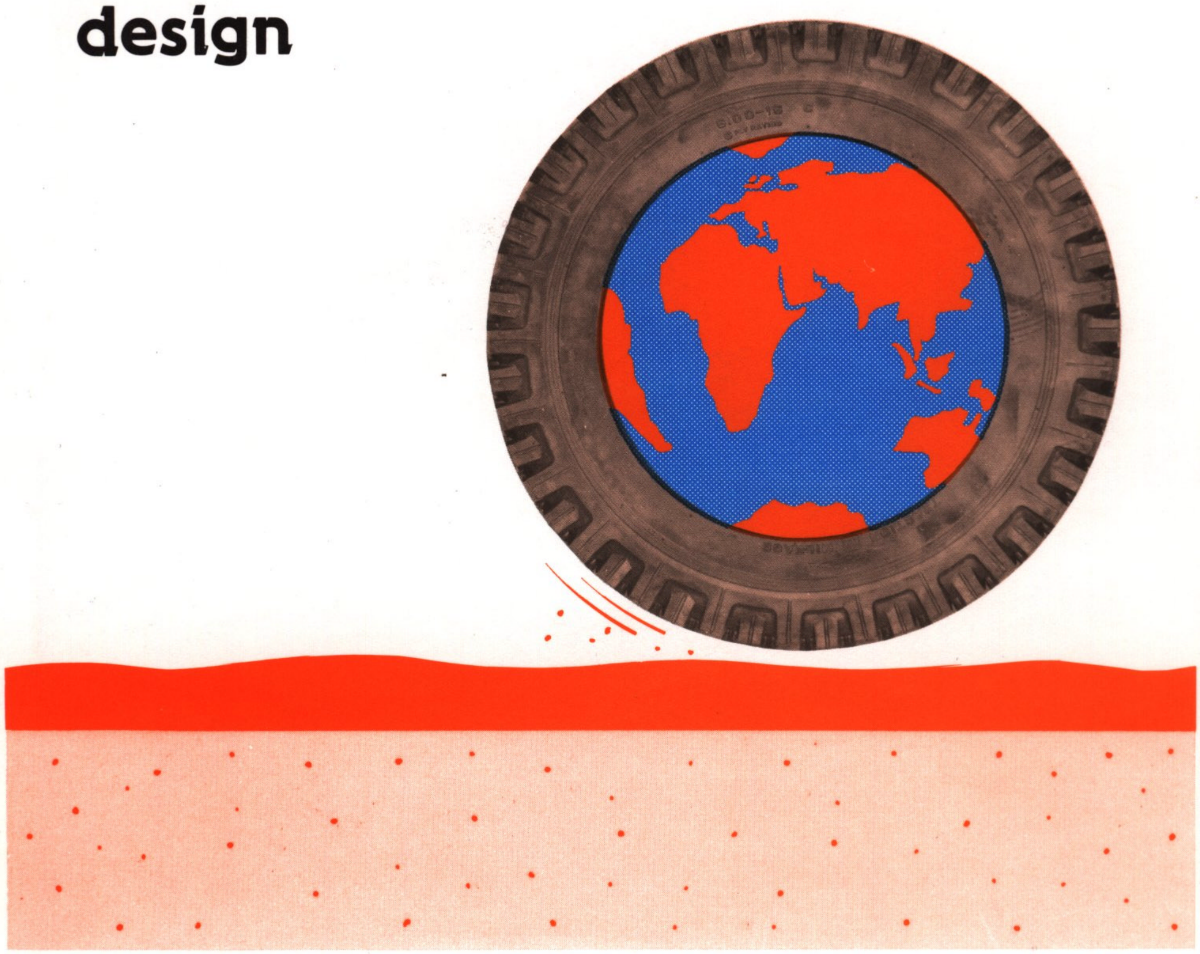
OVERSEAS ROAD NOTE 6

A guide to geometric design



Overseas Unit
Transport and Road Research Laboratory · Crowthorne Berkshire United Kingdom

Transport and Road Research Laboratory Overseas Unit

Department of Transport
Overseas Development Administration

Overseas Road Note 6

A guide to geometric design

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Transport and Road Research Laboratory
Crowthorne Berkshire United Kingdom
1988

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OVERSEAS ROAD NOTES

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INTRODUCTION

PURPOSE OF THIS NOTE

1.1 This Note gives guidance on geometric design and the setting of geometric design standards for single carriageway rural (inter-urban) roads in developing countries. It is aimed at government officials who are responsible for formulating policy on geometric design and at engineers who are responsible for preparing road designs. It will also be of interest to personnel in aid agencies and consultancies who are responsible for the preparation and design of road projects. Many countries will have existing standards different from those described in this guide. This should not preclude the use of the standards in this guide, although where good local cost and benefit information is available, some aspects may need to be reviewed.

1.2 Geometric design is the process whereby the layout of the road in the terrain is designed to meet the needs of the road users. The principal geometric features are the road cross-section and horizontal and vertical alignment. The use of geometric design standards fulfills three inter-related objectives. Firstly, standards are intended to provide minimum levels of safety and comfort for drivers by the provision of adequate sight distances, coefficients of friction and road space for vehicle manoeuvres; secondly, they provide the framework for economic design; and, thirdly, they ensure a consistency of alignment. The design standards adopted must take into account the environmental road conditions, traffic characteristics, and driver behaviour.

1.3 The derivation of the standards recommended in this Note, and summarised in Tables 1.1 and 1.2, is described in TRRL Contractor Report 94 (Boyce et al 1988).

1.4 A glossary of terms in this guide is given as Appendix A.

APPROACH TO DESIGN

Selection of design standards

1.5 The section of design standards is related to road function, volume of traffic and terrain, with additional procedures for the recognition and appropriate treatment of potential hazards (Tables 1.1 and 1.2). Opportunities for the relaxation of standards have also been identified.

1.6 A basic assumption in the approach is that drivers receive clues about the standard of the road from local surrounding features such as the terrain, levels and types of flow, as well as geometric elements. Additional design consideration or special signing will only be necessary where the information available to the driver may lead to incorrect interpretation and consequent danger.

Cross-sectional considerations

1.7 Cross-section parameters are related to traffic flows of all types, and will vary with the requirements of vehicular traffic and with the needs of pedestrians and non-motorised vehicles. In many developing country situations, it will be necessary to consider cost effective ways of segregating non-motorised traffic at the earliest stage in the design process.

Design speed

1.8 Design speed is used as an index which links road function, traffic flow and terrain to the design parameters of sight distance and curvature to ensure that a driver is presented with a reasonably consistent speed environment. In practice, most roads will only be constrained to minimum parameter values over short sections or on specific geometric elements.

Safety

1.9 There is very little information from developing countries on the effects of changes in standards on accident rates. Indeed. equivalent information from developed countries is also limited. Highway engineering safety is usually assumed to be optimised by linking geometric elements to a design or operating speed, so that the resulting geometry has a consistency which reduces the likelihood of a driver being presented with an unexpected situation. This concept of driver expectation forms the basis of this set of design standards.

Economic design

1.10 Designs should be justified economically, and the optimum choice will vary with both construction and road user costs. Construction costs will be related to terrain type and choice of pavement construction, whereas road user costs will be related to level and composition of traffic, journey time, vehicle operation and road accident costs. Methods of determining these costs are given in Overseas Road Note 5 (TRRL Overseas Unit 1988).

1.11 The most economic designs will often not involve the use of minimum standards, as levels of traffic may be such that the additional vehicle operating cost, accident, and travel time saving benefits from wider, straighter and shorter roads may more than offset the extra construction costs needed.

1.12 As flows increase, vehicle-to-vehicle interactions become more important and congestion may result in increases in journey times and accident risk if additional lanes are not added. The scope of this Note has been limited to single carriageway roads, and consideration of the possible introduction of dual carriageways should be made when flows approach 15,000 vehicles per day.

ROAD FUNCTION

1.13 Each inter-urban road may be classified as being arterial, collector or access in nature as shown in Figure 1.1.

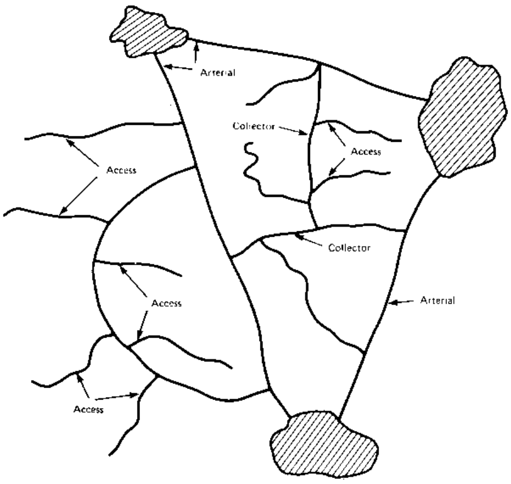


Fig.1.1 Road hierarchy and function

1.14 Arterial roads are the main routes connecting national and international centres. Traffic on them is derived from that generated at the urban centres and from the inter-urban areas through the Collector and Access road systems. Trip lengths are likely to be relatively long and levels of traffic flow and speeds relatively high. Geometric standards need to be adequate to enable efficient traffic operation under these conditions, in which vehicle-to-vehicle interactions may be high.

1.15 **Collector** roads have the function of linking traffic to and front rural areas, either direct to adjacent urban centres, or to the Arterial road network. Traffic flows and trip lengths will be of an intermediate level and the need for high geometric standards is therefore less important.

1.16 **Access** roads are the lowest level in the network hierarchy. Vehicular flows will be very light and will be aggregated in the Collector road network. Geometric standards may be low and need only be sufficient to provide appropriate access to the rural agricultural, commercial and population centres served. Substantial proportions of the total movements are likely to be by non-motorised traffic.

1.17 Whilst this hierarchy is shown simplistically in Figure 1.1, in practice there will be many overlaps of function and clear distinctions will not always be apparent on functional terms alone. This hierarchy should not be confused with the division of administrative responsibilities which may be based on historic conditions.

TABLE 1.1: 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
	A	5,000–15,000	Paved	6.5	2.5	8	85	100	120
Arterial	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 1.2 : SPEED RELATED DESIGN PARAMETER

DESIGN SPEED (km/h)	STOPPING SIGHT DISTANCE (m)	MINIMUM CURVATURE VALUES					MINIMUM SAFE OVER-TAKING 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 e.g. 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	0.35	0.37	0.40	0.43	0.47	0.50	0.55	0.60

1.18 For the lowest Design Class of road, it is inappropriate to design on the basis of geometric standards, and the sole criterion of acceptability will be the achievement of an appropriate level of access. Design, in these situations, should be based on minimum values of radii, width and gradient for the passage of a suitable design vehicle.

TRAFFIC FLOW

Design flow

1.19 The functional hierarchy is such that traffic is aggregated as it moves from Access to Collector to Arterial road, and levels of flow will normally be correlated to road type. However, flow levels will vary between countries and regions and it is important that the designation of a road by functional type should not give rise to overdesign for the levels of traffic actually encountered. Uneconomic designs reduce the likelihood of roads being built and result in wastage of often scarce national resources.

1.20 Design Classes A to F have associated bands of traffic flow as shown in Table 1.1. The range of flows extends from less than 20 to 15,000 motorised vehicles per day, excluding motorcycles, and covers the design conditions for all single carriageway roads.

1.21 Although the levels of flow at which design standards change are based on the best evidence available, the somewhat subjective boundaries should be treated as approximate in the light of the uncertainties inherent in traffic estimation and economic variability. Therefore, design flows should normally be constrained to be no more than one Design Class step higher than the annual average daily traffic (ADT) in the first year of trafficking. Thus, 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 1.1). The design flow band in this case is therefore 400-1000 vehicles per day. Design to the higher Design Class would result in an overdesigned facility during almost the whole of the life of the road and may provide a solution that was less than the economic optimum. If the initial flow were 410 vehicles per day, design would still be to Design Class C. It is particularly important that roads are not overdesigned on the basis of high traffic growth rates which normally incorporate considerable uncertainty.

Composition

1.22 Although, in some situations, heavy vehicles have a greater effect on congestion than light vehicles, no attempt has been made to use passenger car unit (pcu) equivalent values. The relative effects of heavier vehicles vary with level of flow, geometry, and vehicle performance and consistent values that are well researched are not available for the range of flows covered in this design guide. All flows are therefore presented as ADT values. However, where there are very high percentages of heavy vehicles in a traffic stream, consideration may be given to the enhancement of standards, and particularly of carriageway width.

Capacity

1.23 Congestion increases with increased traffic flow when there is a lack of overtaking opportunity. The result is high journey times and vehicle operating costs, often accompanied by more accidents as frustrated drivers take risks.

