Republic of Malawi

Ministry of Transport and Public Works

Low Volume Roads Manual

Volume 2
Geometric Design and Road Safety

July 2020

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Foreword

This Geometric Design and Road Safety Manual for Low Volume Roads applies to District, Community and Private roads in rural areas and lower-order road and street networks in urban environments. The effective management of this important component of the classified road network in Malawi depends to a great extent on the adoption of appropriate and cost-effective standards and road safety measures that meet the needs of road users at minimum life-cycle costs.

The main purpose of the Manual is to provide all practitioners with comprehensive guidance on the wide range of factors that need to be addressed in a holistic and environmentally sustainable manner when undertaking the geometric design of rural roads or urban roads and streets, including the provision of road safety measures. The Manual takes account of best practice developments in low volume roads technology that have evolved both regionally and internationally in the past few decades. The Ministry, therefore, expects all practitioners in the roads sector to adhere to the standards set out in the Manual. This will ensure that a consistent, harmonised approach is followed in the design of low volume roads in the country.

The development of the Manual was overseen by a Technical Steering Committee comprising representatives from a wide range of stakeholder organisations from the Government, the private sector and academia. By its very nature, the manual will require periodic updating to take account of the dynamic developments in low volume roads technology. The Ministry would, therefore, welcome comments and suggestions from any stakeholders as feedback on all aspects of the Manual during its implementation. All feedback will be carefully considered by professional experts in future updates of the Manual.

On behalf of the Ministry of Transport and Public Works, I would like to thank UK Aid through the Department for International Development (DFID) for its support of the development of the Manual. I would also like to thank the Project Management Unit (PMU) of the Research for Community Access Partnership (ReCAP) and Infra Africa Development Consultants for their role in managing the project. In addition, l would commend all the roads sector stakeholders who contributed their time, knowledge and effort during the development of the Manual.

It is my sincere hope that this Manual will herald a new era in the more efficient and cost-effective provision of low volume roads in Malawi. In so doing, it will make a substantial contribution to the improved infrastructure of our country and, in the process, enhance socio-economic growth and development, particularly in the rural areas of the country.

Mr Francis Chinsinga
Secretary.for.Transport.and.Public.Works
Ministry of Transport and Public Works

Acknowledgements

The Ministry of Transport and Public Works wishes to acknowledge the support that was provided by the United Kingdom Department for International Development (DFID) for the preparation of the Geometric Design and Road Safety Manual for Low Volume Roads. The project was carried out under the aegis of the Research for Community Access Partnership (ReCAP) – a DFID-funded research programme that promotes safe and sustainable access for rural communities in Africa.

Technical Steering Committee

The development of the Manual was guided by a Technical Steering Committee comprising professionals from both public and private sector organizations.

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Project Management

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Peer Review

The manual was reviewed by Eng. Charles Bopoto, Independent Consultant (Zimbabwe).

Director of Roads
Roads Authority
Ministry of Transport and Public Works

List of Abbreviations, Acronyms and Initialisms

AADT	Average Annual Daily Traffic
ADT	Average Daily Traffic
ARRB	Australian Road Research Board
BVC	Beginning Vertical Curve
CE	Car Equivalent
CEF	Car Equivalency Factor
CSD	Context-Sensitive Design
CSIR	Council for Scientific and Industrial Research
DFID	Department for International Development
DSD	Decision Sight Distance
EDD	Extended Design Domain
EF	Equivalence Factor
EVC	End Vertical Curve
GDP	Gross Domestic Product
GPS	Global Positioning System
HGV	Heavy Goods Vehicle
HVR	High Volume Roads
iRAP	International Road Assessment Programme
ITE	Institute of Transportation Engineers
LBM	Labour-based Methods
LED	Light-emitting diode
LCC	Life-cycle Cost
LGV	Light Goods Vehicle
LVR	Low Volume Road
LVSR	Low Volume Sealed Road
MAP	Mean Annual Precipitation
MESA	Million Equivalent Standard Axles
MGV	Medium Goods Vehicle
MOTPW	Ministry of Transport and Public Works
NDD	Normal Design Domain
NMT	Non-motorised Traffic
NPV	Net Present Value
O-D	Origin - Destination
ORN	Overseas Road Note
PCU	Passenger Car Units (CE units)
PSD	Passing Sight Distance
PVI	Point of Vertical Intersection

