Geometric Design of Low-Cost Roads in Developing Countries

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The geometric design process involves selecting the alignment and cross section of a road to meet users' needs. The background and approach to developing a guide for the geometric design of roads in developing countries are described. The approach recognizes that road and driving conditions in developing countries often differ from those in the industrialized countries in terms of (*a*) the traffic mix between commercial vehicles and private cars, as well as between motorized and nonmotorized vehicles; (*b*) the rate and nature of road accidents; and (*c*) the level of economic development and its implications for roads. An iterative approach to design is proposed including the following steps: (*a*) identifying traffic flow, terrain type and road function, leading to a choice of "design class"; (*b*) selecting trial alignments; (*c*) identifying alignment elements that are of a lower geometric standard than that of the chosen design class; and (*d*) estimating approach speeds for the above elements. If they are acceptably consistent, the design goes forward to economic evaluation; if not, the alignment may be amended or the standards relaxed with appropriate measures for safety. The thrust of the approach has been to develop a design methodology that emphasizes the economic aspects of geometric design. The standards recommended tend to be lower than many of those in common use. Recommended standards include maximum carriageway widths of 6.5 m with shoulders for use by nonmotorized traffic, roads with 5-m carriageways to carry up to 400 vehicles per day where 1.0-m shoulders may be used for passing, roads of 2.5 to 3.0 m for very low flows of traffic, with room for passing, and horizontal radii as low as 15 m. The guide itself was published by the Transport Research Laboratory as Overseas Road Note 6.

The geometric design process involves selecting the alignment and cross section of a road to efficiently meet the needs of the users. Predetermined design standards are often used. These standards are intended to satisfy two interrelated objectives:

1. To provide acceptable levels of safety and comfort for drivers, and
2. To provide efficient and economic design.

Standards in Developing Countries

Historically, geometric design standards used in developing countries have been based on those in industrialized countries. A study carried out by the then Transport and Road Research Laboratory (TRRL) (*1*) considered the application of the American (*2*), Australian (*3*), and British (*4*) standards to developing countries. The study concluded that roads and driving conditions in developing countries were sufficiently different from those in industrialized countries to merit further consideration. In particular, differences were identified in the following significant areas:

- The traffic mix between commercial vehicles and private cars as well as often between motorized and nonmotorized vehicles,
- The rate and nature of road accidents, and
- The level of economic development and the implications of this development on the function of roads being provided.

As a result of this study, the U.K. Overseas Development Administration (ODA) commissioned Roughton and Partners to carry out further research and studies. The goal was to produce guidance on geometric design specifically for low-volume roads in developing countries. The results of the studies were published by Boyce et al. (*5*), and the resulting design guide was issued as TRRL Overseas Road Note 6 (*6*). This paper is based on the results of that work.

The costs of road construction can be substantial. In developing countries, it is particularly important that economic solutions be found. However, in many developed countries, design standards have been set on the basis of the need to ensure safety, which has often led to high-cost designs, even though the precise relationship between the high standards and accidents has not been established. The approach adopted for ODA has concentrated on the development of a design process that emphasizes the economic aspects of geometric design.

Approach to Design

General

Drivers are usually provided with safety and comfort by development of a consistent alignment so that they do not face an unexpected change. This alignment includes adequate sight distances for the prevailing speeds and road surfaces, road space for vehicle maneuvers, and clear signing and road marking. A road on which a driver can see ahead a sufficient distance to stop safely is likely safe for other road users. Segregation of road users with different characteristics and objectives is also beneficial to safety.

Efficient design requires that the costs of construction match the level of expected benefit. As construction costs increase when a road alignment is made straighter and wider with reduced gradients, the additional benefits must also increase. Economic benefits can be expected in reduced vehicle operating costs, savings in travel time, and reductions in accidents. The latter two benefits assume that values of travel time and accidents can be determined and that the effects of variations in geometric design on accidents can be predicted.

A key issue in the application of design standards is the interaction between such standards and the characteristics of driver behavior, particularly speed.

