OVERVIEW OF CROSS SECTION DESIGN ELEMENTS

L.E. Hall, University of New Mexico
R.D. Powers, Federal Highway Administration
D.S. Turner, University of Alabama
W. Brilon, Ruhr-University Bochum
J.W. Hall, University of New Mexico

INTRODUCTION

The International Symposium on Highway Geometric Design was conducted to analyze and compare design policies and procedures among different countries. The goal was to help designers and researchers better understand worldwide practice, and thus provide a platform for continued research (and implementation of that research) to improve highway geometric design.

This overview paper provided an introduction to the session devoted to cross section elements. In providing an overview of this important topic, the paper addressed the following components:

- A brief discussion of the most prominent cross section elements,
- The results of a limited international survey to identify representative parameters and procedures for these elements,
- An introduction to roadside design, with an emphasis on safety and the clear recovery area concept,
- A synopsis of each of the papers that was presented during this session,
- A summary emphasizing the emerging cross section design issues and research needs.

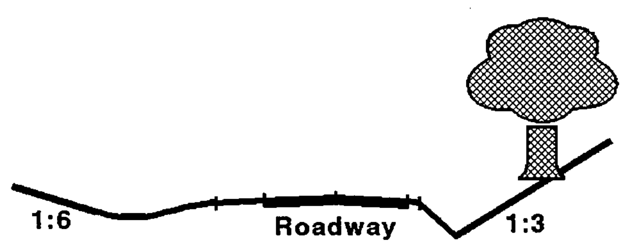
IDENTIFICATION OF CROSS SECTION FEATURES

The cross section of a roadway is the view obtained in a section between the right-of-way lines cut perpendicular to the direction of travel along the road. It includes features on the traveled portion of the road used by vehicular traffic as well as on the roadside. There is strong consensus in the highway engineering community that the design of cross section elements influences a roadway's cost, operation, and safety.

The most obvious element of a roadway is the travel lane; its width constitutes a basic cross section characteristic. A related parameter, the number of lanes, may be increased to accommodate the travel demand for the roadway. Even on the simplest highway, with one lane of travel in each direction, a minimal clearance separating the opposing movements is often provided. The cross section examination of a highway also detects the slope across the travel lane; small slopes are employed on tangent sections to facilitate drainage, while higher cross slopes, referred to as superelevation, are employed on horizontal curves to help counteract lateral acceleration.

Cross section elements continue into the area immediately adjacent to the traveled roadway. Shoulders are often utilized for design and operational reasons. Both the width and slope of shoulders are cross section characteristics. On some facilities, curbs are used to restrict traffic movements or to facilitate drainage. Medians may be installed to separate the opposing directions of traffic on multilane highways; both the presence and the width of a median are cross section design elements. In urban environments, pedestrian sidewalks are common cross section features. Some countries, such as Germany and Japan, include bicycle lanes among roadway cross section elements.

Roadway Cross Section



The portion of the cross section outside the region normally used for vehicular and pedestrian travel may serve multiple purposes, including future expansion and recovery room for errant vehicles. The clearance distance to essential, rigid fixed objects is a very important cross section parameter. The roadside slope and ditch design affect maintenance and the potential for vehicle recovery in this area. The application of breakaway object designs, roadside barriers, and crash attenuators is often considered in cross section plans.

This paper will summarize the standards employed in the United States and in a number of other countries for common cross section features. Designs for these elements in the United States are based principally on the American Association of State Highway and Transportation Officials' (AASHTO) policy on geometric design (*1*) and roadside design guide (*2*), although both documents grant considerable leeway to the designer in selecting appropriate values for a particular location. Some design standards apply only to new street and road construction, while others may be applicable to both new construction and the increasingly more common roadway reconstruction (*3*). The practices for other countries were obtained from standard excerpts provided by engineers in these countries, from a questionnaire survey distributed to highway designers in these countries, and from the technical literature. Because of the diverse sources, information was not available for every country for each cross section element.

STANDARDS FOR CROSS SECTION DESIGN

Most countries have developed sets of geometric design criteria for different roadway classifications. Although the countries responding to the survey indicated they use a range of 0 to 15 categories, the most common schemes identified 4 classes of roads, based on such factors as access control and traffic volume. Japan has developed one of the most detailed categorization systems; their expressway classifications are presented in Table 1, and their non-expressway classifications are shown in Table 2. Another unique and thoughtful approach to classification is that of Germany, which utilizes an indirect but systematic method of relating ADT, design speed, access control, and other factors to cross section elements.