1.24 Practical capacity is usually estimated to have been reached when the level of congestion becomes "unacceptable". Capacity reduces with increased proportions of heavy vehicles, greater unevenness in directional flows, reduced overtaking opportunities, animal drawn vehicles and pedestrian activity. Normally acceptable practical capacity will be about 1500 to 2000 vehicles per hour, but may be increased substantially by the provision of short sections of climbing and overtaking lanes.

1.25 Capacity is only likely to be approached for road Design Class A, or at the higher flow levels, road Design Class B, particularly in the more rugged terrain if adequate overtaking opportunities are unavailable.

TERRAIN

1.26 A simple classification of "level", "rolling" and "mountainous" has been adopted and is defined by both subjective description and by the average ground slope. The average ground slope is measured as the number of 5 metre contour lines crossed per kilometre on a straight line linking the two ends of the road section. (The slope may be interpolated using other contour intervals on a proportional basis).

1.27 **Level** (0-10 five metre ground contours per kilometre). Level or gently rolling terrain with largely unrestricted horizontal and vertical alignment. Minimum values of alignment will rarely be necessary. Roads will, for the most part, follow the ground contours and amounts of cut and fill will be very small.

1.28 **Rolling** (11-25 five metre ground contours per kilometre). Rolling terrain with low hills introducing moderate levels of rise and fall with some restrictions on vertical alignment. Whilst low standard roads will be able to follow the ground contours with small amounts of cut and fill, the higher standards will require more substantial amounts.

1.29 **Mountainous** (Greater than 25 five metre ground contours per kilometre). Rugged, hilly and mountainous with substantial restrictions in both horizontal and vertical alignment. Higher standard roads will generally require large amounts of cut and fill.

1.30 In general, construction costs will be greater as the terrain becomes more difficult and higher standards will become less justifiable or achievable in such situations than for roads in either flat or rolling terrain. Drivers should also expect lower standards in such conditions and therefore adjust their driving accordingly, so minimising accident risk. Design speed will therefore vary with terrain.

CURVATURE STANDARDS

1.31 Minimum horizontal and vertical curvatures are governed by maximum acceptable levels of lateral and vertical acceleration and minimum sight distances required for safe stopping and passing manoeuvres. These design parameters are, in turn, related to the vehicle speeds assumed in the design. Curvature standards are thus either explicitly or implicitly dependent on an assumed design speed.

1.32 Within this guide, the adopted design speeds are explicitly stated and, as shown in Tables 1.1 and 1.2, have been taken to vary with both terrain and level of traffic flow. However, it must be emphasised that these speeds are intended to provide an appropriate consistency between geometric elements rather than as indicators of actual vehicle speeds at any particular location on the road section.

1.33 The use of lower design speeds in the more difficult terrain is intended to incorporate an element of reduced driver expectation and performance as well as the need to keep construction costs to acceptable levels. As flows increase, the level of benefits from reduced road length also increase and generally support higher standards with more direct and shorter routes.

THE DESIGN PROCESS

1.34 The design process is shown in Figure 1.2 with the main features detailed below. The emphasis throughout is on the need to obtain best value for money.

Basic parameters

1.35 Initially, the basic parameters of road function. traffic flow and terrain type are defined.

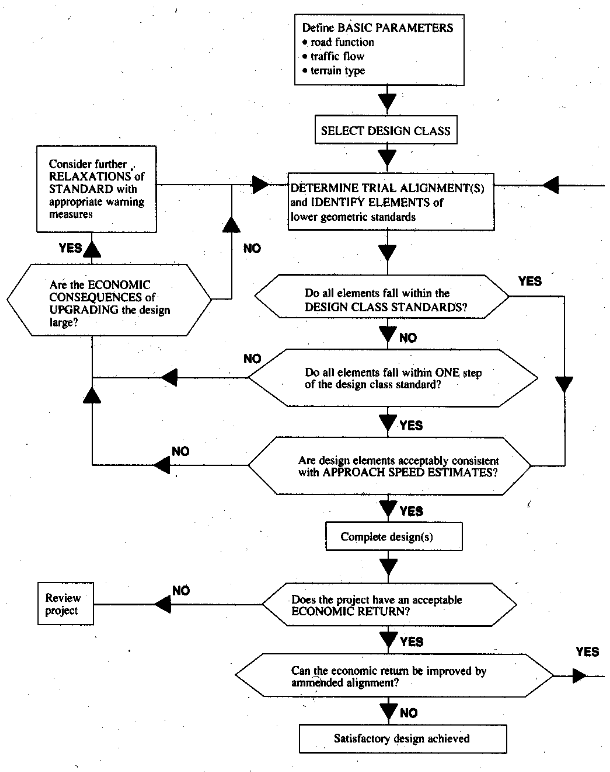
Select Design Class

1.36 On the basis of the above estimates, a Design Class is selected from Table 1.1. Values of Design Class boundaries are for guidance only, and the lower Design Class should be chosen in borderline cases.

Determine trial alignment

1.37 A road consists of a series of discrete geometric elements of horizontal and vertical curvature. Contiguous groups of these elements combine to form sections. In this guide, the minimum length of a road section is considered to be about one kilometre.

FIG. 1.2 : The design process



1.38 The initial stage in selecting an alignment for a new road is to sketch a route on a contoured map or aerial photograph. A similar process can be carried out when investigating the upgrading of an existing road. By reference to the standards, the designer will have some knowledge of appropriate minimum radii for the scale of the map or photograph. Consideration will be given to gradient by reference to the contours of a map, or by relief when using stereo photographs. Several alternative alignments should be tried. The design process should be carried out in conjunction with on-site inspections and surveys. One or two of the alignments should be chosen for additional studies in more detail and be subject to further design and assessment prior to possible construction.

1.39 On two lane roads, the horizontal alignments should be designed to maximise overtaking opportunities by avoiding long, continuous curves. Instead, relatively short curves at, or approaching, the minimum radius for the design speed should be used in conjunction with straights or gentle, very large radius curves. Conversely, an alignment of flowing curves may reduce real overtaking opportunities, thus encouraging injudicious driver behaviour. On two lane single carriageway roads in developing countries, the provision of adequate overtaking opportunities may be particularly important because of the large proportions of slow moving vehicles.

1.40 Often a new road will be built to replace an existing facility. The structural features of the existing road, including bridges, embankments and cuttings may have substantial residual value and influence alignment choice.

1.41 The geometric standard of individual elements of the road will vary with the terrain. It is necessary that elements of lower geometric standard are identified to ensure that they will not result in unacceptable hazards to approaching vehicles. These elements will be readily identifiable from the preliminary horizontal and vertical curvature profiles. The tests for the necessary consistency are simple, as described below, and should be carried out if there is any doubt as to the acceptability of an element.

Design Class standards

1.42 It is recommended that, where the standard of a geometric element falls substantially below that on the approach section, its adequacy should be checked by estimating approach speed from the relationships given in Appendix B. Geometric elements should not normally be designed to a Design Class more than a one Design Class step lower than the approach speed to that element. However, two Design Class steps may be achieved by successive reductions from a design speed of, for example, 85 km/h in rolling terrain to 70 km/h and then 60 km/h (see paras 1.48-51). If this is not possible, consideration must be given to redesign of the element or alterations to the geometry of the approach section to obtain this speed reduction.

Approach speed estimation

1.43 The speeds of freely moving vehicles on an inter-urban road usually conform to a normal distribution within which percentile values of speed are approximately related as follows:

- 1.2 x 15th percentile speed = 50th percentile speed
- 1.2 x 50th percentile speed = 85th percentile speed
- 1.2 x 85th percentile speed = 99th percentile speed.

1.44 The 85th percentile value of speed has been used as the basis of design in this guide. Thus, 15 per cent of the vehicles could be considered to be exceeding the design speed on any section of road. It also follows from the above that, for example, with a design speed of 100 km/h: I per cent would be exceeding 120 km/h; 50 per cent would be exceeding 85 km/h; and 85 per cent would be exceeding 70 km/h. Each such speed change has been taken to represent a consistent design step in Table 1.1. in which rounded values have been used.

1.45 A driver's ability to negotiate a geometric element safely will depend on his approach speed relative to a safe speed on the element. As it is not possible to predict speed profiles accurately, it is recommended that estimates of approach speed are made using the relationships described in Appendix B. These relationships produce estimates of 85th percentile speed. Speeds are modified by geometric characteristics and estimates of approach speed will be based on the geometry of about one kilometre on both approaches to the geometric element under consideration. These approach sections should include complete design elements ie complete horizontal or vertical curves and gradient lengths. There are considerable uncertainties in the accuracy of speed estimation relationships and the results should therefore be treated as approximate.

Economic consequences

1.46 If a geometric element fails to achieve the standard chosen for design, the economic consequences of upgrading to the standard must be considered. The economic consequences should generally be measured as additional cost of construction either in absolute terms or as a proportion of the overall cost. If this cost is small, the road alignment should normally be redesigned. If the cost is large, consideration should be given to further relaxation of standard as described in paras 1.48-51.

1.47 In general, the higher the class of road, and hence volume of traffic, the more likely will benefits from vehicle operating and time cost savings lead to the justification of a shorter, straighter route.

Relaxation of standards

1.48 The standards summarised in Tables 1.1 and 1.2 are intended to provide guidance for designers rather than to be considered as rigid minima. The justification for construction of a particular road will almost always be based on a detailed economic appraisal, and relaxations of standards may be essential in order to achieve an acceptable level of return on investment. In other circumstances, an already acceptable rate of return may be increased substantially by the inclusion of a short section of substandard road where achievement of the design standard would be expensive, although the safety implications of this would need serious consideration.

1.49 Relaxation of one Design Class step implies design to the 50th percentile rather than the 85th percentile speed. Relaxation of two Design Class steps reduces the design to the 15th percentile speed. Experience in the UK has shown that reduction of design parameters by one step, equivalent to a 17 per cent reduction, is likely to have little effect on safety. Normally, a relaxation of two steps, equivalent to a 30 per cent speed reduction, should not significantly increase risk where appropriate signing or other warning measures, such as bend marker posts, are provided. On low flow roads where most of the drivers will be regular users, the increased risk will be less significant and the resultant number of accidents should be negligible. Greater care and consideration should be given to relaxations on high flow/high speed alignments.

1.50 In special circumstances, where standards have been reduced on successive design elements, further relaxations may be made based on those reduced approach speeds. Sight distances, and the potential accident risk as a result of driver error, would need to be considered on a site-specific basis.

1.51 Reductions in standards should only apply to stopping distances and curvature, and suitable values have been included in Table 1.2. Widths should not be reduced as they are particularly flow related, and additional widening may be required on curves with the tighter radii.

Economic return

1.52 All road design projects should be subject to an economic appraisal as recommended in Overseas Road Note 5 (TRRL Overseas Unit 1988). It is essential that those responsible for design should investigate whether amendments to an alignment will produce significant increases in economic rates of return.

2. CROSS-SECTION

BASIC CONSIDERATIONS FOR DETERMINING WIDTHS

2.1 Road width should be minimised so as to reduce the costs of construction and maintenance whilst being sufficient to carry the traffic loading efficiently and safely. Recommended values are given in Table 1.1.

2.2 For Access roads with low volumes of traffic (<100 ADT), single lane operation is adequate as there will be only a small probability of vehicles meeting, and the few passing manoeuvres can be undertaken at very reduced speeds using either passing places or shoulders. Provided sight distances are adequate for safe stopping, these manoeuvres can be performed without hazard, and the overall loss in efficiency brought about by the reduced speeds will be small as only a few such manoeuvres will be involved. It is not cost-effective to widen the running surface in such circumstances and a basic width of 3.0 metres will normally suffice. In some situations, 2.5 metres will allow effective passage.