Design Standards

Design standards can provide an essential base for decision making if they are applied with appropriate understanding of economics and flexibility. The essence of the process is to develop roads that meet a functional objective closely related to the level of traffic. The standard will be related to traffic volume and characteristics, terrain, and the function of the road. Potential hazards must be identified at an early stage and treated in the geometric design process.

The recommended road standards shown in Tables 1 and 2 are linked by design speed, which varies with terrain and design class and level of flow. A mountainous terrain with a low level of traffic would have a lower design speed. However, design speeds arbitrarily linked to function are not the basis for design decisions.

Standards for alignment use the minimum values normally allowed. However, in many situations, terrain and other circumstances are such that minimum values need never be applied and link speeds are substantially above design speed values. The most economic designs often do not involve the use of minimum standards. Levels of traffic may be such that the benefits gained from wider, straighter, shorter roads may offset the necessary extra construction costs. To ensure safe operation, the final alignment must incorporate additional procedures into the design process. These procedures are discussed in the following section.

Design Process

An outline of the design process, which is intended to result in sound economic design, is shown in Figure 1. The design involves the following steps:

1. Traffic flow, terrain type, and road function are defined, and a design class is chosen;
2. Trial alignments are selected (a road consists of discrete geometric elements, contiguous groups of which are combined to form sections; design is undertaken over sections with minimum lengths of about 1 km;
3. Elements of lower geometric standard are identified and compared with the standards of the design class chosen; and
4. Estimates of approach speeds are made for the geometric design elements identified above; if they are consistent, the design goes forward to economic evaluation; if not, the road alignment may be amended or

TABLE 1 Road Standards

ROAD FUNCTION	DESIGN CLASS	TRAFFIC FLOW* (ADT)	SURFACE TYPE	WIDTH (m)		MAXIMUM GRADIENT (%)	TERRAIN/DESIGN SPEED (km/h)		
				CARRIAGE-WAY	SHOULDER		MOUNTAINOUS	ROLLING	LEVEL
Arterial	A	5,000-15,000	Paved	6.5	2.5	8	85	100	120
	B	1,000-5,000	Paved	6.5	1.0	8	70	85	100
	C	400-1,000	Paved	5.5	1.0	10	60	70	85
Collector	D	100-400	Paved/ Unpaved	5.0	1.0+	10	50	60	70
Access	E	20-100	Paved/ Unpaved	3.0	1.5+	15	40	50	60
	F	< 20	Paved/ Unpaved	2.5/3.0	Passing Places	15/20	N/A	N/A	N/A

* The two way traffic flow is recommended to be not more than one Design Class step in excess of first year ADT.

\+ For unpaved roads where the carriageway is gravelled, the shoulders would not normally be gravelled: however, for Design Class D roads, consideration should be given to gravelling the shoulders if shoulder damage occurs.

TABLE 2 Speed-Related Design Parameters

DESIGN SPEED (km/h)	STOPPING SIGHT DISTANCE (m)	MINIMUM CURVATURE VALUES					MINIMUM SAFE OVERTAKING SIGHT DISTANCE (m)*
		HORIZONTAL (m)		VERTICAL CURVES (m)			
		PAVED (10% SUPERELEVATION)	UNPAVED (ZERO SUPERELEVATION)	CREST K TO OBJECT ON ROAD	CREST K TO ROAD SURFACE	SAG K FOR COMFORT	
Two Lane							
120	230	450	-	120	250	22.6	590
100	160	320	-	60	125	13.1	430
85	120	210	-	30	70	8.1	320
70	85	130	190	16	35	4.8	240
60	65	85	125	10	20	3.5	180
50	50	60	80	5	11	2.2	140
40	35	30	40	3	6	1.3	Not applicable
30	25	15	20	1.5	3	0.7	Not applicable
Single Lane							
60	130	85	125	25	20	3.5	
50	100	60	80	15	11	2.2	
40	70	30	40	7	6	1.3	
30	50	15	20	4	3	0.7	

* These values are the normal minimum assuming that an overtaking vehicle may safely abandon the manoeuvre if an opposing vehicle comes into view. The values should be available continuously in all places where overtaking is permitted.