All of the countries responding to the survey indicated that cross section elements change with increasing design speed.

In many cases, these were step functions, with standards changing at 10 or 20 km/h increments. Table 3 shows the speeds cited as crucial in this regard. The average response to this question was six speed classification categories. The US employed the largest number of categories, perhaps due to the maturity and complexity of its highway design criteria, and also to its recent conversion to the metric system.

TABLE 1 Japan's Structural Standard Categories -- Expressways

<table>
<tr><th rowspan="2">Type (Area)</th><th rowspan="2">Class</th><th rowspan="2">Design Speed (km/h)</th><th rowspan="2">Access Control</th><th colspan="4">Designed Daily Volume, veh/day</th></tr>
<tr><th>>30,000</th><th>30,000 - 20,000</th><th>20,000 - 10,000</th><th>< 10,000</th></tr>
<tr><td rowspan="7">1 (Rural)</td><td>1</td><td>120</td><td>F</td><td>N.E. in level terrain</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">100</td><td rowspan="2">F, P</td><td>N.E. in mountainous terrain</td><td colspan="2">N.E. in level terrain</td><td></td></tr>
<tr><td colspan="2">E. in level terrain</td><td></td><td></td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">80</td><td rowspan="2">F, P</td><td></td><td colspan="2">N.E. in mountainous terrain</td><td>N.E. in level terrain</td></tr>
<tr><td colspan="2">E. in mountainous terrain</td><td colspan="2">E. in level terrain</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">60</td><td rowspan="2">F, P</td><td colspan="2"></td><td colspan="2">N.E. in mountainous terrain</td></tr>
<tr><td colspan="3"></td><td>E. in mountainous terrain</td></tr>
<tr><td rowspan="2">2 (Urban)</td><td>1</td><td>80</td><td>F</td><td colspan="4">N.E. & E. except in the center of Metropolis</td></tr>
<tr><td>2</td><td>60</td><td>F</td><td colspan="4">E. in the center of Metropolis</td></tr>
</table>

Note: N.E.: National Expressway
E.: Expressway other than N.E.
F: Full control of access
P: Partial control of access
N: Non-control of access

TABLE 2 Japan's Structural Standard Categories -- Non-Expressways

Type Area	Class	Design Speed, km/h	Access Control	Designed Daily Volume (veh/ day) > 20,000	20,000-10,000	10,000-4,000	4,000-1,500	1500-500	< 500	Remarks
3, Rural	1	80	P, N	N.H. in level terrain						
	2	60	N	N.H. in mountain terrain	N.H., level					
				Pe., Mu., level terrain						
	3	60 50 40	N		N.H., mountain terrain		N.H., Pe., level terrain			
				Pe.,Mu. in mountain terrain			Mu. in level			
	4	50 40 30	N				N.H. & Pe., mountain			
								Mu., level		
							Mu., mountain			
	5	40 30 20	N						Mu., level or moun-tain	1-lane road
4, Urban	1	60	P, N	N.H.						
				Pe., Mu.						
	2	60 50 40	N				N.H.			
						Pe., Mu.				
	3	50 40 30	N				Pe.			
							Mu.			
	4	40 30 20	N						Mu.	1-lane road

Note: N.H.: National Highway
P: Partial control of access
N: Non-control of access
Pe.: Prefectural Road
Mu.: Municipal Road

TABLE 3 Critical Speeds for Design of Cross Section Elements

Country	Critical Speeds for Changes in Cross Section Elements
Brazil	60, 80, 100, 120-140 km/h
China	40, 60, 80, 100 km/h
Czech Republic	50, 60, 70, 80, 100, 120 km/h
Denmark	10-20, 30-40, 50-70, 80-100, 120 km/h
Germany	Each street category has a combination of design speeds and sets of standard cross section elements
Hungary	60, 80, 100, 120 km/h
Indonesia	20, 30, 40, 50, 60, 80, 100 km/h
Japan	20, 30, 40, 50, 60, 80, 100, 120 km/h
Netherlands	60, 80, 90, 100, 120 km/h
Poland	30, 40, 50, 60, 70, 80, 100, 120 km/h
Portugal	60, 80, 100, 120-140 km/h
South Africa	30, 50, 60, 70, 80, 90, 100 km/h
Spain	50, 60, 70, 80, 100, 120 km/h
Sweden	40, 60, 80, 100, 120 km/h
Switzerland	0-20, 30-40, 50-70, 80-100, 120 km/h
United Kingdom	50-60, 80-120, 100-120 km/h
USA	30, 40, 50, 60, 70, 80, 90, 100, 110, 120 km/h
Yugoslavia	40, 50, 60, 70, 80, 100, 120, 120-140 km/h

