance problems, and trees can cause visual obstructions if not carefully located.

Field studies and accident analysis provide similar findings on the operational and safety effects of the median width at intersections.' At rural unsignalized intersections, accidents and undesirable driving behavior decrease as the median width increases. In contrast, at suburban signalized and unsignalized intersections, accidents and undesirable driving behavior increase as the median width increases. [1] *Median Intersection Design*, NCHRP Report 375, Transportation Research Board, National Research Council,

National Academy Press, Washington, DC, 1995.

In other words, at rural unsignalized intersections, wider medians are preferable to narrower medians, unless signalization or suburban development is anticipated. At suburban intersections, the median should not be wider than necessary to accommodate the median leftturn treatment needed to serve current and future traffic volumes.

Example of a median landscape treatment.

Left Turn Lane Warrants and Design

Leftturn lanes may provide added safety and efficiency at both unsignalized and signalized intersections. At signalized intersections, leftturn lane warrants are based on the magnitude of turning movements, accident experience, and general capacity relationships. The design values for leftturn approach tapers, turn bay tapers, and storage lane lengths are based on deceleration in the lane, storage in the lane, or a combination of both. At signalized intersections, the required length of storage bay is a function of signal cycle length.

An example of a simple safety improvement is the addition of a painted leftturn lane at a rural intersection. This action not only reduces the potential for yearend accidents, but also provides drivers with a comfortable way to make a left turn. However, as is discussed in the Issues section of this chapter, the addition of a left turn lane can also affect resources along the side of the road or change the character of the road corridor. These are tradeoffs for designers to consider.

Leftturn lanes can improve safety and capacity.

RightTurn Lane Warrants and Design

Depending on rightturn traffic volumes, accident history, highway speed, and availability of rightofway, rightturn lanes may be appropriate for some intersections. As with leftturn lanes, the taper and storage length design is based on deceleration, storage requirements, or both.

Corner Radius Design

The design for an intersection corner radius is based on the selection of a reasonable design vehicle for the specific location. Design vehicles can range from large (tractortrailer combinations) to small (private autos). There are a number of tradeoffs involved in this decision. Designing the corner radius for large vehicles requires more open intersections, and increases cost, and such intersections are more difficult to mark, signalize, and operate. In addition, the larger the dimensions of the radius, the greater the distance across the intersection from one side of the street to the other. This can make crossing the intersection much more difficult for pedestrians, particularly people who are elderly or have mobility impairments. Conversely, designing the corner radius for small vehicles can create operational problems should a significant number of larger vehicles have to use the intersection. Table 8.1 presents some general guidelines to assist in the selection of the appropriate design vehicle for various highway types.

Table 8.1

Guidelines for the Selection of Intersection Design Vehicles

Highway Type	Design Vehicle
Rural Highways	

Interstate/freeway ramp terminals	WB-50
Primary arterials	WB-50
Minor arterials	WB-50 OR WB-40
Collectors	SU-30
Local Streets	SU-30
Urban Streets	
Freeway ramp terminals	WB-50
Primary arterials	WB-50 or WB-40
Minor arterials	WB-40 or B-40
Collectors	B-40 or SU-30
Residential/local streets	SU-30 or P

Source: *Intersection Channelization Design Guide,* NCHRP Report 279, 1985. Note: WB50 =semitrailer combination, large; WB40 =semitrailer, intermediate; SU30 =single unit truck; B40=single unit bus; P=passenger car.

The actual radius or curb return design can be accomplished in one of four ways. Simple circular radius designs are the most commonly encountered design on lowspeed collector and local streets and in downtown areas. Alternative design methodologies include the use of symmetrical threecentered compound curves, asymmetrical threecentered compound curves, or simple radius curves with tapers. These designs better fit the paths of turning vehicles, thereby providing more efficient operations.

Table 8.2 illustrates some of the operational characteristics associated with a range of intersection corner radius dimensions for simple radius curves. This can be used as a guide in determining the appropriate radius design.

Table 8.2

Operating Characteristics of Intersection Corner Radii

Source: *Intersection Channelization Design Guide,* NCHRP *Report* 279, 1985.

Note: P=passenger car; SU=single unit truck; WB50=semitrailer combination large

Corner Radius	Operatoinal Characteristics
<5	Not appropriate for even P-design vehicles
10	Crawl-speed turn for P vehicles
20-30	Low speed turn for P vehicles: crawl-speed turn for SU vehicles with minor lane encroachment
40	Moderate speed turn for P vehicles; low-speed turn for SU vehicles with

	minor lane encroachment
50	Moderate-speed turns for all vehicles up to WB-50

Designers made use of two traffic islands for rightturning vehicles at this "T" intersection.

(Bloomfield and Windsor, CT)

Traffic Islands

Traffic islands, or channelization, represent one of the most important tools in the design of intersections. Islands can either be painted directly on the roadway surface or they may be raised. Painted or "flush" channelization may be used on highspeed highways to delineate turning lanes, in constrained locations, or where snow removal is a concern. Raised islands, with appropriate channels or curb ramps to accommodate users of wheelchairs or other related devices, should be used where the primary function of the island is to shield pedestrians, locate traffic control devices, or prohibit undesirable traffic movements.