RA	Roads Authority
RSA	Road Safety Audit
RSI	Road Safety Inspection
SSA	Sub-Saharan Africa
SADC	Southern African Development Community
SE	Superelevation
SSD	Stopping Sight Distance
SU	Single Unit Truck
TIA	Traffic Impact Assessment
TLC	Traffic Load Class
TRL	Transport Research Laboratory
TSC	Technical Steering Committee
UK	United Kingdom
UKAID	UK Department for International Development
USA	United States of America
UTG	Urban Transport Guidelines
VEF	Vehicle Equivalence Factor
VOC	Vehicle Operating Costs
VPI	Vertical Point of Intersection

Terminology

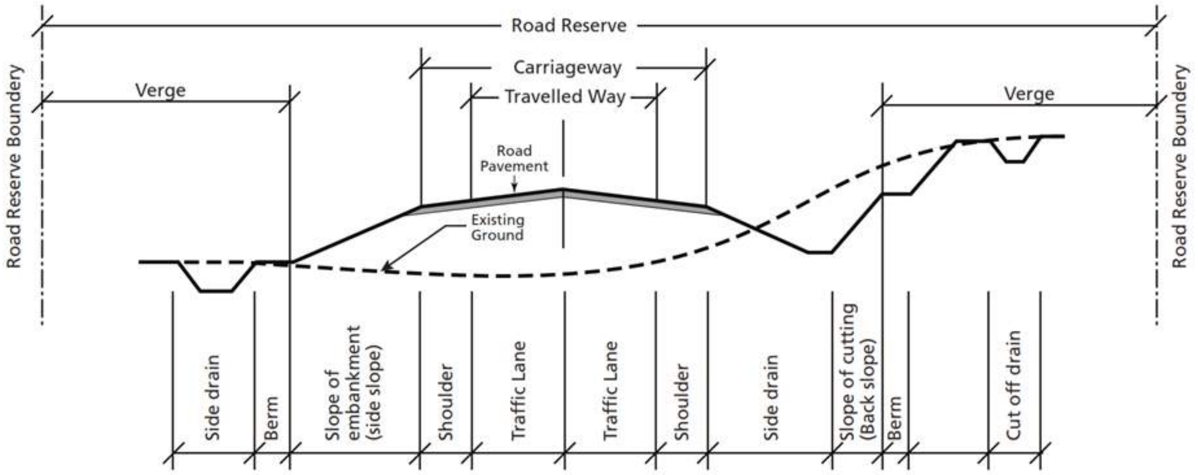

Figure 1: Road cross section

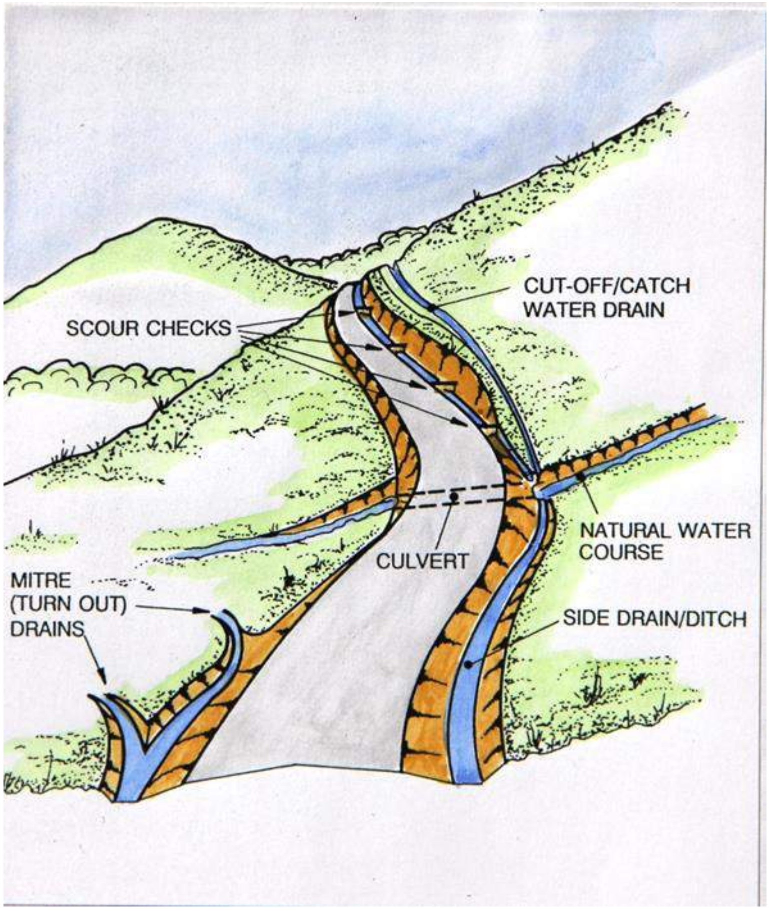

Figure 2: Main drainage elements

Part A

Rural Roads

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1 Overview

2 Approach to Design

3 Fundamental Design Considerations

4 Traffic

5 Cross Section