Lane Width

A fundamental feature of roadway cross section is the width of a travel lane, which must be sufficient to accommodate the design vehicle, allow for imprecise steering maneuvers, and provide clearance for opposing flow in adjacent lanes. Truck widths (2.6 m in the US, 2.55 m in Europe) define the absolute minimum lane width on those roadways where trucks are expected. Additional space to accommodate rear-view mirrors and the lateral movement of vehicles within the lane requires a lane width of at least 3.0 m. According to AASHTO (*1*), other factors that influence the selection of lane width include the design speed and volume, the presence or absence of shoulders, horizontal alignment, and the presence of oncoming traffic. The desirable lane width for major roads in the US is 3.6 m. Germany recognizes that drivers tend to shy away from the centerline of an undivided highway, so they widen the lane bordering oncoming traffic by 0.25 m. Table 4 shows typical lane width design values for various countries. The survey found that lane widths vary from nation to nation, but within reasonably narrow ranges: typically 3.5 to 3.75 m for freeways, 3.0 to 3.75 m for arterials, and 2.75 to 3.65 m for local roads. Additional information on lane widths is presented in the Symposium papers by W. Brilon and F. Weisner, which includes cross section dimensions for ten countries, and P. Velhonoja *et al.*, which discusses experiments with wide-lane roads.

Number of Lanes

The selection of the number of lanes for a roadway is based primarily on the projected traffic volume for the facility. The Highway Capacity Manual (*4*) provides widely accepted methods for estimating the amount of traffic that can be accommodated on facilities with different numbers of lanes. AASHTO (*1*) standards also recognize the issue of lane balance; at freeway entrances and exits, for instance, the number of lanes after the ramp can equal the number of approaching lanes or be smaller by one lane. The basic number of lanes should remain constant throughout a substantial length of the facility; when lanes are added or dropped, the change should be made no more than one lane at a time. Auxiliary lanes may be added for appropriate short sections (e.g., between interchanges on a freeway or at intersections on an arterial) to facilitate operations by accommodating turning movements and weaving maneuvers and by providing hill climbing lanes

TABLE 4 Typical Lane Width Design Values

Country	Roadway Classification		
	Freeway	Arterial	Minor or Local
Brazil	3.75 m	3.75 m	3.0 m
Canada		3.0 to 3.7 m rural collector	3.0 to 3.3 m rural local
China	3.5 to 3.75 m	3.75 m	3.5 m
Czech Republic	3.5 to 3.75 m	3.0 to 3.5 m	3.0 m
Denmark	3.5 m	3.0 m	3.0 to 3.25 m
France	3.5 m	3.5 m	3.5 m
Germany	3.5 to 3.75 m	3.25 to 3.5 m	2.75 to 3.25 m
Greece	3.5 to 3.75 m	3.25 to 3.75 m rural suburban	3.0 to 3.25 m
Hungary	3.75 m	3.5 m	3.0 to 3.5 m
Indonesia	3.5 to 3.75 m	3.25 to 3.5 m	2.75 to 3.0 m
Israel	3.75 m	3.6 m	3.0 to 3.3 m
Japan	3.5 to 3.75 m	3.25 to 3.5 m	3.0 to 3.25 m
Netherlands	3.50 m	2.75 to 3.25 m	3.10 to 3.25 m
Poland	3.5 to 3.75 m	3.0 to 3.5 m	2.5 to 3.0 m
Portugal	3.75 m	3.75 m	3.0 m
South Africa	3.7 m	3.1 to 3.7 m rural 3.0 to 3.7 m urban	2.25 to 3.0 m
Spain	3.5 to 3.75 m	3.0 to 3.5 m	3.0 to 3.25 m
Sweden		3.75 m rural undivided	
Switzerland	3.75 to 4.0 m	3.45 to 3.75 m	3.15 to 3.65 m
United Kingdom	3.65 m	3.65 m	3.0 to 3.65 m
USA	3.6 m	3.3 to 3.6 m	2.7 to 3.6 m
Venezuela	3.6 m	3.6 m	3.0 to 3.3 m 2.7 m if ADT<500
Yugoslavia	3.5 to 3.75 m	3.0 to 3.25 m	2.75 to 3.0 m