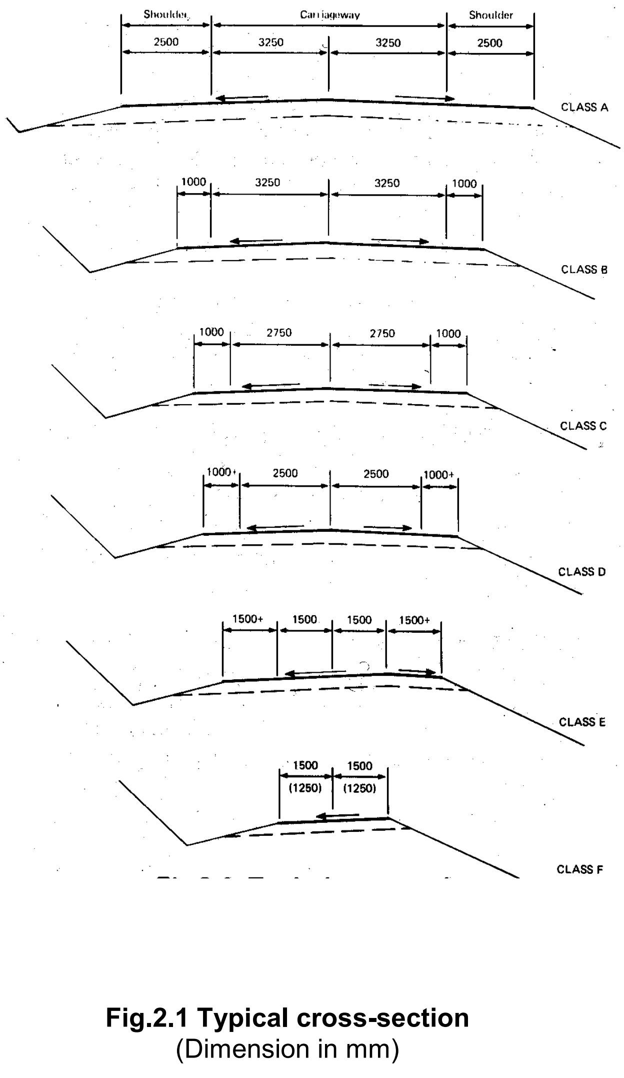


Fig.2.1 Typical cross-section
(Dimension in mm)

2.3 On roads with medium volumes of traffic (100-1000 ADT), the numbers of passing manoeuvres will increase and pavement widening will become worthwhile operationally and economically. However, in view of 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 will remain acceptable for such flow levels and running surface widths of 5.0 and 5.5 metres are recommended. For Arterial roads with higher flows (> 1000 ADT), a running surface 6.5 metres wide will allow vehicles in opposing directions of travel to pass safely without the need to move laterally in their lanes or to slow down.

2.4 Typical cross-sections are shown in Figure 2.1.

CARRIAGEWAYS AND SHOULDERS

2.5 Shoulders are recommended for all but the lowest Design Class and will normally be paved when the carriageway is paved (Figure 2.1.). They are intended to perform three main traffic functions:

- To provide additional manoeuvring space on roads of lower classification and traffic flows
- To provide parking space at least partly off the carriageway for vehicles which are broken down
- To enable non-motorised traffic to travel with minimum encroachment on the carriageway.

2.6 Additionally, it may be desirable to provide sufficient width for two way movement during roadworks.

2.7 Clearly, these functions are not wholly compatible and detailed design recommendations have been based on the following logic.

2.8 Design Class F This class of road provides basic access only and the motorised traffic flows are so low that shoulders are not required. All road users will share the 3.0 (2.5) metre carriageway and passing places will be provided as appropriate. The width should be just sufficient to allow the occasional vehicles to traverse the road and design to specific geometric standards will be inappropriate.

2.9 Design Class E 1.5 metre shoulders have been recommended for this class of Access road as they will allow a total road width of 6.0 metres, sufficient for two trucks to pass with 1.0 metre clearance. Shoulders may also be used by non-motorised traffic and pedestrians, and potential conflicts will be acceptably low with the few motorised vehicles on the road. In difficult terrain, and elsewhere where construction costs are high, 1.0 metre shoulders may be acceptable, particularly when the carriageway and shoulders are paved or where the flow of non-motorised traffic is small.

2.10 Design Class D On paved roads, 1.0 metre paved shoulders are recommended to provide a total paved width of 7.0 metres. this will allow approaching vehicles some lateral movement where necessary, albeit at a reduced speed. If the shoulders are unsurfaced, a high level of maintenance will be necessary to avoid damage and the resulting break up of the edge of the pavement. A minimum of 1.0 metre of surfaced shoulder will also encourage pedestrians and non-motorised users to use the shoulders, rather than the carriageway. Shoulder delineation is particularly important. It is most unlikely that non-motorised traffic will justify the construction of additional width with the levels of motorised vehicles on this class of road. However, the justification for surfaced shoulders or special provision will become greater as flows of traffic of all kinds rise (paras 2.37-42). Conversely, full shoulders may not be necessary in mountainous areas when construction costs are high and non-motorised vehicle flows are low. Where this is the case, the minimum paved width should be 5.5 metres, and side drains may need special consideration for safety reasons (para 5.11*)*.

2.11 Design Class C Roads in this category will normally be paved. Recommendations for 1.0 metre surfaced shoulders are similar to those for Design Class D, but the extra 0.5 metre carriageway width to give a total paved width of 7.5 metres will allow easier passing. Full shoulders may be omitted in mountainous or difficult terrain where the costs of achieving desired cross-sections are very high.

2.12 Design Class B The carriageway of 6.5 metres will allow vehicles to pass with sufficient clearance for there to be little speed reduction or lateral movement. The minimum 1.0 metre shoulder will allow easier overtaking of stopped vehicles as well as the movement of some non-motorised traffic. Shoulders should be paved to provide a total paved width of *8.5* metres. At high levels of flow, where there are substantial traffic movements of wide non-motorised vehicles, such as bullock carts, it may be advisable to increase shoulder width in some circumstances up to a maximum of 2.5 metres, or provide special segregated facilities.

2.13 Design Class A Levels of traffic flow will be such that stopped vehicles blocking any part of the carriageway will be likely to cause a significant hazard. Hence, normal practice will be to provide a 2.5 metre shoulder, at least one metre of which should be paved. However, shoulder width may be reduced to 1.0 metre in difficult terrain where construction costs are high. The shoulder would also be available for non-motorised traffic and should be paved. However, in view of the potentially high levels of service and associated speeds on this class of road, it is recommended that non-motorised traffic be discouraged and alternative segregated facilities provided where possible.

2.14 Dual carriageway construction should be considered where design flows approach about 15,000 vehicles per day. Design of dual carriageways is outside the scope of this guide and reference should be made to the Australian (NAASRA 1980) and British (Department of Transport 1981) standards. The flow value of 15,000 is arbitrary and, in industrialised countries, wider single carriageway roads have been found to carry up to 20,000 to 30,000 vehicles per day, albeit with some reduction in speeds.

PASSING PLACES

2.15 The lowest Design Class with a width of 3.0 (2.5) metres will not allow passing and overtaking to occur and passing places must he provided. The increased width at passing places should be such as to allow two trucks to pass, ie a minimum of 5.0 metres total width, and vehicles would be expected to stop or slow to a very low speed.

2.16 Normally, passing places should be located every 300 to 500 metres depending on the terrain and geometric conditions. Account should be taken of sight distances, the likelihood of vehicles meeting between passing places and the potential difficulty of reversing. In general, passing places should be constructed at the most economic locations as determined by terrain and ground condition, such as at transitions from cut to fill, rather than at precise intervals.

2.17 The length of individual passing places will vary with local conditions and the sizes of vehicles in common use but, generally, a length of 20 metres including tapers will cater for most commercial vehicles on roads of this type.

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

CURVE WIDENING

2.19 Widening of the carriageway on low radius curves will be essential to allow for the swept paths of larger vehicles, and the necessary tolerances in lateral location as vehicles follow a curved path.

2.20 Widths should be increased on horizontal curves to allow for the swept paths of trucks and to allow drivers to manoeuvre when approaching other vehicles. The required amount of widening is dependent on the characteristics of the vehicles using the road, the radius and length of the curve, and lateral clearances. Carriageway widening is also necessary to present a consistent level of driving task to the road users, to enable them to remain centred in lane and reduce the likelihood of either colliding with an oncoming vehicle or driving onto the shoulder.

2.21 The following levels of widening are recommended.

2.22 Single lane roads (3.0m basic width)

Curve radius (m)	20	30	40	60
Increase in width (m)	1.50	1.00	0.75	0.50

These values for widening on tight low speed bends have been based on a typical two-axle truck with an overall width of 2.5 metres, wheel base of 6.5 metres and overall length of 11.0 metres. This type of truck is typical of the two-axle vehicles to be found in most developing countries. Articulated vehicles have not been considered explicitly as they are not common on Access roads.

2.23 Two lane roads

Curve radius (m)	<50	50-149	150-299	300-400
Increase in width (m)	1.50	1.00	0.75	0.50

2.24 The above values are guidelines only and there will be many situations in which widening is neither necessary nor cost-effective.

2.25 Widening should be applied on the inside of a curve and be gradually introduced over the length of the transition.

2.26 On the narrower two lane roads of Design Class C and D, particularly if there are high flows of trucks, it may be desirable to widen the roads on crest vertical curves. Widening of *0.5* metre should be considered where K values are within one Design Class step of the minimum for safe stopping sight distance.

2.27 On lower Design Class roads, E and F, which have substantial curvature requiring local widening, it may be practical to increase width over a complete section to offer a more consistent aspect to the driver. This enhancement of the standards should be undertaken where other advantages such as easier construction or maintenance can be identified and where the additional costs are acceptably small. This argument may also be appropriate for sections of lower curvature on roads of Design Classes C and D.

LATERAL AND VERTICAL CLEARANCES

2.28 Typical maximum truck heights are 4.2 metres and, to allow adequate vertical clearance and the transport of abnormal loads, a 5.0 metres vertical clearance should generally be allowed for in the design.

2.29 Lateral clearances between roadside objects and the edge of the shoulder should normally be 1.5 metres. This may be reduced to 1.0 metre where the cost of providing the full 1.5 metres is high.

2.30 Much smaller clearances will sometimes be necessary at specific locations such as on bridges, although a minimum of 1.0 metre will remain desirable. Minimum overall widths in such circumstances should be sufficient to allow the passage of traffic without an unacceptable reduction in speed, which will depend on the length of the reduced width section and levels of motorised and non-motorised traffic flow. Separate facilities should be provided for pedestrians where possible.

CROSSFALL

2.31 Crossfall should be sufficient to provide adequate surface drainage whilst not being so great as to be hazardous by making steering difficult. The ability of a surface to shed water varies with its smoothness and integrity. On unpaved roads, the minimum acceptable value of crossfall should be related to the need to carry surface water away from the pavement structure effectively, with a maximum value above which erosion of material starts to become a problem.

2.32 The normal crossfall should be 3 per cent on paved roads and 4 to 6 per cent on unpaved roads. Shoulders having the same surface as the carriageway should have the same cross slope. Unpaved shoulders on a paved road should be 2 per cent steeper than the crossfall of the carriageway. The precise choice of crossfall on unpaved roads will vary with construction type and material rather than any geometric design requirement. In most circumstances, crossfalls of 5 to 6 per cent should be used, although the value will change throughout the maintenance cycle.

CARRIAGEWAY MARKINGS

2.33 Carriageway marking should be provided on all two-way paved roads.

2.34 The edge of the carriageway should be delineated by continuous lines and may be supported by surfacing road studs. or other features. The lines should be situated on the shoulder immediately adjacent to the running surface and should be at least lOOmm in width. Alternatively or additionally, delineation can be provided more permanently by sealing the shoulder with a different coloured aggregate to the running surface. (If, contrary to these recommendations, an unsealed shoulder is adopted, the first 150mm should be sealed for marking purposes).

2.35 Centre line markings are also recommended on roads of at least 5 metres width designed for two lane operation in order that a driver may correctly locate his lateral position. These markings should be 100mm wide and normally be discontinuous. except where overtaking is restricted. and may be supported by the use of road studs.

2.36 Within the requirements for centre line and edge markings, local standards and manuals should be used or developed to provide uniformity of marking throughout a national road network. All road markings should conform to international standards.

PROVISION FOR NON-MOTORISED TRAVELLERS

2.37 Consideration needs to be given to the movement of pedestrians. cyclists and animal drawn vehicles either along or across the road. Measurements or estimates of such movements should be made, where possible, to give a firmer basis for making decisions on the design.

2.38 At very low flows of motorised traffic, the problem of interaction is likely to be small. However, care must be taken to ensure that adequate sight distances and/or warnings are given to a driver as he approaches any area of high activity such as a village.

2.39 As flows become greater, the conflicts between slow and fast moving traffic will increase and additional widths of both shoulder and running surface may be necessary. The increase in width will vary with the relative amounts of traffic, their characteristics and the terrain, and should be related to the needs of individual countries and regions as well as individual sections of road. In view of the relatively high costs normally involved in widening, care should be taken to ensure that only those sections of shoulder are widened which are justified by local demand.

2.40 Recommendations for shoulder widths in these situations are given in paras 2.5-2.13.

2.41 There may be substantial movements of pedestrians and non-motorised vehicles which will generally be attracted by the surface quality and all weather properties of roads. Special provisions should be made in situations where such flows are significant with respect to the level of motorised vehicle movements. Some localised shoulder improvements may be appropriate as non-motorised traffic generally increases near towns and villages. Two features which are recommended where large numbers of non-motorised users travel on the shoulders are:

- The shoulders should be sealed
- They should be clearly segregated by the use of edge of carriageway surface markings or other measures.

Special crossing facilities should be provided where possible and necessary.