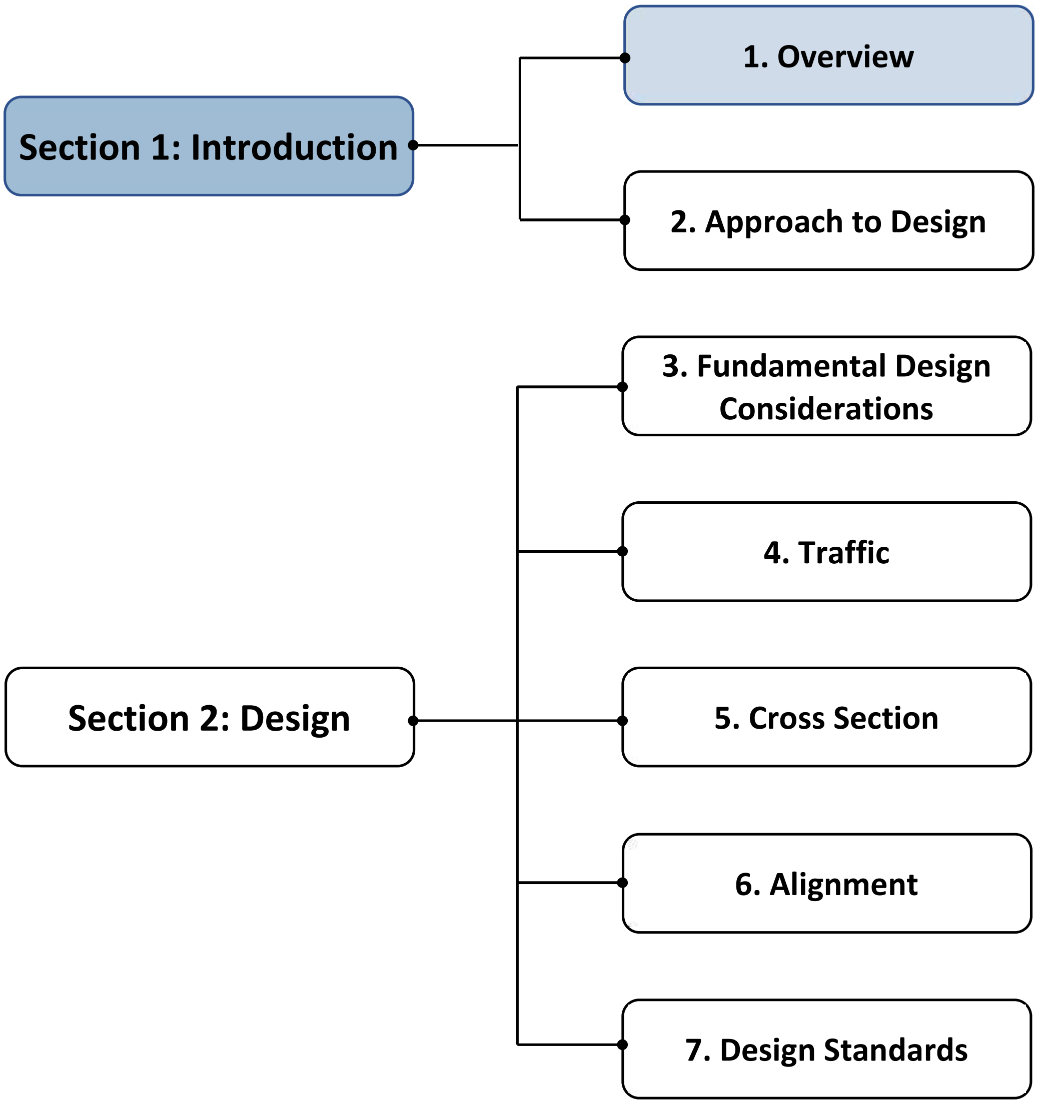
6 Alignment

7 Design Standards

Section 1

Introduction

Low Volume Roads Manual
Part A – Geometric Design: Rural Roads



Chapter 1 – Overview

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1.1 Background

Low volume roads (LVRs) comprise a substantial proportion of the road network in Malawi and serve a large segment of the population that lives in the rural areas of the country where agriculture is the dominant economic activity. LVRs are viewed as a key driver for improving rural well-being, economic development, community livelihoods and food security. The attainment of this goal depends critically on the existence of sound rural road infrastructure. It is therefore important that roads agencies in Malawi are able to apply appropriate, sustainable, country-specific design standards and practices that are tailored to the rural road needs of the country.