TABLE 5 Typical Lane Slope Design Values

Country	Roadway Classification		
	Freeway	Arterial	Minor or Local
Australia		2%, 2.5%, 3%	
Brazil	2% concrete 2.5% asphalt	2% concrete 2.5% asphalt	2% concrete 2.5% asphalt
China	1.0 to 2.0%	1.0 to 2.5%	1.5 to 4.0%
France	2.5%	2.5%	2.5%
Germany	2.5 to 7.0%	2.5 to 7.0%	2.5 to 7.0%
Greece	2.5 to 8.0%	2.5 to 8.0%	2.5 to 8.0%
Hungary	2.5%	2.5%	2.5%
Israel	2.0%	2.0%	2.0%
Japan	2.0%	1.5 to 2.0%	1.5 to 2.0%
Poland	2.0%	2.0%	2.0%
Portugal	2.0% concrete 2.5% asphalt	2.0% concrete 2.5% asphalt	2.0% concrete 2.5% asphalt
South Africa	2.0 to 3.0%	2.0 to 3.0% rural 2.0 to 2.5% urban	2.0 to 2.5%
Spain	2.0%	2.0%	2.0 to 3.0%
Sweden		2.5 to 3.0%	
United Kingdom	2.5% (max. super-elevation 7%)	2.5% (max. super-elevation 7%)	2.5% (max. superelevation 7%)
USA	1.5 to 2.0%	1.5 to 3.0%	1.5 to 6%
Venezuela	2%	2%	2% paved, 4% gravel
Yugoslavia	2.5 to 7.0%	2.5 to 7.0%	2.5 to 7.0%

for trucks. Because of poor safety records, three-lane rural roads (with one lane for travel in each direction and a center lane for passing maneuvers) are no longer approved for use in some countries, including the United States and South Africa. New German standards, however, allow for such roads provided the center lane is divided into lengthy sections (800 to 2000 m) that permit passing in alternate directions in successive sections; the Nordic countries have also been experimenting with such roads for several years. Reversible lanes are sometimes used in the United States to accommodate heavy peak traffic flows; one or more lanes are designated for one direction of travel during certain hours of the day, and for the opposite direction during other hours. These lanes may be part of a standard roadway or may be located in the median of a freeway and be physically separate from the other lanes.

Cross Slope

A cross slope is used on traffic lanes to promote drainage of surface water. According to AASHTO (*1*), the cross slope may be either planar or rounded (parabolic), although the latter should be used only on two-lane roads or for the central two lanes of a multilane facility. Divided highways can be treated as two separate roadways, each having a center crown bordered by slopes to the outside of the pavement, or each direction of travel can be sloped unidirectionally. When three or more lanes are to be sloped the same direction, the two closest to the crown line should be constructed at the minimal slope, and on each successive pair of lanes the cross slope can be increased by 0.5 to 1.0%. AASHTO allows superelevation rates of 10 to 12%, but recommends rates of less than 8% in areas where snow and ice may appear on the roadway. Because of lower speeds and constraints of adjacent property, superelevation on urban arterials is generally 4% or less. Table 5 contains the standard lane cross slopes cited in the international survey. It is interesting to note that there is a relatively high degree of consistency in the responses. It appears that a 2.0 to 2.5% cross slope is the most widely accepted value for design, and that there is little or no variation by roadway class.

Shoulders

Shoulders are used for emergency stopping, for parking of stopped vehicles, and for lateral support of the subbase, base, and surface courses of the travel lanes. On some roadways, shoulders may be used for pedestrian and bicycle traffic where no separate paths are provided for those functions. On divided highways, shoulders are generally provided on both the median and the outside of the roadway. Shoulders should be wide enough to adequately fulfill their purpose, but excessive width encourages drivers to use them as an additional travel lane. Where shoulder widths are minimal, Australian design standards recommend the installation of pull-off areas at intervals, particularly where there are low fills (≤0.5 m) or in transitions between cut and fill sections. The survey responses displayed in Table 6 demonstrate that there is no international consensus on appropriate shoulder widths. For freeways and certain types of divided highways, some nations use different widths for inside and outside shoulders, while others do not. Almost all countries use narrower shoulders for classifications of roadways with lower design speeds. Several studies, summarized in Reference (*5*), have found that wider shoulders produce significant safety benefits.