2.42 On high speed roads with substantial flows of motorised vehicles, non-motorised traffic should be given a separate segregated by a physical barrier such as a kerb. Crossing movements should also be concentrated at specific locations and special crossing facilities provided. Traffic approaching these facilities should be given adequate warning and stopping sight distances which are greater than minimum values should be provided where possible.

RIGHTS-OF-WAY

2.43 **It** is recommended that the rights-of-way should extend to a minimum of three metres from the edge of the road works. This right-of-way should normally be marked by a fence for road Design Classes A and B, and as appropriate for the lower Design Classes.

2.44 The right-of-way must include the acquisition of land necessary for the provision of special facilities for pedestrians and other non-motorised road users. Consideration should also be given to the acquisition of land for short cuts and paths for pedestrians where they exist away from the road.

2.45 Rights-of-way may be reserved for future upgrading of the alignment, although this would not be normal practice.

3. HORIZONTAL ALIGNMENT

CIRCULAR CURVES

3.1 When vehicles negotiate a curve, a sideways frictional force is developed between the tyres and road surface. This friction must be less than the maximum available friction if the bend is to be traversed safely. For any given curve and speed, superelevation may be introduced to enable a component of the vehicle's weight to reduce the frictional need. The general relationship for this effect is:

$$R = \frac{V^2}{127\ (e+f)}$$

where: R = Radius of curve (metres)
V = Speed of vehicles (km/h)
e = Crossfall of road (metres per metre)
f = Coefficient of side friction force developed between the vehicles tyres and road pavement.

The value of e may represent the simple removal of adverse crossfall or include superelevation.

3.2 The side friction factor may be considered to be the lateral force developed by the driver on a level road. The technical evidence indicates that lateral accelerations, and hence side friction factors, increase with reduced radii of curvature and increased speed. The range is considerable and values of "f' found from public road measurements have varied from just over 0.1 for high speed roads to over 0.5 on lower speed roads. The results of empirical studies have indicated 0.22 as a value of "f' above which passengers experience some discomfort. The much higher values found on low radius curves indicate that drivers and passengers have a much higher tolerance in these situations. The values of "f' chosen to calculate minimum radii requirements in this guide range from 0.15 to 0.33. A substantial reserve exists between these comfort and control related values, and those at which the vehicle would start to slide sideways.

3.3 In this guide, it is recommended that curves are designed such that it is necessary for vehicles travelling at the design speed to steer into a bend.

3.4 The minimum radii values shown in Table 1.2 were derived on the basis of sideways friction factors and superelevation. In some situations with minimal lateral clearances, sight distance will be the factor controlling minimum radii. Sight distances may be improved by increasing curve radius or sight distance across the inside of the curve.

3.5 Where only small numbers of specialist vehicles are involved and the costs of improving the alignment are high, not all vehicles can expect to traverse a curve on a single lane road in a single manoeuvre and reversing may be necessary.

ADVERSE CROSSFALL

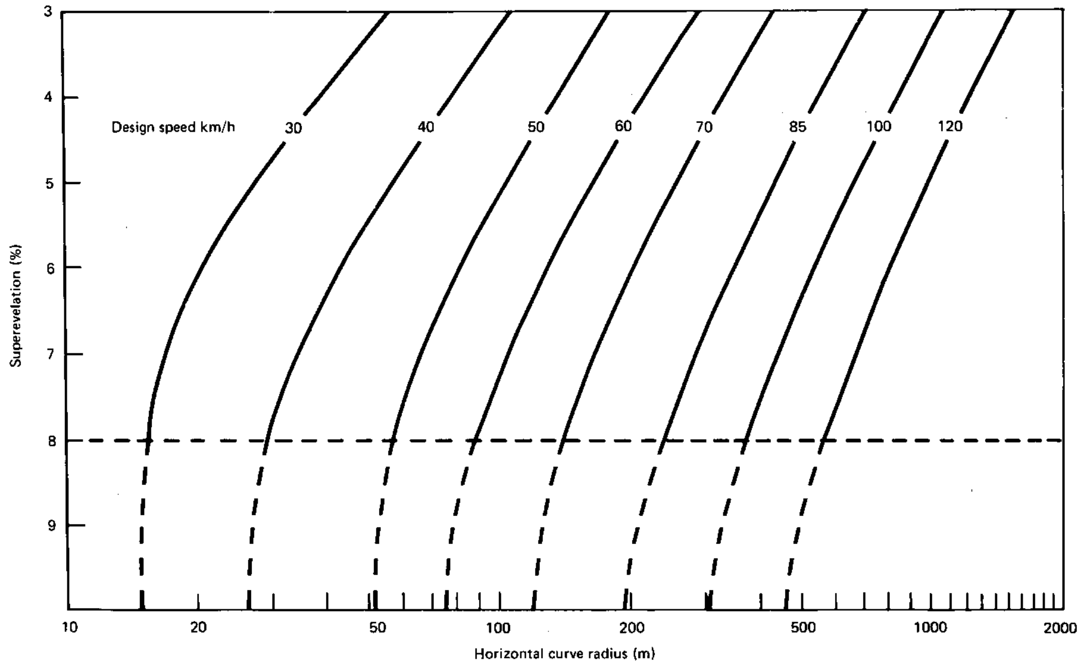
3.6 The normal crossfall on a road will result in a vehicles on the outside lane of a horizontal curve needing to develop high levels of frictional force to resist sliding; the amount of increase being dependent on speed, curve radius and crossfall. In order to achieve the necessary cornering stability, it is recommended that adverse crossfall is removed. The identification of speed and radius combinations at which this should occur is rather subjective as there is no evidence linking adverse crossfall to accident risk. A side friction factor of 0.07 has been taken as giving suitable minimum radii below which adverse crossfall should be removed. With a normal crossfall of 3 per cent, this value results in a minimum radii shown in Table 3.1. Values for unpaved roads are based on a 4 per cent crossfall which is the minimum crossfall that should be allowed before maintenance is carried out if effective cross-drainage is still to be provided.

TABLE 3.1: MINIMUM RADII OF CURVES BELOW WHICH ADVERSE CROSSFALL SHOULD BE REMOVED

DESIGN * SPEED (km/h)	MINIMUM RADII (metres)	
	PAVED	UNPAVED
	3% crossfall	4% crossfall
120 (103)	2,800	
100 (87)	2,000	
85 (73)	1,400	
70 (62)	1,000	1,300
60 (52)	700	1,000
<50 (44)	500	700

* Values in the brackets are the design speeds in km/h with zero lateral accelerations for 3 per cent crossfall ie the speeds at which curve can be negotiated with "hands off" (approximately one speed design step lower).

3.7 The values shown in the table are approximate and cut-off levels should be varied to offer consistency to the driver. For example, two adjacent horizontal curves on a road link, one of which is marginally above the cut-off whilst the other is marginally below the minimum radii given, should be treated in a similar manner in the design.



F ig.3. 1 Superevelation design curves

3.8 Removal and restoration of adverse crossfall should take place over similar distances to superelevation as described in the following Section.

SUPERELEVATION

3.9 For small radius curves and at higher speeds, the removal of adverse crossfall alone will be insufficient to reduce frictional needs to an acceptable level, and crossfall should be increased by the application of superelevation. A minimum radius is reached when the maximum acceptable frictional and superelevation derived forces have been developed. These minimum radii values are identified in Figure 3.1 for maximum levels of superelevation of 10 per cent. These relate to paved roads only. Although this percentage is rather arbitrary, it is widely considered to be a value above which drivers may find it difficult to remain centred in lane as they negotiate a bend.

3.10 On unpaved roads, the crossfall is designed to remove rainwater quickly and effectively, and will be dependent on local conditions and materials. Values of superelevation lower than the value of the crossfall will fail to drain the surface, whist higher values will be likely to result in erosion. On unpaved roads, the maximum superelevation will therefore be the elimination of adverse crossfall (see Table 3.1).

3.11 Where transition curves are used (paras 3.14-19), superelevation should be applied over the length of the transition curves. Otherwise it should be introduced such that two thirds are applied prior to the start of the circular curve.

3.12 For curves with radii above the minimum values, but below the values at which adverse crossfall should be eliminated, it is advisable to improve passenger comfort by introducing superelevation and reducing the sideways force. Intermediate values of superelevation are given in Figure 3.1.

3.13 On paved roads with unsealed shoulders, the shoulders should drain away from the paved area to avoid loose material being washed across the road.

TRANSITION CURVES

3.14 The characteristic of a transition curve is that it has a constantly changing radius. Transition curves may be inserted between tangents and circular curves to reduce the abrupt introduction of the lateral acceleration. They may also be used to link straights or two circular curves.

3.15 In practice, drivers employ their own transition on entry to a circular curve and transition curves contribute to the comfort of the driver in only a limited number of situations. However, they also provide convenient sections over which superelevation or pavement widening may be applied, and can improve the appearance of the road by avoiding sharp discontinuities in alignment at the beginning and end of circular curves. For large radius curves, the rate of change of lateral acceleration is small and transition curves are not normally required.

3.16 Several methods exist for the calculation of transition curves and any may be used in most situations. The rate of pavement rotation method has been adopted here. The rate of pavement rotation is defined as the change in crossfall divided by the time taken to travel along the length of transition at the design speed. The length of transition curve is derived from the formula:

$$L_s = \frac{e.V}{3.6n}$$

where L_s = Length of transition curve (metres)
e = Superelevation of the curve (metres per metre)
V= Design speed (km/h)
n = Rate of pavement rotation (metres per metre per second)

3.17 The same values of rate of change of pavement rotation should be used to calculate the minimum length (L_c) over which adverse camber should be removed on a tangent section prior to the transition:

$$L_c = \frac{e_n.V}{3.6n}$$

Where L_c =Length of section over which adverse camber is removed
e_n =Normal crossfall of the pavement (metres per metre).

3.18 The length of transition curve (L_s) is used to apply the superelevation, with the adverse camber removed on the preceding section of tangent (L_c). The change from normal cross-section to full superelevation at the start of the circular curve is achieved over the superelevation run-off distance which is the sum of L_s and L_c.

3.19 Several relationships are available to calculate the coordinates of a transition curve. The shift, ie the offset of the start of the circular curve from the line of the tangent, should be at least 0.25 metres for appearance purposes. The transition should be omitted if the shift is less than this value.

OTHER CONSIDERATIONS

3.20 For small changes of direction, it is often desirable to use large radius curves. This improves the appearance of the road by removing rapid changes in edge profile. It also reduces the tendency for drivers to cut the comers of small radius curves. Providing the curve radii are sufficiently large, visibility should not be restricted enough to prevent safe overtaking.

3.21 The use of long curves of tight radii should be avoided where possible, as drivers at speeds other than the design speed will find it difficult to remain in lane. Curve widening reduces such problems. In such situations, it will usually be more important to provide adequate overtaking opportunities with longer straights and tighter curves, and to overcome terrain constraints, than to allow for detailed operational problems.

3.22 Abrupt changes in direction from successive curves should be avoided where possible by the inclusion of a tangent section in between. This will allow appropriate changes to be made in crossfall and superelevation.

3.23 Successive curves in the same direction should also be separated by an appropriate tangent, as drivers are unlikely to anticipate what may be an abrupt change in radial acceleration.

4. VERTICAL ALIGNMENT

COMPONENTS OF THE VERTICAL ALIGNMENT

4.1 The two major aspects of vertical alignment are vertical curvature, which is governed by sight distance and comfort criteria, and gradient which is related to vehicle performance and level of service

4.2 Vertical curves are required to provide smooth transitions between consecutive gradients and the simple parabola is recommended for these. The parabola provides a constant rate of change of curvature, and hence visibility, along its length and has the form:

$$y = \frac{G.L}{200}\left[\frac{x}{L}\right]^2$$

where y = vertical distance from the tangent to the curve (metres)
x = horizontal distance from the start of the vertical curve (metres)
G = algebraic difference in gradients (%)
L = length of vertical curve (metres)

CREST CURVES

4.3 The minimum lengths of crest curves have been designed to provide sufficient sight distance during daylight conditions. Longer lengths would be needed to meet the same visibility requirements at night on unlit roads. Even on a level road, low meeting beam headlight illumination may not even show up small objects at the design stopping sight distances. However, it is considered that these longer lengths of curve are not justified as high objects and vehicle tail lights will be illuminated at the required stopping sight distances on crest curves. Vehicles will be identified by the approaching illumination and drivers should be more alert at night and/or be travelling at reduced speed.

4.4 The greater sight distances required to provide safe overtaking opportunities are not easily provided on crest curves. If full overtaking sight distance cannot be obtained, the design should aim to reduce the length of crest curves to provide the minimum stopping sight distance, thus increasing overtaking opportunities on the gradients on either side of the curve.