The cost of providing rural road infrastructure based on traditional standards and design methods can be prohibitive. This is because these approaches, aimed at mobility, tend to be ill-matched to the dictates of access in the local road environment. As a result, they are generally far too costly for application to the rural road network in Malawi. This has led to a need to develop new Design Manuals for Low Volume Roads in Malawi that are tailored to the needs of the country and take account of the many advances in LVR technology that have taken place in recent times in the region and internationally.

1.2 Purpose

The purpose of the Manual is to provide guidance on geometric design standards for single carriageway rural roads. It deals with new construction where no roads existed previously (greenfield sites) and with rehabilitation and upgrading of existing roads (brownfield sites).

The Manual is aimed at government officials who are responsible for formulating policy on the geometric design of LVRs and engineers who are responsible for preparing road designs. It will also be of interest to personnel in aid agencies and Consultants who are responsible for the preparation and design of road projects.

1.3 Scope

The Manual highlights the approach to the geometric design of low volume access roads in terms of a number of factors that differ significantly from higher volume mobility roads. The fundamental design parameters that influence the development of an appropriate design solution are then addressed as a basis for selecting appropriate design standards in terms of cross section elements, horizontal and vertical alignment as well as road safety considerations. The thrust of the approach has been to develop a design methodology that emphasizes the economic aspects of geometric design for LVRs.

1.4 Development of the Manual

The development of the Manual was overseen by a Technical Steering Committee (TSC) comprising the following stakeholder organisations:

- Roads Authority
- Ministry of Transport and Public Works – Roads Department
- Ministry of Local Government and Rural Development
- Technology Transfer (T2) Centre
- University of Malawi, The Polytechnic
- Malawi Institution of Engineers
- Directorate of Road Traffic and Safety Services
- Association of Consulting Engineers

As a result of the high level of local participation in the development of the Manual, it has been possible to capture and incorporate a significant amount of local knowledge in the document.

1.5 Structure of the Manual

Due to the many differences between the geometric design requirements of rural and urban roads, geometric design is separated in two self-standing Parts of the Manual, namely, Part A which deals with rural roads, and Part B, which deals with urban and peri-urban roads and streets, as shown in Table 1-1.

Road safety, which to a large degree is common to both rural and urban roads, is addressed in Part C of this Manual.

Table 1-1: Structure and Content of the Manual

Part A – Geometric Design: Rural Roads	
Section	**Chapter**
1. Introduction	1. Overview
	2. Approach to Design
2. Design	3. Fundamental Design Considerations
	4 Traffic
	5. Cross Section
	6. Alignment
	7. Design Standards

Part B – Geometric Design: Urban Roads	
Section	**Chapter**
1. Introduction	1. Overview
	2. Approach to Design
2. Design	3. Fundamental Design Considerations
	4. Traffic
	5. Stormwater Drainage
	6. Cross Sections
	7. Alignment
	8. Intersections

1.6 Benefits of Using the Manual

There are a number of benefits to be derived from adopting the approaches advocated in the Manual. These include providing LVRs that:

- Are less expensive, in economic terms, to build and to maintain through the adoption of more appropriate LVRR technology including geometric design standards that are better suited to local conditions.
- Take a better account of the needs of all stakeholders, particularly the local communities served by such roads.
- Ultimately, facilitate the longer-term goal of socio-economic growth, development and poverty alleviation in Malawi.

1.7 Sources of Information

In addition to providing general information and guidance, the Manual also serves as a valuable source document because of its comprehensive lists of references from which readers can obtain more detailed information to meet their particular needs. A bibliography can be found at the end of each chapter of the Manual. Where the sources of any tables or figures are not specifically indicated, they are attributed to the authors.

1.8 Updating of the Manual

As LVR technology is continually being researched and improved, it will be necessary to update the Manual periodically to reflect improvements in practice. All suggestions to improve the Manual should be in accordance with the following procedures:

- Any proposed amendments should be sent to the Chief Executive Officer of the RA, motivating the need for the change and indicating the proposed amendment.
- Any agreed changes to the Manual will be approved by the Chief Executive Officer of the RA, after which all stakeholders will be advised accordingly.