AASHTO (*1*) recommends that shoulders be differentiated from the travel lanes by the use of color or texture to discourage their use as travel lanes and to alert drivers when they depart from the travel lane. Visual contrast can be accomplished by using different colors of pavement for shoulders and through lanes, or by striping and pavement markings; texture contrast can be attained by varying the aggregate content of the pavement. Many jurisdictions have experienced a safety benefit from the placement of corrugated depressions (rumble strips) on the shoulder (*6*).

Shoulder Slopes

Cross slopes should be used on shoulders to provide adequate drainage, but care must be taken to keep the slope small enough to accommodate proper vehicular use of the shoulder. In some countries shoulders are sloped at the same rate as the adjacent roadway lane, while in others the shoulder slope can be as much as 2% greater than the adjoining lane. Table 7 shows representative design values from various countries. When superelevation is employed, AASHTO (*1*) recommends that all or part of the outside shoulder be sloped upward at the same rate or a slightly lower rate than the adjacent lane.

Medians

Medians separate opposing streams of traffic; they provide a recovery area for out-of-control vehicles, an emergency stopping area, and space for storage and speed changing by turning vehicles. They are also used to preserve space for a future increase in the number of lanes on the facility. On urban streets, medians can be used as two-way turn lanes. Shrubbery or anti-dazzle fences in the median can help minimize headlight glare from oncoming vehicles. If insufficient space is available for an adequate median, barriers can be installed between opposing traffic streams. Sweden's standards, for example, call for a minimum median width of 12 m on motorways; recognizing the reality of cost constraints, however, medians as narrow as 0.8 m are allowed when equipped with bilateral guardrail. Because of their relatively poor safety record, undivided four-lane highways are no longer built in Germany, and medians will be incorporated in all new designs.

Table 8 shows standard median widths reported by survey respondents from various countries. Less is known about design of median widths for safety and operations than for many other cross section elements, and this is reflected in the variations shown in the table. For example, minimum freeway median width ranges from 1.5 m to over 4.5 m. In general, consensus values have not been reached for median widths for any category of roadway.

Curbs

Curbs are used on roadways for a variety of purposes, such as facilitating drainage, channelizing islands, and separating sidewalks from vehicle lanes. Mountable curbs are designed so that vehicles can traverse them when necessary, while barrier curbs are relatively high and steep to discourage vehicles from leaving the roadway. Canada defines a third category, semi-mountable curbs, which can be crossed in an emergency whereas mountable curbs can be traversed easily. Survey respondents described mountable curbs ranging in height from 25 mm to 150 mm, with slopes (rise:run) varying from 1:16 to 2:3 in different countries. Barrier curbs, on the other hand, ranged from 100 mm high to 420 mm high, with slopes of 1:3 or more. AASHTO (*1*) reports that vehicles striking barrier curbs at high speeds are likely to overturn or become airborne; consequently, the use of such curbs on freeways or high-speed roadways is discouraged in the US. The international survey indicated that most nations limit the use of curbs to drainage and channelization purposes, and that such uses are normally restricted to low speed or urban facilities.

TABLE 6 Typical Shoulder Width Design Values

Country	Roadway Classification		
	Freeway	Arterial	Minor/Local
Brazil	3.0 m left 1.0 m right	2.5 m	1.5 to 2.5 m
Canada		1.5 to 3.0 m, rural collector	1.0 m, rural local
China	2.0 to 3.25 m	0.75 to 2.5 m	0.5 to 1.5 m
Czech Republic	1.5 to 2.5 m	0.25 to 1.5 m	
Denmark	3.5 m	2.5 m	1.0 m
France	3.0 m + 0.75 m earth	2.5 m + 0.75 m earth	2.5 m + 0.75 m earth
Germany	1.5 m (+ up to 2.5 m gravel)	1.5 m (+ up to 2.5 m gravel)	1.0 to 1.5 m
Greece	1.5 m	1.5 to 2.0 m, rural suburban	1.5 m
Hungary	4.0 m	2.0 to 2.5 m	0.75 to 1.5 m
Indonesia	1.5 to 4.0 m	1.0 to 3.0 m	0.25 to 2.5 m
Israel	3.0 m	3.0 m	2.0 to 2.5 m
Japan	> 2.5 m	> 1.75 m	> 0.5 m
Netherlands	1.25 m	0.20 to 0.45 m	0.15 to 0.45 m
Poland	2.5 to 3.0 m	2.0 to 2.75 m	1.0 to 1.5 m
Portugal	3.0 m left 1.0 m right	2.5 m	1.5 to 2.5 m
South Africa	> 2.0 m	rural 1.0 to 3.0 m; urban not essential	
Spain	0.5 to 1.0 m left 2.5 to 3.0 m right	1.5 to 2.5 m	0.5 to 2.0 m
Sweden		0.75 m, rural undivided	
Switzerland	1.0 to 2.5 m	0.5 to 1.5 m	no shoulders
United Kingdom	3.3 m left 1.0 m right D2 only	1.0 m left 1.0 m right	no shoulders
USA	3.0 to 3.6 m right 1.2 to 3.6 m median	1.2 to 2.4 m	0.6 to 2.4 m
Venezuela	2.4 to 3.0 m right 0.9 to 1.2 m left	1.8 to 2.4 m	not specified
Yugoslavia	1.5 m	1.35 to 1.5 m	1.2 to 1.35 m