Note : The following assumptions have been made in calculating the above :

- Reaction time of 2 sec.
- Eye height of 1.05m. Object height of 0.2m for stationary object on the road and 1.05m for approaching vehicle. (Zero object height values have been included for use where it is necessary to see the road surface, eg. approaching a ford or drift.) The values for single lane roads have been based on the assumption that approaching vehicles should be able to stop safely before colliding.
- The following values of side and longitudinal friction factor were taken to estimate acceptable values of horizontal curvature for both paved and unpaved conditions.

Design speed (km/h)	120	100	85	70	60	50	40	30
Side friction factor	0.15	0.15	0.18	0.20	0.23	0.25	0.30	0.33
Longitudinal friction factor	0.33	0.37	0.40	0.43	0.47	0.50	0.55	0.60

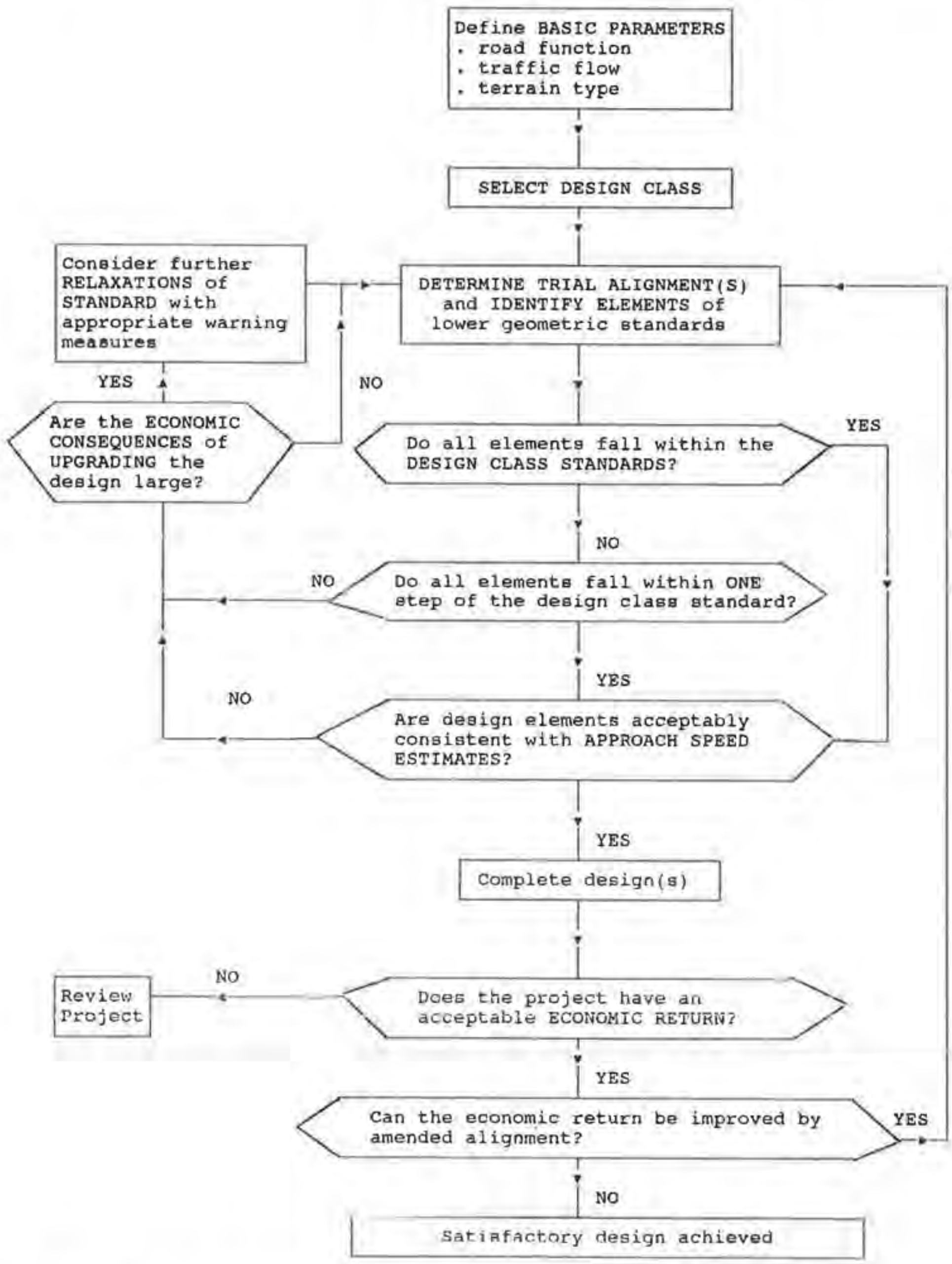

FIGURE 1 Design process.

the standards relaxed with the appropriate measures taken for safety.

Road Function

Each interurban road may be classified as arterial, collector, or access. Figure 2 and Table 1 demonstrate this classification.

Arterial roads are the main routes connecting national and international centers. Traffic on these roads is generated at the urban centers and from interurban areas through the collector and access road systems. Trip lengths are usually relatively long and levels of traffic and speed relatively high. Geometric standards must enable efficient traffic operation under these conditions because vehicle-to-vehicle interactions may be high.