1.9 Departure from Standards

There may be situations where the designer will be compelled to deviate from the standards presented in this Manual. Where the designer departs from a standard, he/she must obtain written approval and authorization from the RA. The designer shall submit the following information to the RA:

- The aspect of design for which a Departure from Standards is desired.
- A description of the standard, including the normal value, and the value of the Departure from Standards.
- The reason for the Departure from Standards.
- Any mitigation to be applied in the interest of reducing, for example, road accidents.

The designer must submit all major and minor Departures from the Standards and his/her proposal for approval. If the proposed Departures from the Standards are acceptable, such departures will be given approval by the Chief Executive Officer of the RA.

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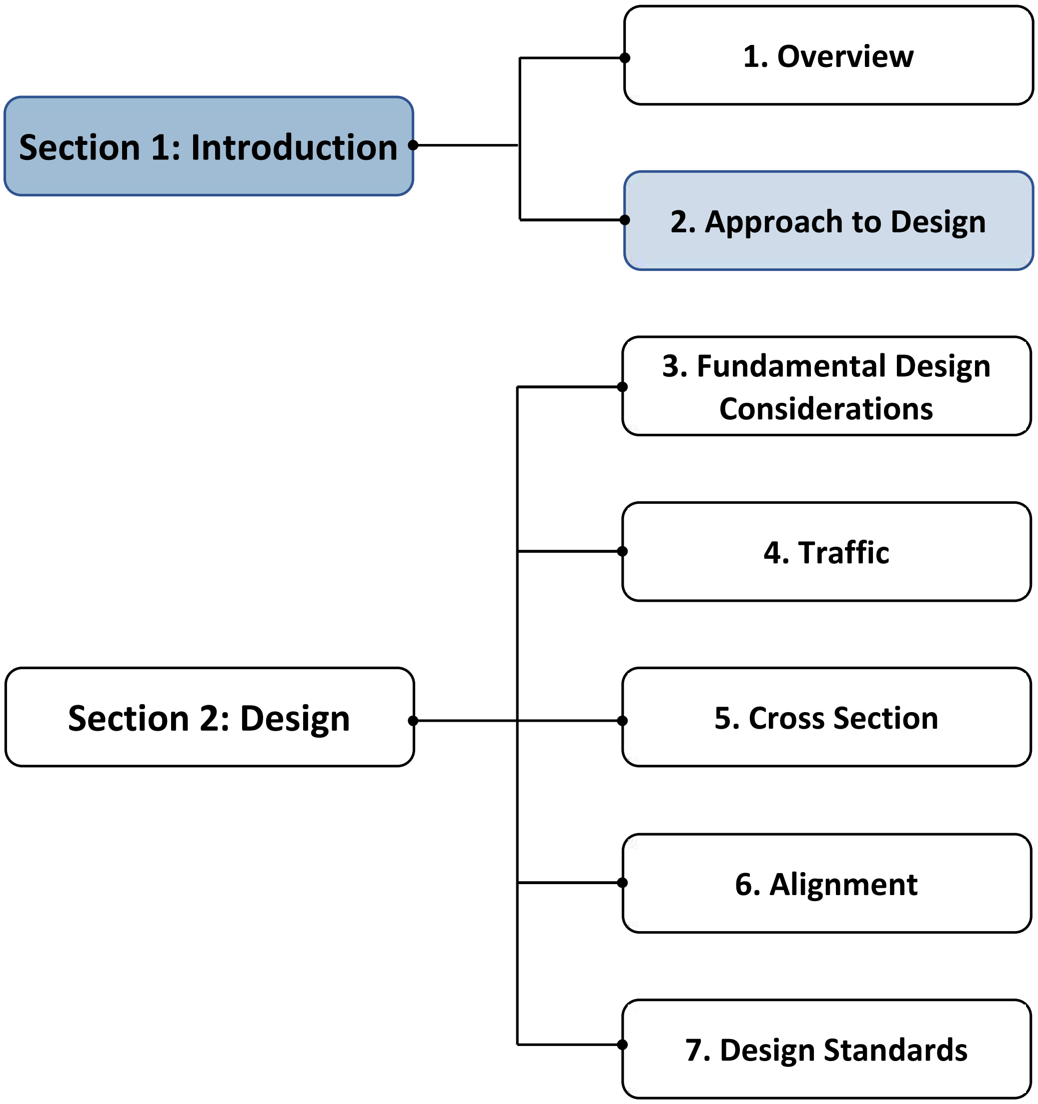
Low Volume Roads Manual
Part A – Geometric Design: Rural Roads



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2.1 Introduction

2.1.1 Background

Conventional highway geometric design relates higher standards to increasing speed, the volume of traffic, and user comfort and convenience, which has led to relatively high-cost solutions. The application of these standards on LVRs cannot be justified since the costs would far exceed the commensurate benefits. Thus, a more holistic approach needs to be taken in which the over-riding criterion of acceptability is the achievement of an appropriate level of all-year access to communities at "least cost" (in terms of total life-cycle costs), while at the same time ensuring the LVRs are "fit for purpose" in terms of user requirements and road safety.