4.5 Two conditions exist when considering minimum sight distance criteria on vertical curves. The first is where sight distance is less than the length of the vertical curve, and the second is where sight distance extends beyond the vertical curve. Consideration of the properties of the parabola results in the following relationships for minimum curve length to achieve the required sight distances:

For S<L: $$L_m = \frac{G.S^2}{200\,(\sqrt{h_1} + \sqrt{h_2})^2}$$

For S>L: $$L_m = 2S - \frac{200\,(\sqrt{h_1} + \sqrt{h_2})^2}{G}$$

where L_m = minimum length of vertical crest curve (metres)
S = required sight distance (metres)
G = algebraic difference in gradients (%)
h_1 = driver eye height (metres)
h_2 = object height (metres)

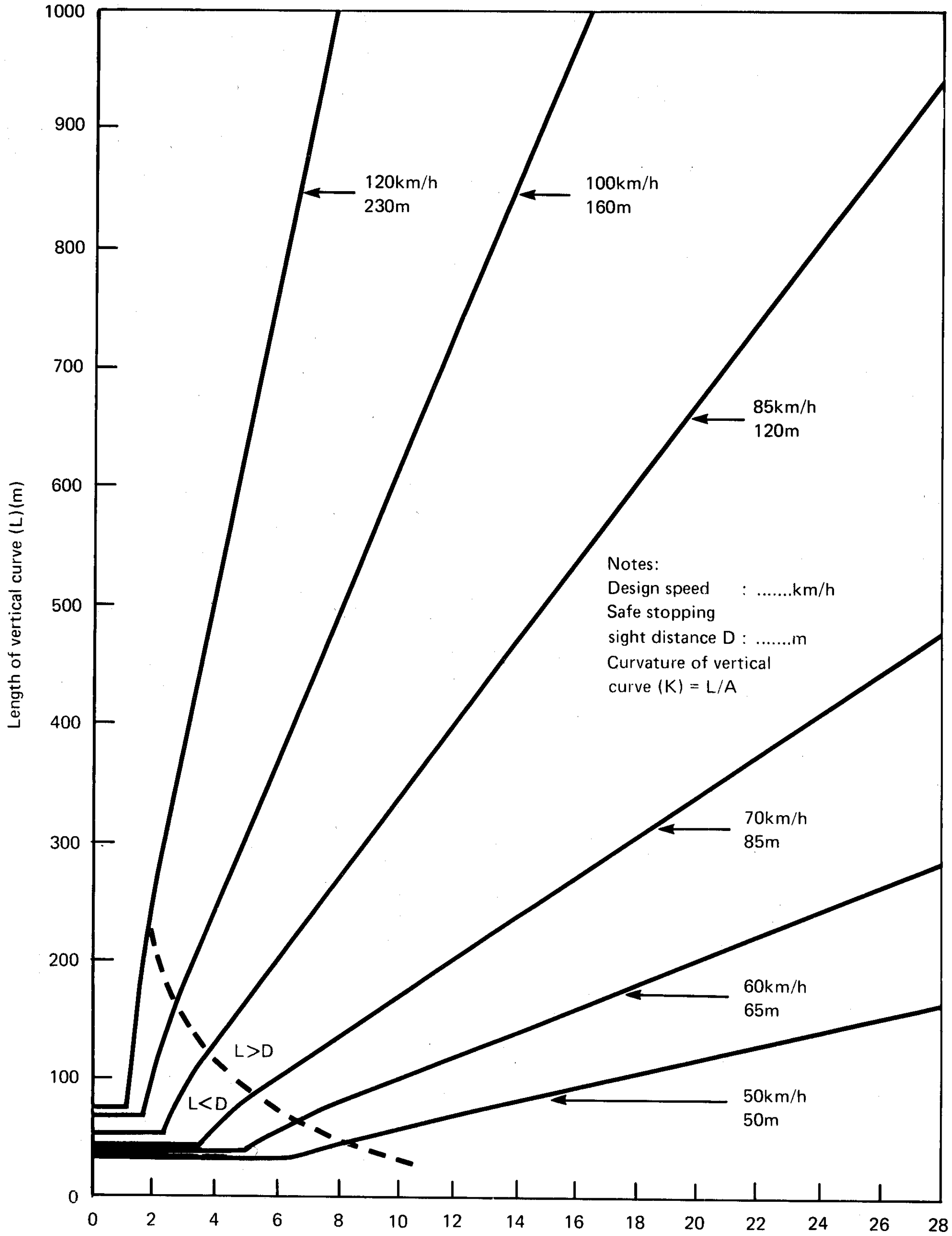
4.6 For S<L, the most common situation in practice, L = K.C where K is a constant for a given design speed (minimum safe stopping speed), eye and object heights.

4.7 Eye height (h_1) has been taken as 1.05 metres, and object heights have been adopted of 0.2 metres above the road surface and to the road surface itself. The need to see the road surface is only applicable in particular circumstances such as a vertical curve on the approach to a ford or drift where a driver may have to stop because of the presence of surface water.

4.8 Two approaching vehicles on a single lane road require twice the distance in order to stop safely and avoid collision, and in this instance an object height of 1.05 metres has been used. The K-values relating change in gradient to minimum vertical curve length are given in Table 1.2 for the various object heights.

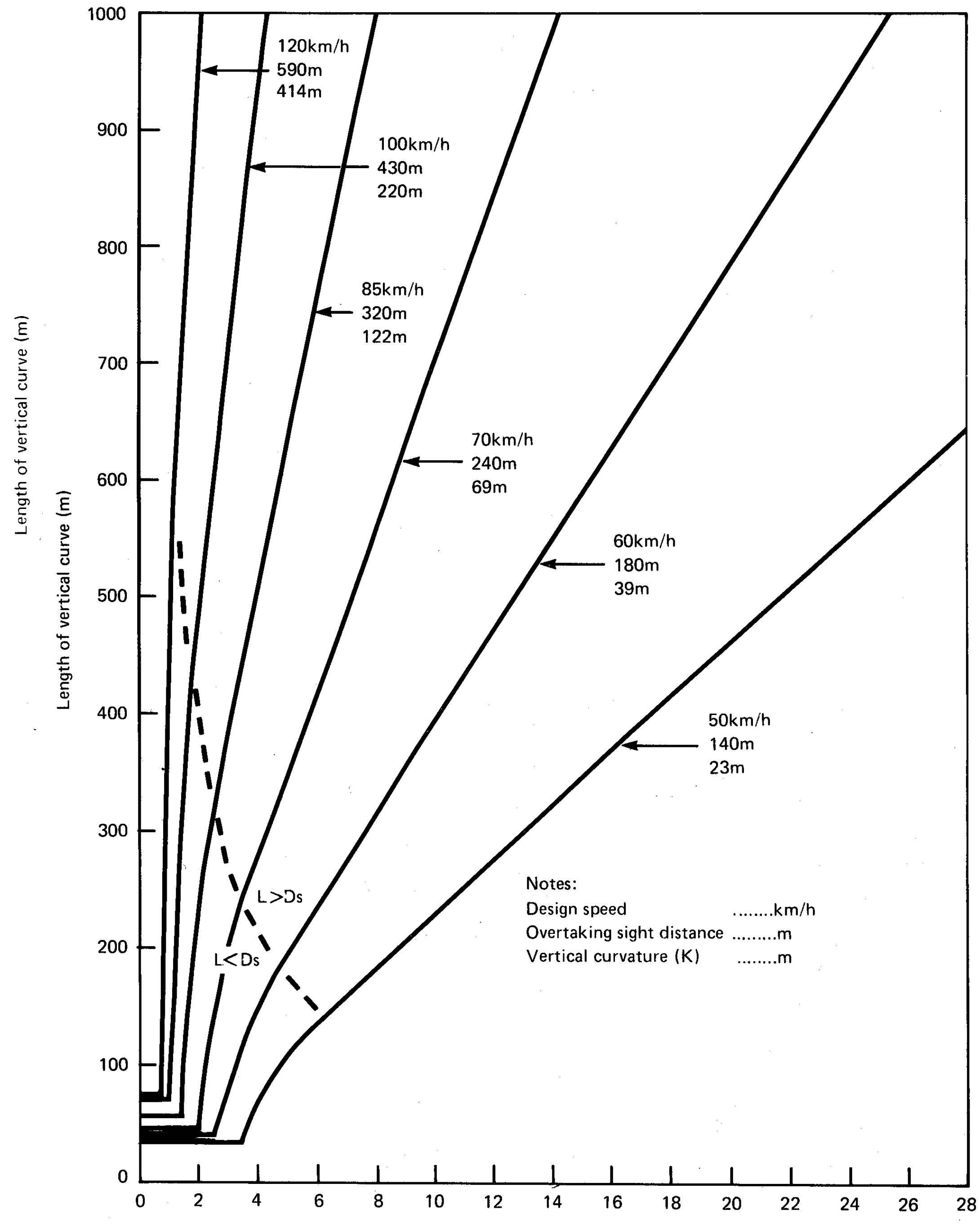
4.9 Charts of required lengths of vertical curves for safe stopping for an object on the road, safe overtaking and for meeting vehicles on a single lane, are shown in Figures 4.1, 4.2 and 4.3 respectively. Minimum values have been derived from considerations of appearance.

4.10 Sight distances have been based on the characteristics of car drivers as, although braking distances are greater with trucks, they will usually be travelling more slowly and the eye height of truck drivers is about 1.0 metre higher. Requirements are related to rates of deceleration available with an emergency stop. Skid resistance values are dependent



Algebraic difference in gradient (A)(%)

Fig.4.1 Length of crest vertical curves for safe stopping sight distance



Algebraic difference in gradient A (%)

Fig.4.2 Length of crest vertical curve for overtaking sight distance

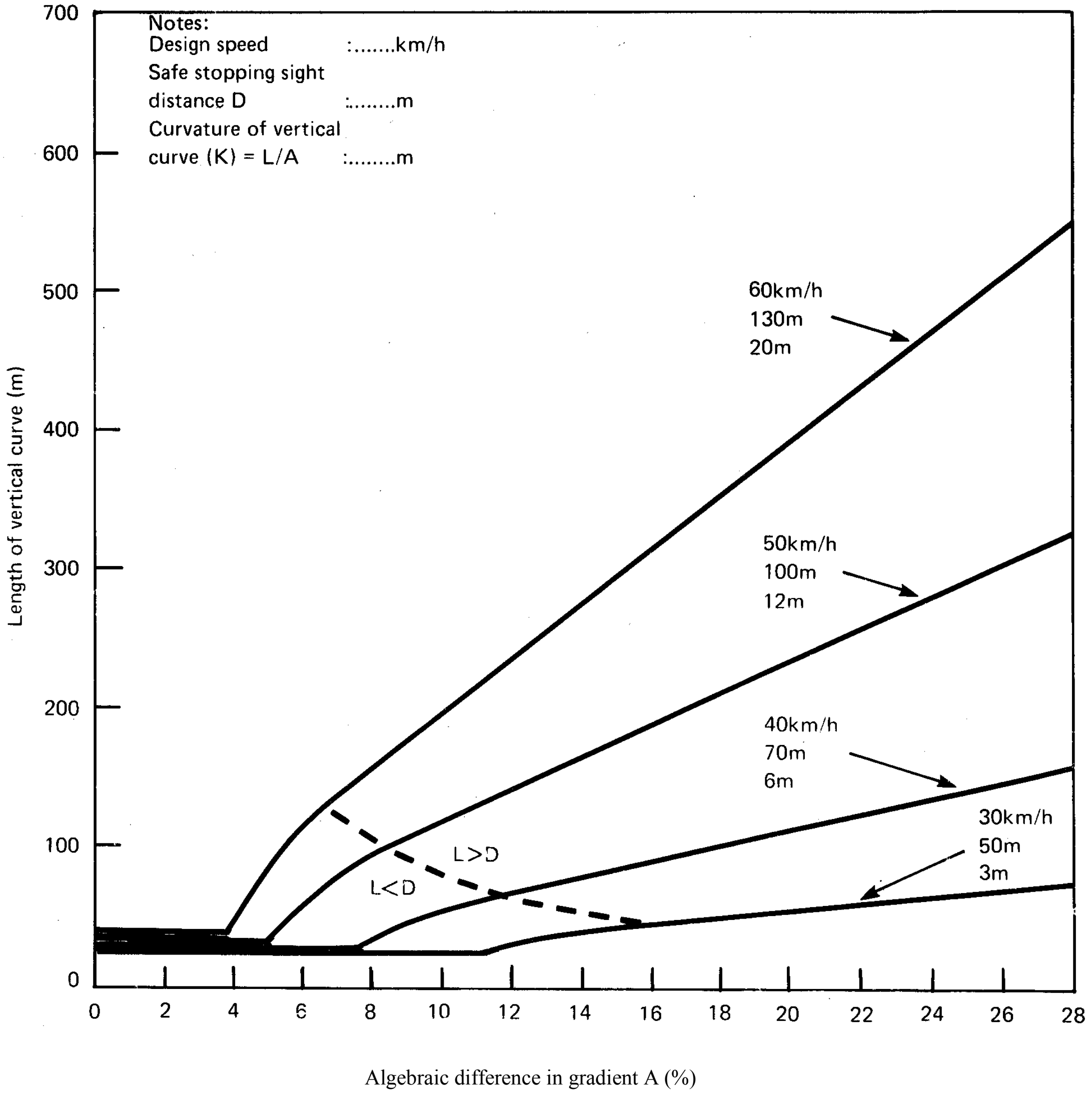


Fig.4.3 Length of crest vertical curve for safe stopping sight distance for meeting vehicles

on tyre, road surface conditions and speed, and vary substantially. The values for available longitudinal friction in this guide are given in Table 1.2. A reaction time of 2.0 seconds has been assumed. Drivers will react more quickly when alert and in a situation where action is expected and, in practice, reaction times normally vary from about 0.5 to 1.7 seconds.