Collector roads link traffic to and from rural areas, to adjacent urban centers, or to the arterial road network. These roads have intermediate traffic flows and trip lengths; the need for high geometric standards is therefore less important.

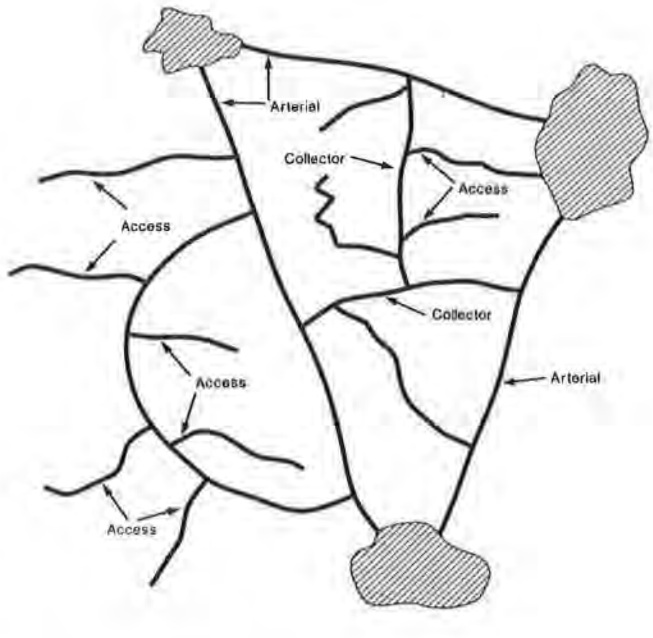

FIGURE 2 Road hierarchy and function.

Access roads are the lowest level in the network hierarchy. Traffic is light and aggregated in the collector road network. Geometric standards may be low and need only provide appropriate access to the rural agricultural, commercial, and population centers served. Most of the total movements will be nonmotorized traffic.

The hierarchy shown in Figure 2 will have many overlaps of function, and clear distinctions will not always be apparent on functional terms. This hierarchy should not be confused with the division of administrative responsibilities, which may be based on historic conditions.

It is inappropriate to design the lowest design class of road on the basis of geometric standards. The sole criterion of acceptability is the achievement of an appropriate level of access. In these situations, design should be based on minimum values of the radius, width, and gradient for the passage of a suitable design vehicle.

Design Flow

Within the functional hierarchy, traffic is aggregated as it moves from access to collector to arterial road, and levels of flow are normally correlated with road type. However, flow levels vary between countries and regions. Designation of a road by functional type should not lead to overdesign for the levels of traffic actually encountered. Designs that are not cost-effective reduce the likelihood that roads will be built, which results in wasting important national resources.