TABLE 7 Typical Shoulder Slope Design Values

Country	Roadway Classification		
	Freeway	Arterial	Minor/Local
Australia		up to 2.0% more than adjacent lane, rural	
Brazil	2.5 to 4.0%	2.5 to 4.0%	2.5 to 4.0%
China	1.0 to 2.0%	1.0 to 2.5%	1.5 to 4.0%
Czech Republic	2%	2%	
Denmark	1.5%	1.5%	1.5%
Germany	6.0%	6.0%	6.0%
Greece	6 to 12%	6 to 12%	6 to 12%
Hungary	5%	5%	5%
Indonesia	3%	3%	4.0 to 6.0%
Israel	2.0 to 4.0%	2.0 to 4.0%	2.0 to 4.0%
Japan	> 2%	> 2%	> 2%
Poland	2%	6 to 8%	6 to 8%
Portugal	2.5 to 4.0%	2.5 to 4.0%	2.5 to 4.0%
South Africa	2.0 to 3.0%	2.0 to 3.0%; 4.0% if unpaved	
Spain	same as lane	same as lane	same as lane
Switzerland	same as lane	same as lane	no shoulders
United Kingdom	same as lane	same as lane	same as lane
USA	2 to 6%, right shoulder	2 to 6%	2 to 8%
Venezuela	same as lane	same as lane	same as lane
Yugoslavia	6.0%	6.0%	6.0%

Sidewalks and Bicycle Lanes

Sidewalks are provided mainly in urban areas. AASHTO (*1*) standards specify widths of 1.2 m to 2.4 m for both residential and commercial areas, assuming a 0.6 m planting strip is located between the sidewalk and the curb at the edge of the traveled way; in the absence of such a planting strip, the sidewalk width should be increased by 0.6 m. When sidewalks are constructed along rural roads, they should be well removed from the traffic lanes. In some installations, pedestrians and bicyclists may share a lane separate from the vehicular lanes of a roadway; if volumes are sufficient, however, both sidewalks and bicycle lanes may be built. German standards specify bicycle lanes of width 2.25 m to 2.5 m, separated from motorized traffic lanes by 1.75 m to 2.0 m.

CONFERENCE PAPERS ON CROSS SECTION DESIGN ELEMENTS

Of necessity, current design standards must rely on the knowledge that has been gained in the past; if these standards are to improve significantly, rather than incrementally, the highway engineering community must seek meaningful ways to extend the existing knowledge base. The International Symposium on Highway Geometric Design Practices was conducted for such a purpose. The

TABLE 8 Typical Median Width Design Values

Country	Roadway Classification		
	Freeway	Arterial	Minor/Local
Brazil	2.0 to 6.0 m	2.0 to 6.0 m	2.0 to 6.0 m
China	1.5 to 3.0 m	1.5 to 3.0 m	
Denmark	3.0 m	2.0 m	
France	12 m; 3 m curbed	12 m; 3 m curbed	12 m; 3 m curbed
Germany	3.0 to 3.5 m	3.0 to 3.5 m	no median
Greece	3.0 to 3.5 m	3.0 to 3.5 m	
Hungary	3.0 m	1.5 to 3.0 m; 2.5 m curbed	
Indonesia	2.0 to 2.5 m	1.5 to 2.0 m	1.0 m
Israel	3.0 m	2.5 m for 4-lane roadways	
Japan	> 4.5 m	> 1.75 m	> 1.0 m
Netherlands	12.0 m	3.0 to 4.5 m	
Poland	3.5 to 5.0 m	3.0 to 5.0 m	
Portugal	2.0 to 6.0 m, curbed	2.0 to 6.0 m, curbed	2.0 to 6.0 m, curbed
South Africa		9.2 m rural; 1.5 m urban, curbed	none
Spain	10 to 12 m; 3.0 m curbed		
Switzerland	3.5 m; 2.0 m curbed		
United Kingdom	4.0 m	4.0 m rural; 1.8 to 3.0 m urban	
USA	minimum 3.0 m	1.2 to over 20 m	
Venezuela	not defined	not defined	not defined
Yugoslavia	4.0 m	4.0 m	3.0 m