SAG CURVES

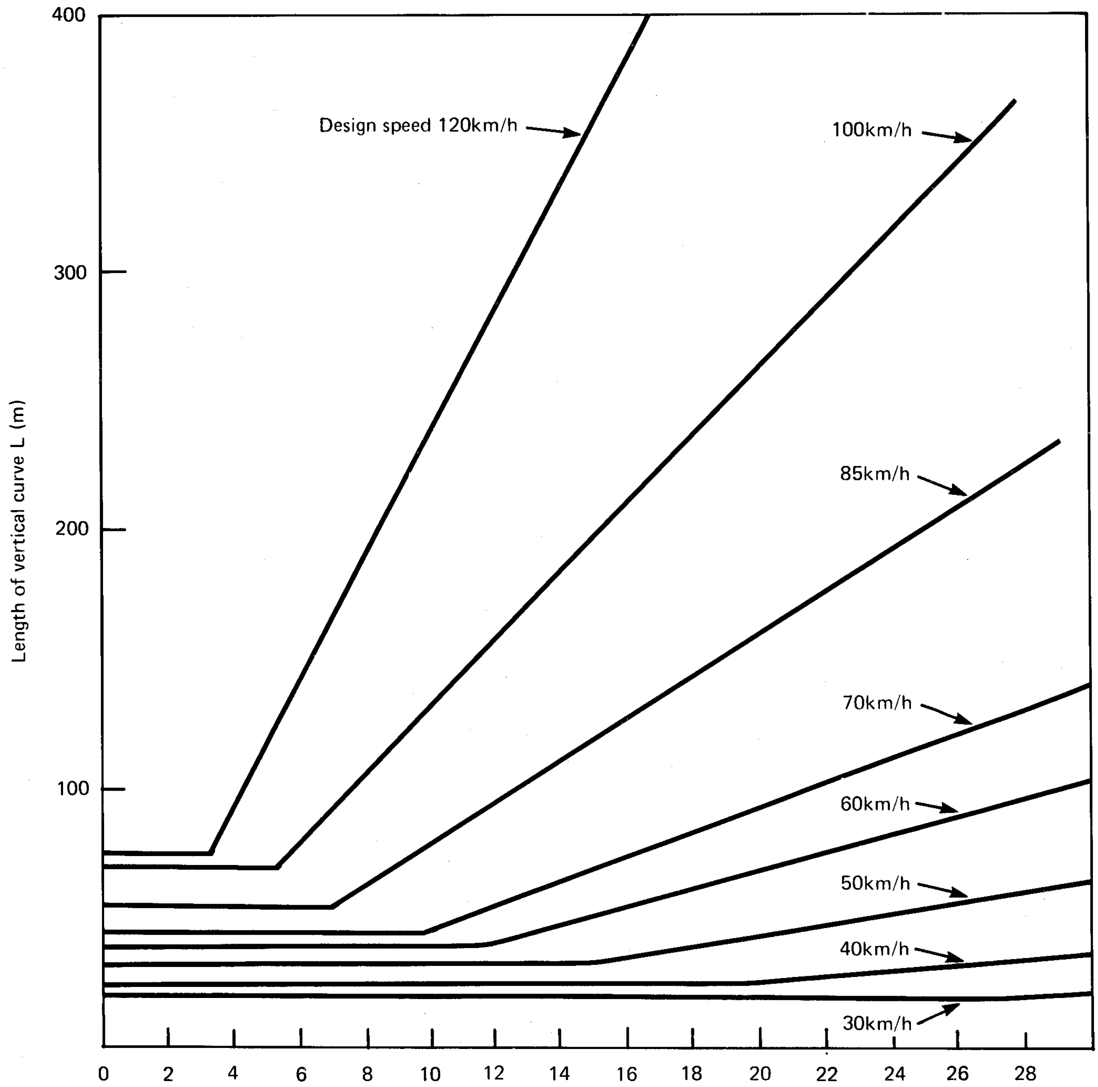
4.11 It has been assumed that adequate sight distance will be available on sag curves in daylight. However, at night, visibility is limited by the distance illuminated by the headlamp beams, and minimum sag curve length for this condition is given as:

For S < L: $$L_m = \frac{G.S^2}{200\,(h_l + S.\tan\theta)}$$

For S > L: $$L_m = 2S - \frac{200\,(h_l + S.\tan\theta)}{G}$$

where h_l = headlight height (metres)
θ = angle of upward divergence of headlight beam (degrees)

Appropriate values for h_l and θ are 0.6 metres and 1.0 degrees respectively.



Algebraic difference in gradient A (%)

Fig.4.4 Length of sag vertical curve for adequate riding comfort

4.12 The use of these equations can lead to requirements for unrealistically long vertical curves as, especially at higher speeds, sight distances may be in excess of the effective range of the headlamp beam, particularly when low meeting beams are used. Thus, the only likely situation when the above equations should be considered for use is on the approaches to fords and drifts and other similar locations where flowing or standing water may be present on the road surface. Most of these structures occur on low speed road where headlamp illumination is more likely to reach the full sight distances.

4.13 It is recommended that, for most situations, sag curves are designed using the driver comfort criterion of vertical acceleration. The values used are given in Table 4.2 and the resulting curve length values are shown in Figure 4.4. with minimum length values for satisfactory appearance.

TABLE 4.2 : MINIMUM LEVELS OF ACCEPTABLE VERTICAL ACCELERATION

Design speed km/h	120	100	85	70	60	50	40	30
Vertical acceleration (Proportion of g in m/sec^2)	0.05	0.06	0.07	0.08	0.08	0.09	0.10	0.10

GRADIENT

4.14 Vehicle operations on gradients are complex and depend on a number of factors: severity and length of gradient; level and composition of traffic; the number of overtaking opportunities on the gradient and in its vicinity.

4.15 For very low levels of traffic flow with only a few four-wheel drive vehicles, the maximum traversable gradient is in excess of 20 per cent. Small commercial vehicles can usually negotiate an 18 per cent gradient. whilst two-wheel drive trucks can successfully tackle gradients of 15-16 per cent except when heavily laden. These performance considerations have formed the basic limiting criteria for gradient as shown in Table
1 1

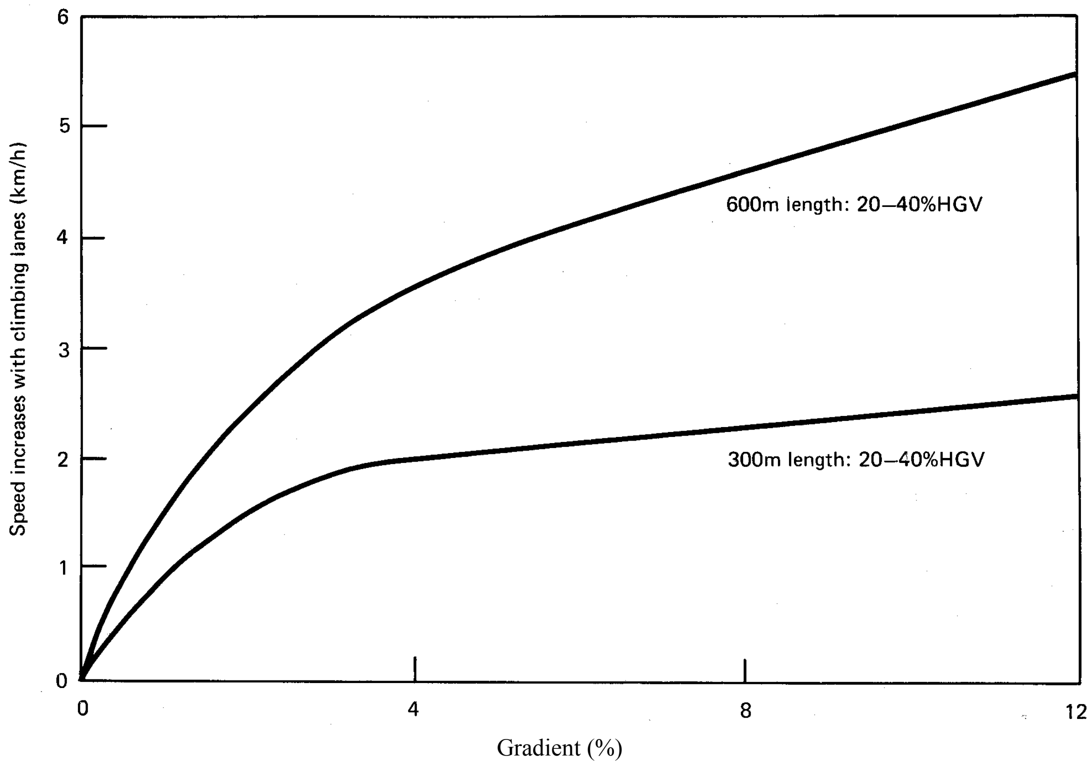


Fig.4.5 Estimated speed increases with climbing lanes

Note:

1) The above results are estimations based on simulation. Vehicle performance and driver characteristics will vary from country to country and the assumptions incorporated here should be considered as coarse approximations.

2) Climbing lanes on gradients of up to 100 metres in length were shown to have little effect.

3) Varying the percentage of heavy vehicles (HGV) from 20 percent to 40 percent has little effect on the mean speed reduction.

4) The above curves are based on directional flows of 200 vehicles per hour. For lower flows. the benefits of a climbing lane were small, although for higher flows of 400 to 600 vehicles per hour. the benefits were found to increase by about 25 percent on a 300 metre gradient, and by about 60 percent on a 600 metre long gradient.

5) The speed increases shown in the above Figure are values averaged over a 1.0 kilometre section of road which contains the gradient section.

4.16 Gradients of 10 per cent or over will usually need to be paved to enable sufficient traction to be achieved, as well as for pavement maintenance reasons. There will often be considerable non-motorised movement on the lower Design Class roads and, whilst pedestrian and animal movements are possible on very steep inclines, some laden animal drawn carts may find steep grades difficult to traverse because of a lack of grip.

4.17 As traffic flows increase, the economic disbenefits of more severe gradients, measured as increased vehicle operating and travel time costs, are more likely to result in economic justification for reducing the severity and/or length of a gradient. On the higher Design Classes of road, the lower maximum recommended gradients (Table 1.1) reflect the economics, as well as the need to avoid the build up of local congestion. However, separate economic assessment of alternatives to long or severe gradients should be undertaken where possible or necessary. An estimation of vehicle operating cost savings may be made from relationships such as those incorporated in the TRRL road investment model (micro-RTIM2), or the World Bank's highway design and maintenance standards model (HDM-III).

CLIMBING LANES

4.18 A climbing lane may be introduced as a more cost effective alternative to reducing a gradient.

4.19 Benefits from the provision of a climbing lane accrue because faster vehicles are able to overtake more easily, resulting in shorter average journey times and reduced vehicle operating costs. Benefits will increase with increases in gradient, length of gradient, traffic flow, the proportion of trucks, and reductions in overtaking opportunities. The effect of a climbing lane in breaking up queues of vehicles held up by a slow moving truck will continue for some distance along the road.

4.20 The effects of a climbing lane on the mean operating speed of a traffic stream have been estimated with a simulation model and are given as Figure 4.5 for guidance. These mean speeds should be used with local values of travel time savings. appropriate vehicle operating costs savings, and the additional costs of construction, to estimate overall economic returns of the alternatives to enable the most cost-effective solution to be determined. With the generally low values of travel time found in developing countries and excluding accident considerations, climbing lanes are unlikely to be justified other than on a small proportion of Arterial roads with very high flows. In view of the uncertainties associated with simulation, local data should be used where available.

4.21 As climbing lanes will be used largely by trucks and buses, they must be a minimum of 3.0 metres in width. They must be clearly marked and, where possible, should end on level or downhill sections where speed differences between different classes of vehicle are lowest to allow safe and efficient merging manoeuvres.