There are two basic types of traffic islandscorner islands that separate rightturning vehicles and median or divisional islands that separate opposing traffic flows on an intersection approach. Although islands in general provide a safe refuge for pedestrians, corner islands that separate rightturning vehicles in particular may make crossing intersections more difficult for pedestrians. These islands tend to widen the crossing distance. They can also make it more difficult for pedestrians to maneuver through the intersection, see oncoming traffic making right turns, and know where to cross, if the islands are not clearly delineated.

Traffic Control Devices

Traffic control devices are installed to designate rightofway at intersections and to provide for the safest and most efficient movement of all traffic, including pedestrians and bicyclists. The standards established in the latest edition of the *Manual on Uniform Traffic Control Devices for Streets and Highway*s (MUTCD), published by the FHWA, must be followed to determine proper intersection control.

A multiway stop installation is useful as a safety measure at some locations.

NEW INTERSECTION DESIGN CONCEPTS

In recent years, a new intersection design concept has evolved to provide an alternative to the traditional T, fourleg, and multileg intersections. This design concept is called a roundabout.

Modern roundabouts are increasingly being recognized as design alternatives to the use of traditional traffic signals for intersections for arterials. They improve both safety and efficiency for pedestrians and bicyclists, as well as motor vehicles. So far, roundabouts have been built in such States as California, Colorado, Maryland, Nevada, Florida, and Vermont. These roundabouts are different from rotary or traffic circles that have been used in the United States for a number of years to give entering traffic the rightofway and encourage higher design speeds.

The modern roundabout is designed to slow entering traffic and allow all the traffic to flow through the junction freely and safely. Unlike the older rotary design, entering vehicles must yield the rightofway to vehicles already in the circle. A deflection at the entrance forces vehicles to slow down. Traffic signals are not used, and pedestrians cross the streets at marked crosswalks.

Modern roundabouts can reduce delay and increase safety.

(Cecil Co., MD)

All vehicles, including bicycles, are forced to slow down and pay attention when entering a modern roundabout. (Cecil Co., MD)

The average delay at a roundabout is estimated to be less than half of that at a typical signalized intersection. Decreased delay may mean that fewer lanes are needed. Signalized intersections often require multiple approach lanes and multiple receiving lanes, which leads to a wider road.

Perhaps the greatest advantages of roundabouts are their urban design and aesthetic aspects. Roundabouts eliminate the clutter of overhead wires and signal poles and allow signage to be reduced. They can be distinctive entry points into a community or mark a special place. The central island offers an opportunity for a variety of landscape designs, as well.

ISSUES

Each of the various components of intersection design can cause conflicts between the need for a safe and adequate design, on the one hand, and the need to minimize impact to the surrounding physical and human environments, on the other. In addition, the need to accommodate pedestrians and bicyclists can sometimes cause conflicts with the need to provide an efficient operating environment for vehicular traffic.

Accommodating Pedestrians

The safe and efficient accommodation of pedestrians at intersections is equally important as the provisions made for vehicles. Pedestrian movements should be provided for and their locations controlled to maximize safety and minimize conflicts with other traffic flows. Too often, pedestrians are a secondary consideration in the design of roadways, particularly at intersections in suburban areas.

Solution

For all but a few exceptions, pedestrian crosswalks should be located at intersections, should have appropriate curb ramps for accessibility, and should be clearly marked. Two parallel painted lines generally are not enough of a distinguishing marking. Often motorists confuse these lines with the stopping line and pull right up to the edge of the crosswalk. At a minimum, some type of striping or painting inside the crosswalk area is recommended to improve safety. Many cities and suburban areas have gone beyond this and added aesthetic treatments to their crosswalk designs, including use of the following:

- Distinguishing materials for crosswalks, such as brick, patterned concrete, and cobblestone
- Granite edging
- Colored pavement or solid painting of crosswalks.

A welldesigned pedestrian crosswalk.

(Annapolis, MD)

A clearly delineated and elevated crosswalk, signage, and appropriate turning radius design contribute to this pedestrianfriendly intersection.

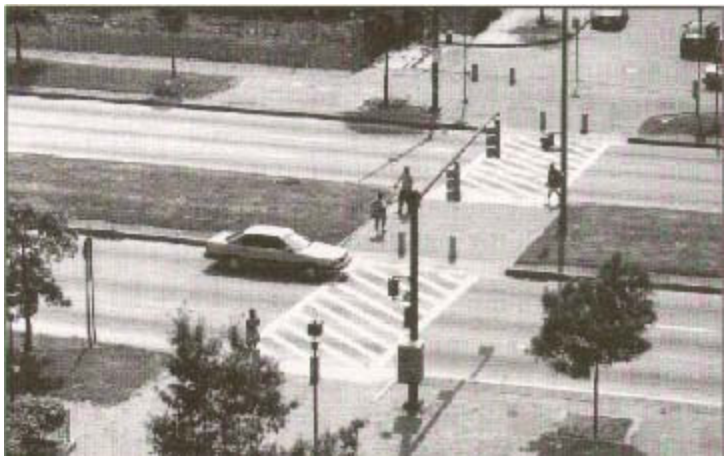
Pedestrian signals integrated with a combination traffic signal support and street light pole.