2.1.2 Purpose and Scope

The main purpose of this chapter is to outline the approach for the design of LVRs in a manner that is context-sensitive, and that emphasises the economic aspects of geometric design whilst taking due account of the road safety aspects. Flexibility in the application of the guidance given in this chapter is encouraged so that independent designs tailored to particular situations can be developed.

The chapter firstly presents the definition and classification system used in the Manual for LVRs in Malawi. This is then followed by an overview of the Context Sensitive Design (CSD) concept and the application of this concept in terms of a number of design considerations that influence the geometric design process. Finally, an elaboration of the CSD concept is presented in Appendix A whilst a generic Table of Contents for a design report is presented in Appendix B.

2.2 Definition of Low Volume Roads

For pavement design purposes, Low Volume Roads (LVRs) are defined as those roads that have a base year average daily traffic (ADT) of up to about 300 motorised, 4-wheeled vehicles, including about 20-25% commercial vehicles, and a related traffic loading of up to about one million Equivalent Standard Axles (MESA) per lane over a design life of typically 10 – 15 years. Depending on the number and mass of the commercial vehicles in the traffic stream, the base year traffic for pavement design purposes, thus, could be somewhat more or less than 300 vpd for the same traffic loading. For geometric design purposes, however, the traffic at mid-life is required and this could exceed 300 motor vehicles per day. However, none of these figures provide a complete picture of the unique characteristics of LVRs in that there are many other aspects that need to be considered in their design as discussed below.

2.3 Road Classification System

2.3.1 General

Malawi's road network comprises various types of rural and urban roads, each of which fulfils a particular function in facilitating vehicular travel between points of origin and destination as well as providing access to property. The classification of the network is essential for a variety of purposes, including policy and planning activities. It entails an orderly grouping of roads into a set of sub-systems according to the type of service they are intended to provide to the public.

2.3.2 Classification System

The key objective of a well-conceived classification system is to facilitate road user accessibility to all parts of the road network, thereby improving transport efficiency and, in turn, improving, sustaining and supporting social and economic growth and development. In this regard, Malawi's roads have been classified on the basis of their function, i.e. the purpose or the character of the service that they are intended to provide in terms of connecting different centres of population and economic activity. Based on the current Public Roads Bill, six distinct classes of roads have been defined in relation to whether they serve an essentially *mobility* or *access* function as shown in Table 2-1. This functional classification system is not related in any way to the pavement design of the road which is based on the cumulative traffic loading over its design life.

Table 2-1: Road classification system

Basic Function	Class No.	Level of Service	Road Class	Road Definition
Mobility	1	*Very.high:* Provides the highest level of service at the greatest speed for the longest uninterrupted distance, with minimal degree of access control. To be designed to the highest standards.	International Arterial	Roads that link international centres. Connection between the national road system and those of neighbouring countries.
	2		National Arterial	Roads that link cities, towns and centres of economic importance with each other and with major border posts or link to international roads.
	3	*High:* Provides a less highly developed level of service at relatively high speed for shorter distances by collecting traffic from main centers of population and connecting them with primary national roads.	Secondary-Arterial	Roads that link major towns to each other or link to the international road network.
			Secondary-collector	Roads that link towns, villages, agricultural, commercial, recreational or major tourist areas to each other or link to the national road network.
Access	4	*Moderate:.*Provides a moderate level of service at moderate speed	District	Roads that link district centres, villages, local centres of population and developed areas with each other or link to higher order roads of the road network.
	5	*Moderate-Low:.*Provides a relatively low level of service at moderate-low speed	Community	Roads that provide access to land adjacent to the collector network, or to villages or link to tertiary or higher order roads of the road network.
	6	N/A	Cycleway / Walkway	Paths or tracks that link communities or settlements with each other.