5. ECONOMICS AND SAFETY

ECONOMIC ASSESSMENT

5.1 All road schemes must be worthwhile economically. However, a road scheme with higher than necessary geometric standards may achieve a target rate of return without giving best value for money. In developing countries, finance is usually scarce and it is particularly important that minimum effective designs are used to enable the funds saved to be applied elsewhere. The standards recommended in this guide are intended to encourage the identification of such minimum effective designs.

5.2 In most developing countries, the economic benefits from road schemes are mainly derived from vehicle operating cost savings. Other benefits are savings in travel time and reduced accident rates. All three types of benefit are increased by reducing route length and, for higher flow roads, such savings may well outweigh the additional costs of straightening a tortuous alignment. Whilst this process is reflected in the design steps shown in Figure 1.2, care must be taken to ensure that a proper range of alternative alignments is considered to achieve the best economic return.

5.3 The choice of an appropriate unit value of travel time is often contentious and, in most situations, the extent and value of potential accident savings is difficult to define. A recommended approach to costing in both of these areas is given in Overseas Road Note 5 (TRRL Overseas Unit 1988).

SAFETY

5.4 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 non-motorised traffic, and low levels of training and control of road users.

5.5 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. Therefore, accident rates must be monitored accurately to identify the need for specific remedial treatment, and to form a basis for future local amendments to the design procedure.

5.6 In general, designers should be aware of the need to consider safety, and should make use of opportunities which may arise at design or construction stages, and which may result in substantial benefits at little additional cost. The following factors should be considered when designing for safety.

Non-motorised traffic

5.7 This traffic should normally be segregated onto sealed shoulders of appropriate width. **Clear delineation is essential** and may be achieved by road markings, use of different coloured surfacing, surface texture, or kerb features.

5.8 Kerb features may include edge strips or intermittent placement of slightly raised blocks, sufficient to deter drivers from travelling over them at speed, but not so raised as to be likely to cause loss of control or damage to the vehicles. Such features should not be more than about 20mm high. They must be clearly marked and should only be introduced on roads of Design Class A and B with running widths of 6.5 metres.

5.9 Traffic on the approach to crossing facilities, or through villages where many crossing pedestrian movements are concentrated, may be slowed down by the use of road humps or other pavement features. Road humps should be designed as shown in Figure 5.1. Short sharp humps are not recommended as they can damage tyres and suspensions, and lead to loss of control. They must not be placed on high speed roads. Warning signs must be provided on the approaches to road humps and where crossing movements are concentrated. Proper maintenance of the profiles of road humps is essential. Alternative effective features include "rumble strips", which are short sections of road with a coarse surface texture.

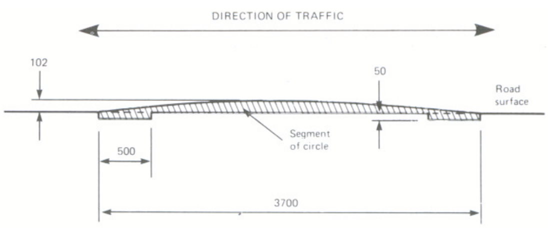


Fig.5.1. Road hump cross-section and dimensions
(Dimensions in mm)

5.10 Shoulder width must reflect the characteristics of the non-motorised traffic using it and additional width may be required where there are substantial flows of pedestrians, cycle rickshaws, bullock carts, etc. Segregation is recommended where such flows coincide with heavy flows of motorised vehicles, or where it may be achieved through low cost measures.

Driver safety

5.11 Occasionally a driver will lose control and swerve off the road. Design features should be such that the effects of such a manoeuvre will be minimised:

- Steep open side drains should be avoided as these will increase the likelihood of vehicles overturning; trees should not be planted immediately adjacent to the road
- Because of their high costs of installation and maintenance, guard rails should only be introduced at sites of known accident risk.

5.12 The detailed design of junctions and accesses is beyond the scope of this guide. However, they should he situated at locations where full safe stopping sight distances are available.

5.13 A check list of engineering design features that affect road safety is given in Figure 5.2.

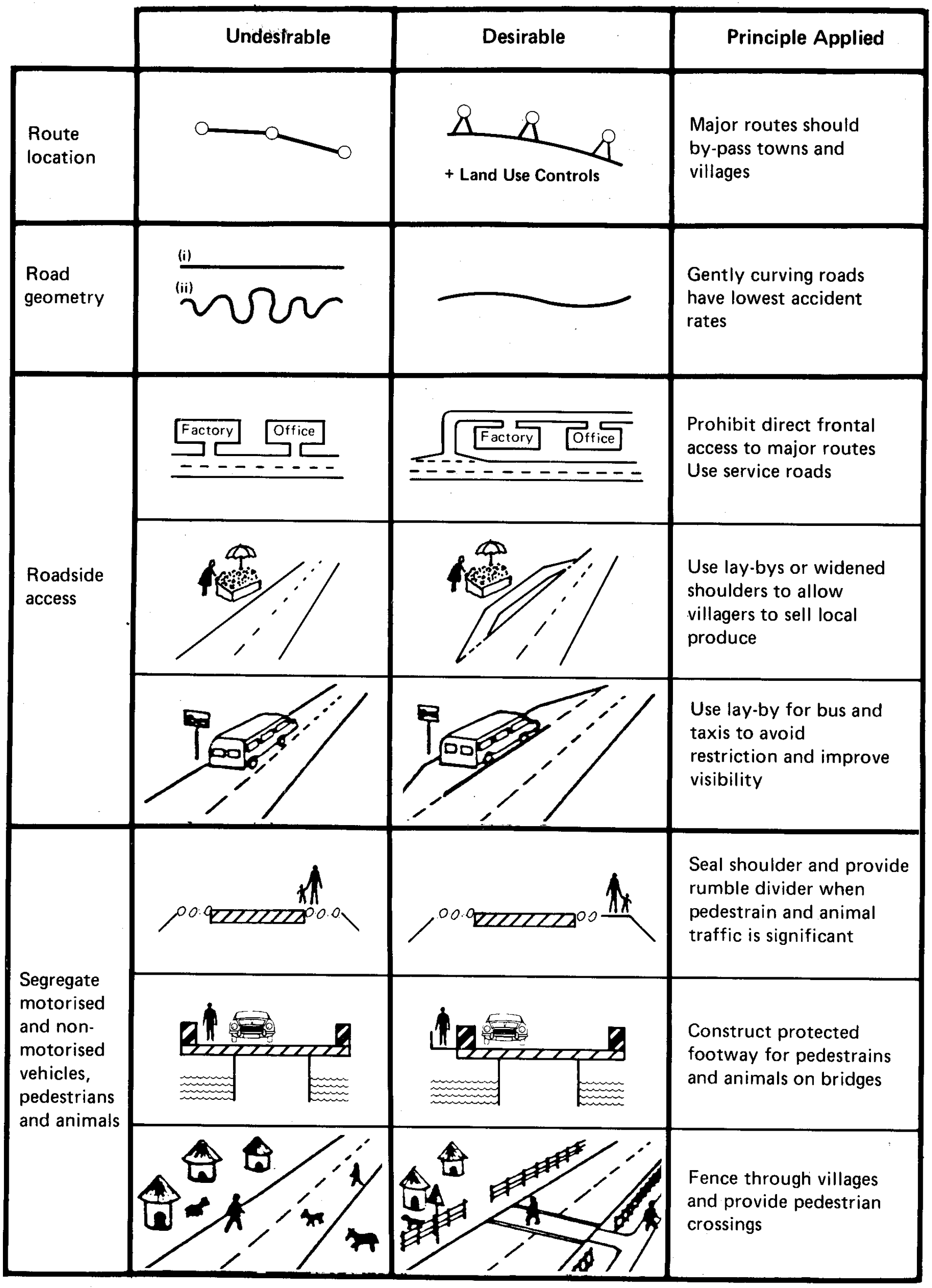


Fig.5.2. Example of effect of engineering design on road safety

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APPENDIX A

GLOSSARY OF TERMS

Access Road. The lowest level of road in the network hierarchy with the function of linking traffic to and from rural areas, either direct to adjacent urban centres, or to the Collector road network; a feeder road or tertiary route (see Fig 1.1).

Adverse crossfall. Crossfall on a horizontal curve that tilts away from the centre of the curve.

Annual average daily traffic (ADT). The total annual traffic in both directions on a road link divided by 365.

Arterial road. A main route connecting national or international centres: a primary route (see Fig 1.1).

Capacity. The maximum practicable traffic flow in given circumstances.

Carriageway. That part of the road constructed for use by moving traffic, including auxiliary lanes, climbing lanes and passing places (see Figure 2.1).

Climbing lane. An auxiliary lane provided on an up gradient for use by slow moving vehicles and to facilitate overtaking.

Coefficient of friction. The ratio of the frictional force on the vehicle, and the component of the weight of the vehicle perpendicular to the frictional force.

Collector road. A road that has the function of linking traffic to and from rural areas, either direct to adjacent urban centres, or to the Arterial road network; a secondary route (see Fig 1.1).

Crest. A peak formed by the junction of two gradients.

Cross-section. A vertical sect ion of the road at right angles to the centre line.

Crossfall. The difference in level measured traversely across the surface of the carriageway.

Design Class. The classification of roads for geometric design purposes according to traffic and road function (see Table 1.1).

Design Speed. The 85th percentile speed of vehicles on any particular section of road.

Dual carriageway. A road having two separate carriageways for travel in opposite directions.

Edge strip. A flush border of stone, concrete or other material laid or formed at the edge of the carriageway to delineate the shoulder.

Eye height. An assumed height of drivers' eyes above the surface of the carriageway used for the purpose of determining sight distances.

Free speed. The speed at which a vehicle travels on uncongested, flat, straight, smooth and wide sections of road in the particular environment under consideration.

(Road) function. The objective of providing a particular road link in terms of being "Arterial", "Collector" or "Access".

Geometric element. An individual horizontal or vertical curve, transition curve, gradient, or straight section of road.

Geometric (design) standards. Guidelines for limiting values of road alignment and cross-section design.

Gradient. The rate of rise or fall on any length of road, with respect to the horizontal.

Guard rail. A continuous barrier erected alongside a carriageway to minimise the consequences of vehicles running off the road.

"Hands off" speed. The speed at which, for a particular combination of horizontal curvature and superelevation, a vehicle will follow the curve without any necessity to steer to the left or the right.

Horizontal alignment. The direction and course of the centre line in plan.

Horizontal curve/curvature. A curve/succession of curves, normally circular, in plan.

K-value. The ratio of the minimum length of vertical crest curve in metres to the algebraic difference in percentage gradients adjoining the curve.

Kerb. A border, flush or up-standing, of stone, concrete or other material laid or formed at the edge of a carriageway, shoulder or footway.

Lane. A strip of carriageway intended to accommodate a single lane of moving vehicles, frequently defined by carriageway markings.

Level (terrain). Flat or gently rolling terrain with largely unrestricted horizontal and vertical alignment; the road line crosses 0-10 five metre ground contours per kilometre (see para. 1.27).

Mountainous (terrain). Terrain that is rugged and very hilly with substantial restrictions in both horizontal and vertical alignment; the road line crosses more than 25 five metre ground contours per kilometre (see para. 1.29).

Network (hierarchy). The classification of roads according to Arterial, Collector and Access (see Fig. 1.1).

Normal distribution. A symmetrical hell-shaped curve relating the probability of occurrence of an event to the range of events possible; for the mathmatical formulation of the normal distribution, any standard text on statistics should be consulted.

Object height. An assumed height of a notional object on the surface of the carriageway used for the purpose of determining sight distance.

Passenger car unit (pcu). A unit for converting the equivalence in terms of effect on capacity of different vehicle types in terms of one normal passenger car.

Passing place. A local widening of a narrow carriageway to enable vehicles to pass or overtake each other.

Pavement. The part of a road designed to withstand the weight or loading by traffic.

Percentile. The percentage of the total below which the given number of values fall.

Rate of pavement rotation. The ratio of the change in crossfall to the time taken to travel along the length of a transition curve when travelling at the design speed.

Residual value. The value of a road which remains at the end of the economic evaluation period; normally taken as the difference in cost between rebuilding the road at the end of its life using the structure remaining from the initial project, and the building cost if the first project were not to take place.

Right-of-way. The physical extent of the right of access that is granted in association with a road.

Road hump. A physical obstruction, normally of semi-circular profile, placed transversely on the surface of the carriageway for the purpose of reducing traffic speed.

Rolling (terrain). Terrain with low hills introducing moderate levels of rise and fall with some restrictions on vertical alignment; the road line crosses 11-25 five metre ground contours per kilometre (see para. 1.28).

Rumble strip. A strip of coarse textured surfacing material placed on the surface of the carriageway for the purpose of altering drivers.

Sag (curve). A depression formed by the junction of two gradients.