Pedestrian signals should be used in conjunction with vehicular traffic signals at all signalized intersections where pedestrians are likely to be present. Push buttons can be used at isolated intersections or where vehicular demand warrants maximizing the time for vehicular movement through the intersection. Fixedtime traffic signals with relatively short cycle lengths are more appropriate in urban or downtown areas.

A raised pedestrian crosswalk and narrow corner radius design discourage nonlocal traffic and high speeds in this residential neighborhood.

(Carbondale, IL)

Painted diagonal pavement markings.



Appropriate Corner Radius Design

As mentioned earlier, there are many tradeoffs involved in the selection of the appropriate type and dimension of radius designs. Issues arise when all of the factors involved in the design decision are not considered. For example, if the primary intent of the intersection design is to move traffic through as quickly as possible, a higher corner radius would be selected. The dimensions of the corner radius send a message to drivers entering residential neighborhoods regarding the speed they can drive and should be designed with this in mind. Encouraging fast speeds around intersection corners into residential areas will undermine efforts to lower operating speeds within the neighborhoods themselves. In addition, faster speeds create an unsafe environment for pedestrians.

Pedestrians rely on intersection locations to cross roadways. At the same time, by adding left and rightturn lanes and large turning radii, intersections can be and often are the widest parts of roadways. The distance pedestrians must cross is an important consideration in design.

Addition of LeftTurn Lanes

A common conflict arising from the use of channelization, or separation of traffic into definite paths of travel by traffic islands, medians, or pavement markings, is the addition of leftturn lanes. While there is no doubt that this can create a smoother flowing intersection, especially on twolane roads, the addition of a leftturn lane can significantly widen the width of the roadway, unless there is a median. This can change the character of an area, affect adjacent

development or resources, and cause the road to be out of scale with its surroundings.

Solution

In cases where a leftturn lane is truly needed to improve safety and operational efficiency in a constricted rightofway, there may not be an easy solution to this issue. Sometimes the addition of leftturn lanes depends on new growth and development along the corridor. If the scenic, historic, or cultural resources are such that any additional widening would affect these resources, it may be that decisions made at the land use stage of planning should be reconsidered. Limiting development along the corridor will limit traffic volumes and the need for additional leftturn lanes. Another option is to lower traffic volumes on the roadway through other means, including creating or widening alternative routes.

Painted turn lanes improve traffic safety and capacity at intersections but may be a tradeoff for communities that do not want a widened roadway.

The most important point is that the necessity of the leftturn lane must be carefully determined. If it is truly needed, designers can use the flexibility available to them in the applicable geometric design standards to try to minimize any additional widening of the traveled way and limit the impact on adjacent resources to the fullest extent possible.

Aesthetics of Traffic Signals and Sign Hardware Supports

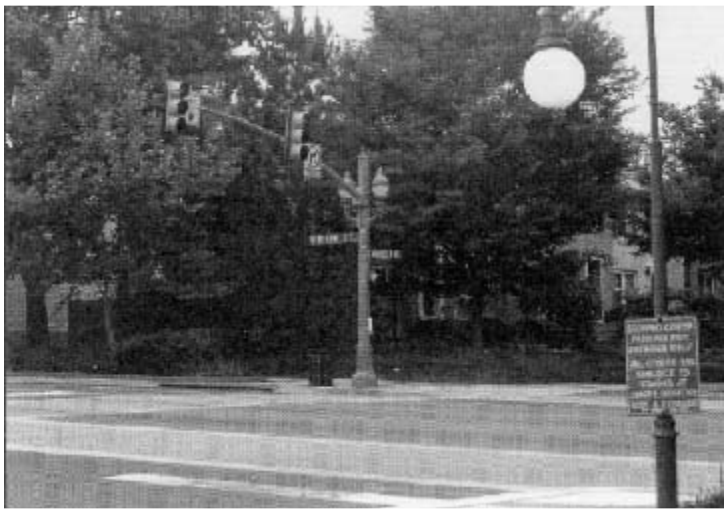
Traffic control devices are beneficial in improving the safety and efficiency of intersections. In addition, there are many alternative design treatments that meet MUTCD and crashworthy standards and can be used to fit the design into the surrounding context.

Solution

Traffic control device supports should be designed to be safe and compatible with their surroundings. This may be a particular concern for designers in scenic or historic settings. Options for the designer include:

- Span wire installations for traffic signals that allow the poles to be set back, out of the direct line of sight
- Combination poles that carry street lights and traffic signals

- Decorative traffic signal poles
- Tapered mast arm traffic signal designs in lieu of span wire.



Combination poles carry traffic signals, signs, and street lights. This type of design can be very appropriate in certain settings. (Falls Church, VA)

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