breadth and depth of innovative topical coverage on cross section design elements presented at this conference suggested numerous opportunities for enhancing traffic efficiency and safety though improved roadway design and operation. The papers in this session summarized the efforts of researchers from twelve countries to better understand the interaction among such roadway features as lane and shoulder widths, shoulder surface, number of lanes, existence of medians, and clear roadsides. Their individual and collective contributions will help advance the state-of-the-art in this area.

The types of papers presented in this session of the symposium fell into four categories. The first group involved an overview of roadway cross section elements. In addition to this session overview paper, R.D. Powers et al. presented a synopsis of the relationship between safety and roadside elements (*7*). The paper discusses the development of the "forgiving roadside" theory and illustrates this theory by describing applications to roadside slopes, drainage structures, roadside hardware, and traffic barriers.

Of the remaining papers, the second category involved the dynamic widths of trucks (one paper), the third category involved accident studies (two papers), and the final category involved the search for new roadway types and new design dimensions (three papers).

Dynamic Widths of Vehicles

In their study of truck widths and paths, Berard and Bourion analyze the dynamic width of trucks in France, Germany, and Belgium, taking into account not only the physical dimensions of a vehicle, but also its normal lateral movement within the lane. This effective width is examined in relation to various geometric features such as lane width, roadway curvature, and embossed edge markings; observations were made of isolated trucks as well as ones being passed by other vehicles in adjacent lanes. A limited program of road markings and embossings was used to affect truck lateral placement. The results will be useful for selecting optimal values for that basic cross section element, lane width.

Accident Studies

Bester and Makunje examined "The Effect of Rural Road Geometry on Safety in Southern Africa" by relating accident statistics to the cross section elements of 27,000 km of rural roads in three separate studies. Although the project's results were generally similar to those of previous studies in the US, a major difference was noted with respect to the safety benefit of paved shoulders. Engineers are thus reminded that research findings from one country do not necessarily transfer into another cultural setting.

In "Safety Effects of Cross-Section Design on Rural Multi-Lane Highways," Wang, Hughes, and Stewart describe their development of a Poisson regression model that can be used to predict accident rates for alternative designs of rural multi-lane roadways. The model may also be used to estimate accident reductions that can be expected as a result of proposed improvements to cross section elements on existing facilities. Among the variables used in formulating the model were the frequency of intersections per mile (both with and without turn lanes), shoulder width, and roadside hazard rating.

Search for "Intermediate Road" Types and New Design Dimensions

Brilon and Weiser's comprehensive paper "Recent Developments in Highway Cross Section Design in Germany" outlines the newest revisions to that country's guidelines for the design of roadway cross sections. Prescribed values for lane widths, medians, and shoulder widths are being updated. The paper discusses the rationale behind the newly approved three-lane roadway. The authors offer a critical reminder that consideration must be given to the economic benefits of selecting cross section elements, in terms of both construction costs and potential accident savings.

The new German intermediate cross section (three-lane road design) is the outgrowth of an eight-year study described by Durth in "Implementation of Intermediate Cross Sections." The innovative key feature of the design is a center lane that changes its direction every few kilometers, giving vehicles traveling in each direction frequent opportunities to pass slower vehicles without conflicting with opposing traffic. Such roadways require less right-of-way and are less expensive to construct than four-lane facilities; they have also exhibited good accident rate and traffic flow characteristics. In addition, Durth presents findings on the placement of median barriers on existing four-lane undivided roadways, facilities that have a relatively poor safety record in Germany.