Design Classes A to F have associated bands of traffic flow, as shown in Table 1. The range of flows extends from fewer than 20 to more than 15,000 motorized vehicles per day, excluding motorcycles, and covers the design conditions for all single-carriageway roads.

The levels of flow at which design standards change are based on the best evidence available. However, the somewhat subjective boundaries should be treated as approximate to account for the uncertainties inherent in traffic estimation and economic variability. Therefore, design flows should normally be constrained to no more than one design class step higher than the annual average daily traffic (ADT) in the first year. A road with a first-year traffic flow of 390 vehicles per day rising to 1,100 vehicles per day should be constructed to Design Class C rather than Design Class B geometry (see Table 1). The design flow band in this case is 400 to 1,000 vehicles per day. Design to the higher Design Class would result in an overdesigned facility during most of the life of the road and could provide a solution that was not cost-effective. If the initial flow were 410 vehicles per day, design would still be to Design Class C. It is particularly important that roads not be overdesigned on the basis of high traffic growth rates, which are normally uncertain in developing countries.

Composition

In some situations, heavy vehicles have a greater effect on congestion than light vehicles. However, no attempt has been made to use passenger car unit (pcu) equivalent values, as these can vary substantially with composition and conditions. The relative effects of heavier vehicles vary with level of flow, geometry, and vehicle performance, and well-researched, consistent values are not available for the range of flows covered in this design guide. All flows are presented as ADT values. However, high percentages of heavy vehicles in a traffic stream may require consideration of enhanced standards, particularly carriageway width standards.

Capacity

Congestion increases with increased traffic flow when there is no safe passing opportunity. The result is long journey times, increased vehicle operating costs, and sometimes more accidents as frustrated drivers take risks.

Practical capacity is usually estimated to have been reached when the level of congestion becomes "unacceptable." Capacity is affected by increased proportions of heavy vehicles, greater unevenness in directional flows, reduced passing opportunities, animal-drawn vehicles, and pedestrian activity. Normally acceptable practical capacity is about 1,500 to 2,000 vehicles per hour. This may be increased substantially by the provision of short sections of climbing and passing lanes.

Terrain

A simple classification of "level," rolling," or "mountainous" has been adopted and is defined by subjective description and the average ground slope. The average ground slope is measured as the number of 5-m contour lines crossed per kilometer on a straight line that links the two ends of the road section. However, where the corridor for the road is already known, counting contours within the corridor could lead to a more appropriate terrain classification. Definitions of the classification terms follow.

- **Level** (0 to 10 five-meter ground contours per kilometer): Level or gently rolling terrain with largely unrestricted horizontal and vertical alignment. Minimum values of alignment are seldom necessary. Roads follow the ground contours for the most part; amounts of cut and fill are very small.
- **Rolling** (11 to 25 five-meter ground contours per kilometer): Rolling terrain with low hills introducing moderate levels of rise and fall with some restrictions on vertical alignment. While low-standard roads can follow the ground contours with small amounts of cut and fill, the higher standards require more substantial amounts of cut and fill.
- **Mountainous** (more than 25 five-meter ground contours per kilometer): Rugged, hilly, and mountainous with substantial restrictions in both horizontal and vertical alignment. Higher-standard roads generally require large amounts of cut and fill.

In general, construction costs are greater as the terrain becomes more difficult. Higher standards become less justifiable or achievable in these situations than for roads in flat or rolling terrain. Drivers should also expect lower standards in such conditions and adjust their driving accordingly to minimize the risk of accident. Design speed therefore varies with terrain.

Cross Section

Roads should be wide enough to safely and efficiently carry traffic but no wider than necessary to minimize cost of construction and maintenance. Recommended values are given in Table 1, and typical cross sections are shown in Figure 3.

For access roads with volumes of traffic lower than 100 ADT, single-lane operation is adequate since there is small probability that vehicles will meet. Passing can be achieved at reduced speeds in designated passing zones or on shoulders. If sight distances are adequate for safe stopping, cars can pass without hazard, and the overall loss in efficiency brought about by the reduced speeds will be small. It is not cost-effective to widen the running surface in such circumstances—a basic width of 3.0 m is normally sufficient. In some situations, even 2.5 m is adequate.