Shoulder. That part of the road outside the carriageway, but at substantially the same level (see Figure 2.1).

Sight distance. The distance at which' an object becomes visible to an observer, the height above the carriageway of observer and object being specified.

Speed environment The speed below which 85 percent of vehicles are driving on the longer straights and large radius curves of a section of road where speed is not constrained by traffic or geometric elements.

Superelevation. The inward tilt or transverse inclination given to the cross-section of a carriageway throughout the length of a horizontal curve to reduce the frictional requirements between the vehicles' tyres and the road surface.

Superelevation run-off. The length of road over which superelevation is reduced from its maximum value to zero.

Taper. The transition length between a passing place, auxiliary lane or climbing lane and the standard carriageway.

Transition curve. A curve in which the radius changes continuously along its length, used for the purpose of connecting a straight with a circular curve, or two circular curves of different radii.

Vertical alignment. The direction and course of the centre line in profile.

Vertical curve/curvature. A curve/succession of curves, normally parabolic, in profile.

APPENDIX B

ESTIMATION OF VEHICLE SPEED

B.1 In order to estimate the 85th percentile approach speed of a particular class of vehicle on the road under investigation, it is necessary to determine the "free speed" of that class of vehicle. This is defined as the speed at which vehicles of different classes are observed to travel on uncongested, flat, straight, smooth and wide sections of road in the environment under investigation. These speeds have been found to be affected by the general layout of the roads in the area and overall characteristics of driver behaviour which are not, at this stage, amenable to modelling. For example, vehicles operated in predominantly hilly regions are found to have considerable lower free speeds than those in rolling terrain. Similarly, the free speeds of vehicles operated on roads where straying animals are common, or that tend to have slow-moving animal-drawn carts, are lower than those of vehicles operated on roads which are free of such obstacles

B.2 The following tables enable estimates of speed to be made over any section of road. Where possible, free speeds should he determined by field measurement on a flat, straight, smooth and wide section of road. Where it is not possible to determine a local value, the mid value for the range given in the tables should be used. Starting with the estimate of 85th percentile free speed, reductions from this are successively made to take account of road rise, fall, horizontal curvature, width, etc, for the road section approaching the geometric element being designed. In most cases, the design vehicle will be a car, and Table B 1 should be used.

B.3 These tables give only crude estimates of the 85th percentile speed and SHOULD BE USED WITH CAUTION

TABLE B1:CAR SPEEDS

		85th percentile "free speed" of cars (km/h)								
		65	70	75	80	85	90	95	100	105
	10	1	1	2	2	3	3	4	4	5
	20	1	2	3	4	5	6	7	8	9
	30	2	4	5	7	8	10	11	13	14
Reduction in	40	3	5	7	9	11	13	15	17	19
speed (km/h)	50	3	6	9	11	13	16	18	21	24
due to rise	60	4	7	10	13	16	19	22	25	28
(m/km)	70	5	8	12	15	19	22	26	29	33
	80	6	10	14	18	22	26	30	34	38
	90	6	11	15	20	24	29	33	38	42
	100	7	12	17	22	27	32	37		
	110	8	13	19	24	30	35			
	120	8	14	20	26	32				
	130	9	16	22	29					
	140	10	17							
	10	1	1	1	1	1	1	1	1	1
	20	1	1	2	2	2	2	2	2	2
	30	2	2	2	2	2	3	3	3	3
Reduction in	40	3	3	3	3	3	3	3	4	4
speed (km/h)	50	3	4	4	4	4	4	4	5	5
due to fall	60	4	4	5	5	5	5	5	5	6
(m/km)	70	5	5	5	6	6	6	6	6	6
	80	6	6	6	6	6	7	7	7	7
	90	6	6	7	7	7	8	8	8	8
	100	7	7	8	8	8	8	9		
	110	8	8	8	9	9	9			
	120	8	9	9	9	10				
	130	9	9	10	10					
	140	10	10							
	100	3	5	6	7	9	10	11	13	14
	200	7	9	12	15	17	20	23	25	28
Reduction in	300	10	14	18	22	26	30	34	38	42
speed (km/h)	400	13	19	29	29	35	40	45		
due to	500	17	23	30	37	43	50			
curvature	600	20	28	36	44	52				
(degrees/km)	700	24	33	42	51					
	800	27	37	48						
	900	30	42							
	1000	34	47							

REDUCTION IN SPEED DUE TO ROAD WIDTH

Width (metres)	≥5.0	4.5	4.0	3.5	3.0	2.5
Reduction in speed (km/h)	0	5	10	15	19	24

REDUCTION IN SPEED DUE TO ROAD TYPE AND CONDITION

Road	Reduction in speed (km/h)
"Good" paved	2
Pot–holed paved	5
"Good" gravel	4
"Average" gravel	7
Corrugated	11

TABLE B2 : TRUCK AND BUS SPEEDS

		85th percentile free speed of trucks and buses (km/h) 55	60	65	70
Reduction in speed (km/h) due to rise (m/km)	10	2	3	5	7
	20	3	7	10	14
	30	5	10	15	21
	40	7	14	21	27
	50	9	17	26	34
	60	10	21	31	41
	70	12	24	36	48
	80	14	28	41	55
	90	16	31	46	62
	100	17	34	52	
	110	19	38	57	
	120	21	41		
	130	22			
	140	24			
Reduction in speed (km/h) due to fall (m/km) *Increase in speed	10	2	1	0	1*
	20	3	2	0	1*
	30	5	3	0	2*
	40	7	4	0	3*
	50	9	5	1	3*
	60	10	6	1	4*
	70	12	6	1	5*
	80	14	7	1	5*
	90	15	8	1	6*
	100	17	9	1	
	110	19	10	1	
	120	21	11		
	130	22			
	140	29			
Reduction in speed (km/h) due to curvature (degrees/km)	100	2	4	6	8
	200	3	7	12	16
	300	4	11	17	24
	400	6	15	23	
	500	8	18	29	
	600	10	22		
	700	11	26		
	800	13	29		
	900	14			
	1000	16			

INCREASE IN SPEED DUE TO POWER TO WEIGHT RATIO

		85th percentile "free speed" of trucks and buses (km/h) 55	60	65	70
Increase in speed (km/h) due to power to weight ratio (bhp/tonne)	5:1	3	4	6	7
	10:1	6	9	11	14
	15:1	9	13	17	21
	20:1	12	17	22	27
	25:1	15	21	28	34
	30:1	18	25	33	41
	35:1	21	30	39	48
	40:1	24	34	44	55

REDUCTION IN SPEED DUE TO ROAD WIDTH

Width (metres)	≥5.0	4.5	4.0	3.5	3.0	2.5
Reduction in speed (km/h)	0	4	7	11	15	19

REDUCTION IN SPEED DUE TO ROAD TYPE AND CONDITION

Road	Reduction in speed (km/h)
"Good" paved	4
Pot-holed paved	6
"Good" gravel	5
"Average" gravel	8
Corrugated	15

APPENDIX C

PHASING OF THE VERTICAL AND HORIZONTAL ALIGNEMNT

DEFECTS IN THE ALIGNMENT DUE TO MISPHASING

C.1 Phasing of the vertical and horizontal curves of a road implies their coordination so that the line of the road appears to a driver to flow smoothly, avoiding the creation of hazards and visual defects. It is particularly important in the design of high-speed roads on which a driver must be able to anticipate changes in both horizontal and vertical alignment well within his safe stopping distance. It becomes more important with small radius curves than with large.

C.2 Defects may arise if an alignment is misphased. Defects may be purely visual and do no more than present the driver with an aesthetically displeasing impression of the road. Such defects often occur on sag curves. When these defects are severe, they may create a psychological obstacle and cause some drivers to reduce speed unnecessarily. In other cases, the defects may endanger the safety of the user by concealing hazards on the road ahead. A sharp bend hidden by a crest curve is an example of this kind of defect.

TYPES OF MISPHASING AND CORRESPONDING CORRECTIVE ACTION

C.3 When the horizontal and vertical curves are adequately separated or when they are coincident, no phasing problem occurs and no corrective action is required. Where defects occur, phasing may be achieved either by separating the curves or by adjusting their lengths so that vertical and horizontal curves begin at a common chainage and end at a common chainage. In some cases, depending on the curvature, it is sufficient if only one end of each of the curves is at a common chainage.

C.4 Cases of misphasing fall into four types. These are described below together with the necessary corrective action for each type.

Insufficient separation between the curves.

C.5 If there is insufficient separation between the ends of the horizontal and vertical curves, a false reverse curve may appear on the outside edge-line at the beginning of the horizontal curve, or on the inside edge-line at the end of the horizontal curve. This is a visual defect. It is illustrated in Figs Cl(a) and Cl(b).

C.6 Corrective action consists of increasing the separation between the curves

The vertical curve overlaps one end of the horizontal curve

C.7 If a vertical crest curve overlaps either the beginning or the end of a horizontal curve, a driver's perception of the change of direction at the start of the horizontal curve may be delayed because his sight distance is reduced by the vertical curve. This defect is hazardous. The position of the crest is important because vehicles tend to increase speed on the down gradient following the highest point of the crest curve, and the danger due to an unexpected change of direction is consequently greater. If a vertical sag curve overlaps a horizontal curve, an apparent kink may be produced. This visual defect is illustrated in Fig C1(c).

C8 The defect may be corrected in both cases by completely separating the curves. If this is uneconomic, the curves must be adjusted so that they are coincident at both ends, if the horizontal curve is of short radius, or they need be coincident at only one end, if the horizontal curve is of longer radius.

Both ends of the vertical curve lie on the horizontal curve

C.9 If both ends of a crest curve lie on a sharp horizontal curve, the radius of the horizontal curve may appear to the driver to decrease abruptly over the length of the crest curve. If the vertical curve is a sag curve, the radius of the horizontal curve may appear to increase. An example of such a visual defect is illustrated in Fig C1(d). The corrective action is to make both ends of the curves coincident, or to separate them.

The vertical curve overlaps both ends of the horizontal curve

C.10 If a vertical crest curve overlaps both ends of a sharp horizontal curve, a hazard may be created because a vehicle has to undergo a sudden change of direction during passage of the vertical curve while sight distance is reduced.

C.11 The corrective action is to make both ends of the curves coincident. If the horizontal curve is less sharp, then a hazard may still be created if the crest occurs off the horizontal curve because the change of direction at the beginning of the horizontal curve will then occur on a downgrade (for traffic in one direction) where vehicles may be increasing speed.

C.12 The corrective action is to make the curves coincident at one end so as to bring the crest on to the horizontal curve.

C.13 No action is necessary if a vertical curve that has no crest is combined with a gentle horizontal curve.

C.14 If the vertical curve is a sag curve, an illusory crest or dip, depending on the "hand" of the horizontal curve, will appear in the road alignment.

C.15 The corrective action is to make both ends of the curves coincident or to separate them.

THE ECONOMIC PENALTY DUE TO PHASING

C.16 The phasing of vertical curves restricts their movement and fitting to the ground so that the designer is prevented from obtaining the lowest cost design. Therefore, phasing is usually bought at the cost of extra earthworks and the designer must decide at what point it becomes uneconomic. He will normally accept curves that have to be phased for reasons of safety. In cases when the advantage due to phasing is aesthetic, the designer will have to balance the costs of trial alignments against their elegance.

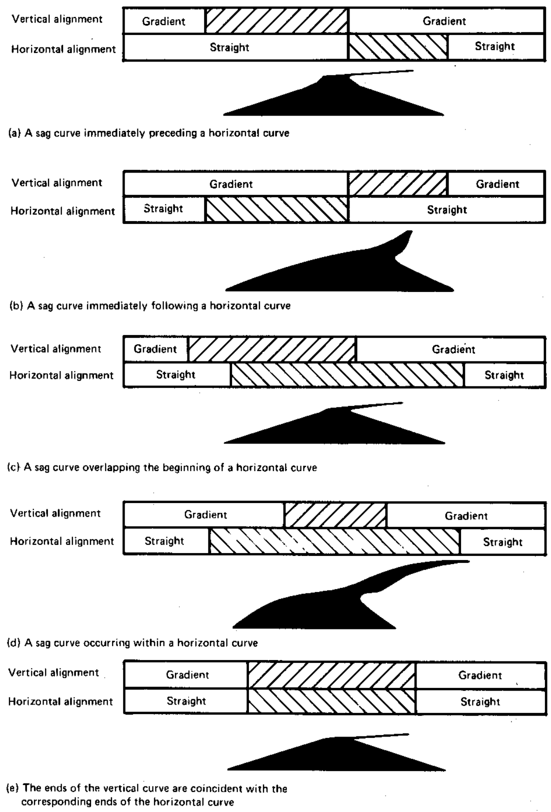

Fig C.1. Examples of some combinations of horizontal and vertical curves

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