Note: The term "level of service" referred to in Table 2-1 does not indicate the capacity Levels of Service (LoS) A to F. It refers to the quality/standard of road provided, in that a high order road, such as a Primary International road, has a relatively high level of service meaning wider road reserve, wider lanes, maximum road signs, rest areas, landscaping, and so forth.

Mobility roads

These relatively high-trafficked roads are designed to move traffic over relatively long distances quickly, effectively and efficiently. They are therefore higher speed through routes on which movement is dominant, and access and pedestrian crossings are limited to defined and clearly demarcated positions at widely spaced intervals.

Access Roads

These are relatively low volume roads designed to provide access to the various land uses and activities associated with access, such as turning, stopping, parking, pedestrian safety and associated low-speed movements (the activity/access function). The provision of access allows both vehicles and pedestrians entry to and from adjacent land. As such, care must be taken to keep speeds low for the safety of slow-moving pedestrians and turning traffic.

The majority of District and Community roads are essentially, but not necessarily, LVRs. However, the functional class associated with different mixes of traffic can sometimes alter these generalisations (e.g. a LVR serving a military function or a road serving a quarry that uses particularly large vehicles), but this is not common.

This Manual deals with the design of low volume, access-type roads only for which the standards are quite different from those for mobility roads, which generally attract more traditional design standards. Such standards may be found in the *SATCC.Draft.Code.of.Practice.for.the.Geometric Design of Trunk.Roads* (September 1998; reprinted July 2001).

The functional relationship between road class and function is illustrated in Figure 2-1.

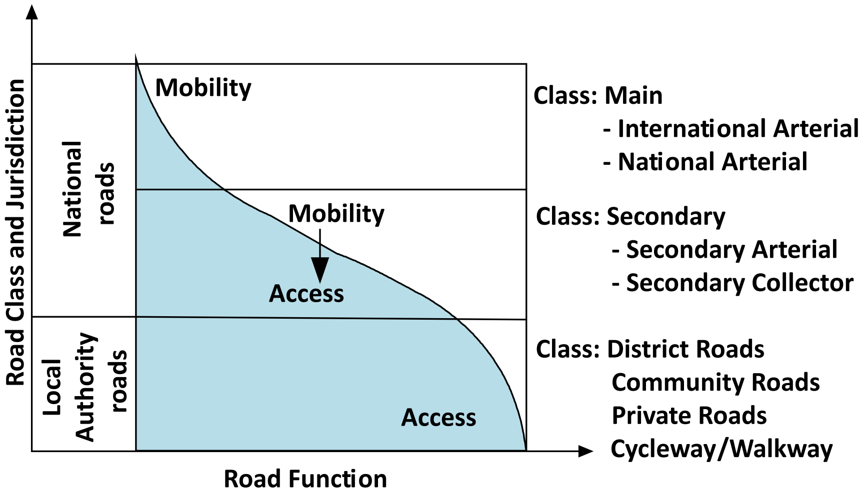

Figure 2-1: Relationship between Road Class and Road Function

2.3.3 Hierarchy of Roads

A schematic diagram of the various road classes is illustrated in Figure 2-2. The purpose of the diagram is to illustrate the relative function of the road classifications in terms of primary/secondary and district/community roads. This is a generic diagram and, in practice, there will be many overlaps of function and clear distinctions may not always be apparent in functional terms alone.