On roads with traffic volumes of 100 to 1,000 ADT, the amount of passing increases and pavement widening becomes worthwhile operationally and economically. However, with the generally high cost of capital for construction in developing countries and the relatively low cost of travel time, reductions in speed when approaching vehicles pass remains acceptable for such traffic levels. Running surface widths of 5.0 and 5.5 m are recommended. For arterial roads with traffic volumes of more than 1,000 ADT, a running surface 6.5 m wide will allow vehicles in the opposite direction to pass safely without needing to move laterally in their lanes or slow down.

Shoulders are recommended for all but the lowest design class, and these should normally be paved when the carriageway is paved. Shoulders are intended to perform three main traffic functions:

- To provide additional maneuvering space on roads of low functional classification and traffic flow,

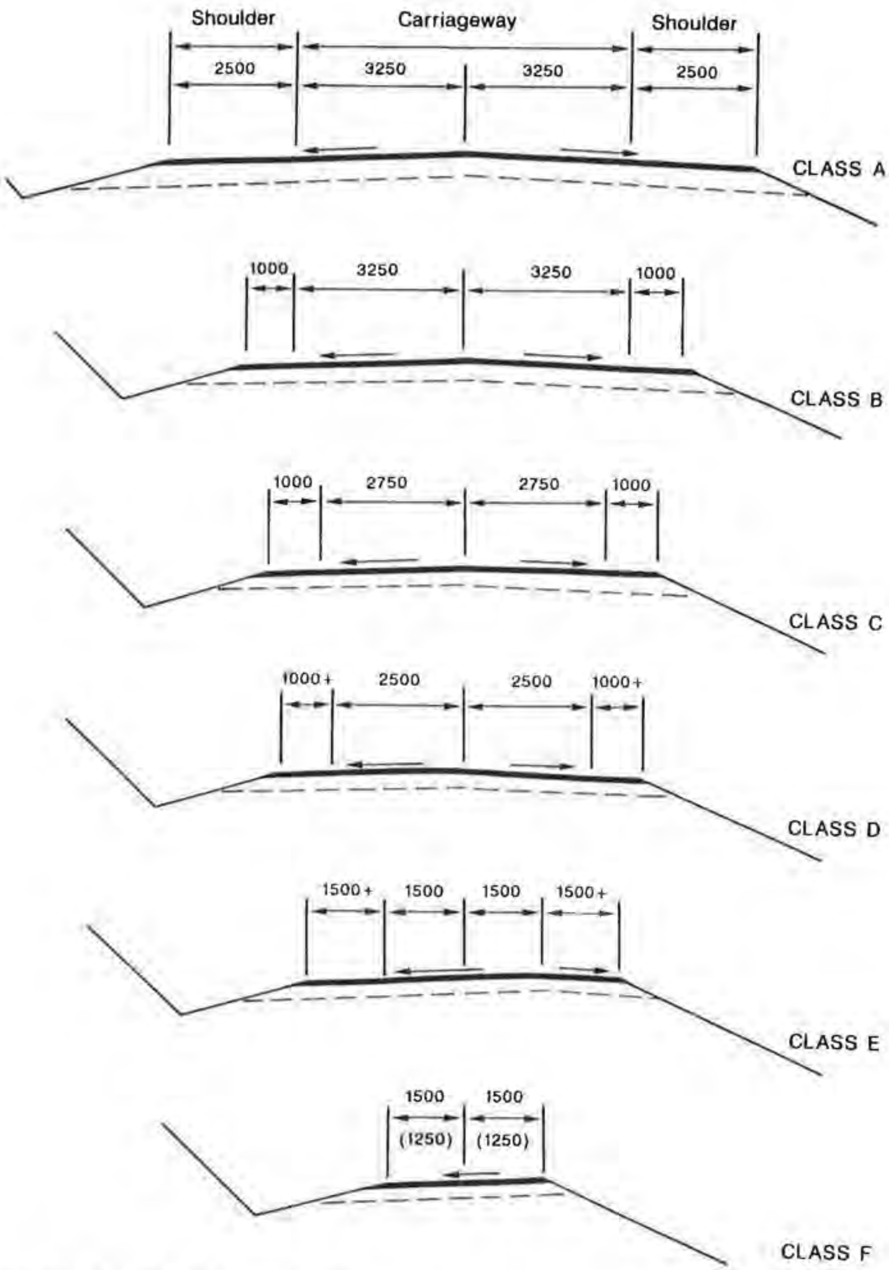

FIGURE 3 Typical cross section.