Preliminary results from an evaluation of experimental intermediate highway designs are presented in "The Operational and Safety Effectiveness of New Road Types -- Experiences from the Nordic Countries" by Velhonoja, Rehnström, Poulsen, and Hovd. Since the late 1980s Finland, Sweden, Denmark, and Norway have been examining both three-lane roads and wide-lane roads (two 5.5 m lanes in opposing directions, with a total pavement width of 13.0 m). Sweden, for example, found notable differences in the percentage of dangerous or "suspect" passing maneuvers on three-lane roads, wide-lane roads, and ordinary two-lane roads. Interviews show that drivers like the experimental roadways. The paper provides a preliminary comparison of speeds, accidents, and injury and fatality rates for the different roadway types, although the data bases are still too small for conclusive results.

SUMMARY

There is convincing evidence that cross section design has a significant effect on roadway operations and safety. While the international survey of highway cross section design practice and parameters found numerous differences among countries, there was an interesting degree of consistency in certain areas. Perhaps because cross section design is a fundamental and relatively mature topic, there was general consensus on several basic parameters, including lane width and road surface cross slope. The survey found that these topics were relatively stable and that the international design community selects values within a fairly narrow range. By contrast, other subjects, particularly roadside issues such as the appropriate embankment slopes and criteria for barrier usage, vary considerably from one country to another.

The sharing of experiences and analyses through this symposium affords the opportunity for highway designers to benefit from the expertise of others, and in turn to create safer roadways and roadsides. The process is inherently a slow one, since revised design standards are implemented gradually as roadways are improved one kilometer at a time. Nevertheless, the materials presented at this symposium can guide and facilitate this process by helping to establish a consensus on the most critical future directions for research and practice in the design of cross section elements for new

facilities and the retrofit treatment of potentially adverse components of existing streets and highways.

Based on the papers presented in this session and the limited survey of international practices, it appears that current research needs may be generalized as shown below:

- The relationship between cross section elements and accident rates/severities.
- The relationship of cross section elements to traffic operations and capacity.
- The selection of reduced cross section design parameters to diminish construction and maintenance costs.
- Design of roadside elements for safety and efficiency.
- Development of criteria for intermediate roadway types capable of handling traffic volumes above those of two-lane roads but below those of freeways (approximately 12,000 to 24,000 vehicles per day).

Although individual nations may have interests different from the preceding list, these topics appear to offer the greatest potential for substantial improvement in the design of cross section elements. It would be most desirable if the international community could approach them with a united purpose of sharing information and progress toward the goal of continuously improving the world's roadway system.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of John M. Mason and Chris Poe in the design of the international survey, and the participation in the survey of the following individuals: Erich Marx of Austria, Ross Walker of Canada; František Lehovec of the Czech Republic; Wang Fujian, Li Fang, and Geio-Xing Peng of the Peoples Republic of China; Ole Djurliuus and Steen Ogstrup of Denmark; Jean-Michel Pont of France; Rudiger Lamm of Germany; Basil M. Psarianos of Greece; Kovâcshâzy Frigyes and Csatsa Koren of Hungary; Karl Lennart Bang of Indonesia; Abi Polus of Israel; Mitsuhiro Nakagaki of Japan; John P. Boender of The Netherlands; Hab. Marian Tracz and St. Gaca of Poland; Joao Cardoso of Portugal; M. Gullon of Spain; Christo J. Bester and Herman Joubert of South Africa; Erich Ch. Boppart and Andreas Gantenbein of Switzerland; Mike Garnham of the United Kingdom; Ray Krammes of the U.S.A.; Pedro Andueza and Freddy A. Mulino-Betancourt of Venezuela; and Vera Mijuskovic and Zarko Atanaskovic of Yugoslavia.

REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO), *A Policy on Geometric Design of Highways and Streets*, 1990.
2. AASHTO, *Roadside Design Guide*, 1988.
3. *Designing Safer Roads*. Special Report 214. TRB, National Research Council, Washington, D.C., 1987.
4. *Highway Capacity Manual*, Third Edition, Transportation Research Board Special Report 209, 1994.
5. Zegeer, C. V., and J. A. Deacon, "Effect of Lane Width, Shoulder Width, and Shoulder Type on Highway Safety," in *Relationship Between Safety and Key Highway Features*. TRB State of the Art Report 6, 1987.
6. Harwood, Douglas W., *Synthesis of Highway Practice 191: Use of Rumble Strips to Enhance Safety*. TRB, National Research Council, Washington, D.C., 1993.
7. Powers, R.D., J.W. Hall, L.E. Hall, and D.S. Turner, "The 'Forgiving Roadside Design of Roadside Elements," presented at the International Symposium on Highway Geometric Design Practices, August 30, 1995.