- To provide parking space at least partly off the carriageway for vehicles that have broken down, and
- To enable nonmotorized traffic to travel with minimum encroachment on the carriageway.

Additionally, it may be desirable to provide sufficient width for two-way movement during road work.

The lowest design class with a width of 3.0 (2.5) m is not adequate for passing and overtaking. Passing zones must be provided. The increased width in such zones should be enough to allow two trucks to pass (i.e., a minimum of 5.0 m total width). Vehicles would be expected to stop or slow to a very low speed.

Normally, passing zones should be located every 300 to 500 m, depending on the terrain and geometric conditions. Sight distances, the likelihood of vehicles meeting between passing zones, and the potential difficulty of backing up should be considered. In general, passing zones should be constructed at the most economic locations as determined by terrain and ground condition—such as transitions from cut to fill—rather than at precise distance intervals.

The length of individual passing zones will vary with local conditions and the sizes of vehicles in common use. Generally, a length of 20 m, including tapers, is sufficient for most commercial vehicles on these roads.

A clear distinction should be drawn between passing zones and lay-bys. Lay-bys may be provided for specific purposes, such as parking or bus stops, to allow vehicles to stop safely without impeding through traffic.

Safety

The operating conditions on roads in developing countries are normally very different from those in developed countries. Principal areas of difference are the substantial variations in vehicle performance and condition, the often large amounts of nonmotorized traffic, and the low levels of training and control of road users.

Road accident rates in developing countries are high and result in substantial economic loss as well as pain, grief, and suffering. However, in view of the uncertainties of accident prediction, it has not been possible to evaluate the specific effects of the geometric design parameters recommended in this guide on accident rates. Therefore, accident rates must be monitored carefully to identify the need for specific remedial treatment and to form a basis for future local amendments to the design procedure.

In general, designers should be aware of the need to consider safety. Designers should take advantage of opportunities during design or construction to provide substantial benefits at little additional cost. The following factors should be considered when designing for safety:

1. Nonmotorized traffic should be segregated by physical barriers such as raised curbs as much as possible. Designs should include features to reduce speeds in areas of significant pedestrian activity, particularly at crossings.
2. To minimize the effect of a driver who has lost control and left the road, the following steps should be taken:
    a. Steep open side drains should be avoided since these increase the likelihood that vehicles will overturn; trees should not be planted immediately adjacent to the road.
    b. Because of their high costs of installation and maintenance, guardrails should only be introduced at sites of known accident risk.
    c. Junctions and accesses should be located where full safe stopping sight distances are available.

A checklist of engineering design features that affect road safety is given in Figure 4.

Conclusion

The objective of this study was to review existing design standards and methods and make recommendations for designs in developing countries. Many aspects of design standards are based on good practice, and there is little hard evidence to link particular features such as width of cross section to safety. The application of standards over long periods has meant that little evidence is available to compare alternatives. For example, the standard 7.3-m single-carriageway road width in the United Kingdom is a direct metrication of the 24-ft standard, which has been used for more than 50 years. In all probability, a 6.5-m carriageway would perform as safely and save considerable costs. The additional length of new construction that could be incorporated for the same total funds could result in an overall accident saving. For developing countries, more results are becoming available that indicate the boundaries at which increased risk becomes significant. These results formed the basis for the recommended standards (5). Key design features for optimum economic return include the following:

1. Maximum carriageway widths of 6.5 m with shoulders designed to reflect use by nonmotorized traffic,
2. Roads with 5-m carriageways for flows of up to 400 vehicles per day where the 1.0-m shoulders may be used for passing,
3. Roads of 2.5 to 3.0 m width for very low flows with passing zones, and
4. Horizontal radii as low as 15 m.

However, side friction factor varies with speed. The highest speed is lower than it is in some developed country standards, which better reflects recent research results.

Design guidance often results in designs that are of a lower geometric standard than those previously used. However, the economic return will be greater, and there is no evidence that higher standards are significantly safer.

A major issue in the selection of a design standard is the design flow; in developing countries, traffic growth can fluctuate substantially. These recommendations tend toward lower standards where future flows are uncertain. In developing countries, excess expenditure on overly ambitious geometric standards can result in the removal of key resources from other sectors of the community. Also, the history of maintenance indicates that too much expense on new construction has limited the budget available for maintenance. The often resulting reductions in surface roughness are usually much more significant economically than a shorter, straighter alignment is.

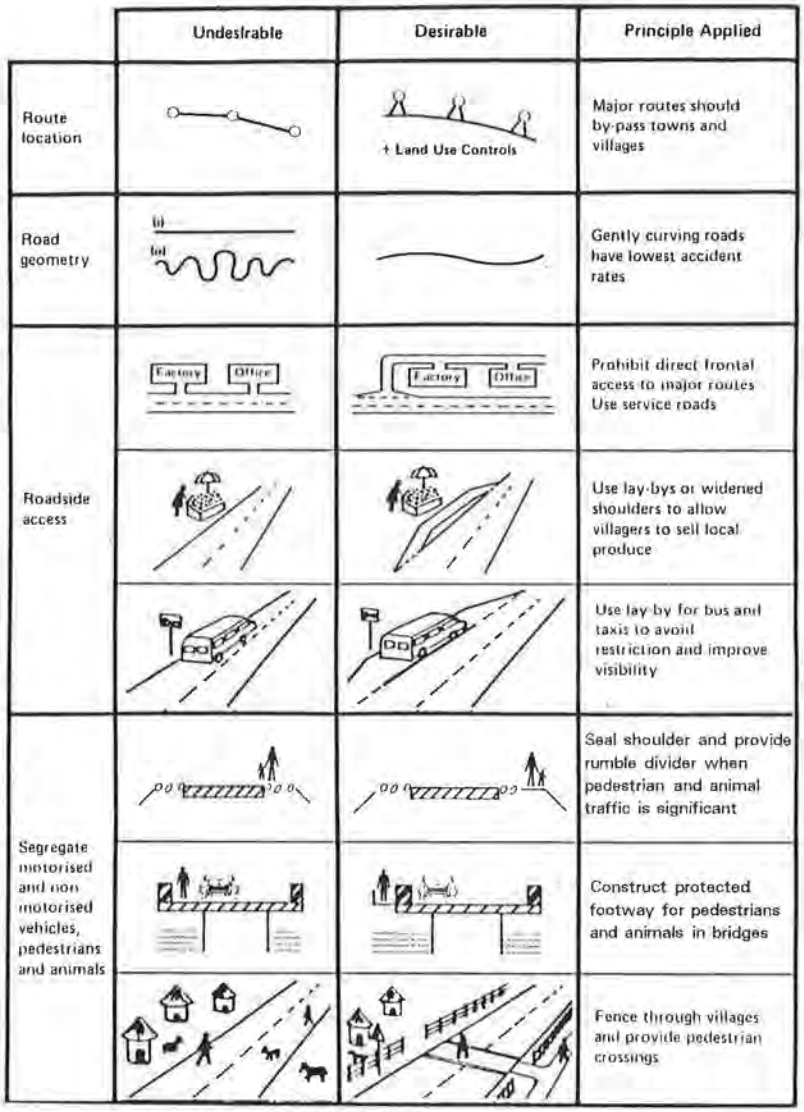

FIGURE 4 Checklist of engineering design features affecting road safety.

ACKNOWLEDGMENTS

The research described was undertaken by ROUGHTONS, Consulting Engineers, under contract to the Overseas Unit of TRL.

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