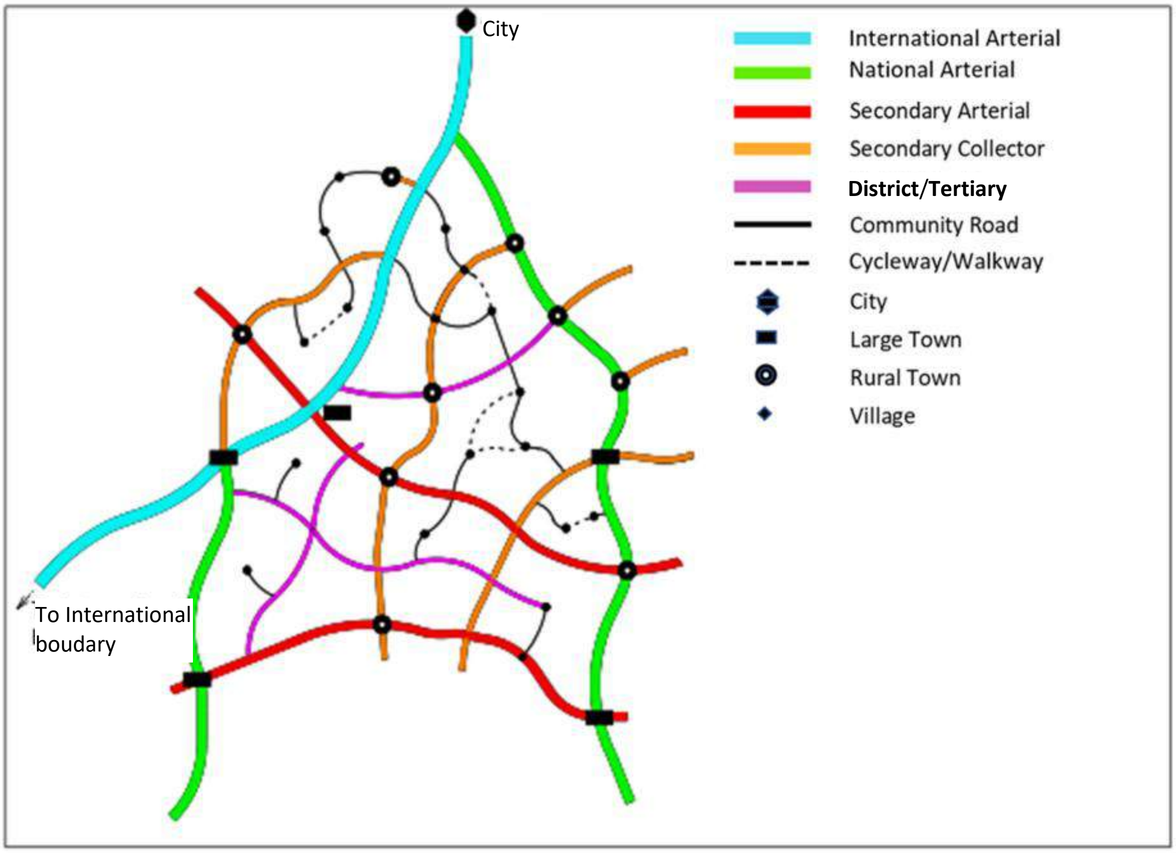

Figure 2-2: Road hierarchy and functions

Based on the functional classification system described above, Table 2-2 shows the traffic levels of those classes of roads which, for geometric design purposes, may be defined as low volume roads.

Table 2-2: Classification of LVRs - Road Design Classes

Road Design Class	AADT at Mid Design Life	Functional Class
LVR5	>400	Could be District or Community roads
LVR4	200 – 400	
LVR3	100 – 200	
LVR2	50 – 100	
LVR1	< 50	

As stated in Section 2.2, for geometric design purposes, the mid-life ADT rather than the base year or end of life ADT, traffic is used. This is to strike an economic balance between ensuring that the road is not significantly over-designed at the beginning of its life (by adopting an end design life traffic ADT), or under-designed at the end of its design life (by adopting a base year ADT). Thus, a LVR with a base year ADT < 300 (in accordance with the LVR definition) may have a mid-life ADT > 400 depending on the forecasted traffic growth, and be classified on that basis as LVR5. Similarly, a LVR with base year ADT = 40 may have a mid-life ADT of 50 – 100 and be classified on that basis as LVR2.

2.4 Characteristics of Low Volume Roads

The particular characteristics of LVRs affecting their geometric design include the following:

- LVRs often need to cater for high proportions of NMT, including pedestrians, bicycles and animal-drawn carts as well as motorcycle traffic, a traffic mode that has grown tremendously during the last few years in many parts of southern Africa and elsewhere and often constitute the main means of public transport.
- The majority of LVRs are relatively short in length and travel time, and therefore, speed is not a deciding factor for the required service level and associated geometric standard.
- Existing land use and adjacent properties often limit the effective cross-section width that can be constructed without causing major disturbances to the local population and high associated costs for land acquisition and compensation.
- Existing land use and adjacent properties often limit the effective cross-sectional width that can be constructed without causing major disturbances for the local population and associated costs for land acquisition and compensations.
- Most road users are familiar with the terrain and alignment of the road and will, therefore, take necessary precautions to avoid conflicts and accidents.
- LVRs are often constructed by labour-based methods, which limits the volume of earthworks that can be constructed within reasonable costs.

In light of the above LVR characteristics, the main concerns of the engineer are:

- To design a road that is “fit for purpose” by fitting the road into the physical environment at least cost allowing the existing alignment to fix the travel speed and variable cross section width to accommodate the prevailing traffic.
- To address potential “black spots” with properly engineered solutions such as appropriate traffic calming or road widening and lane segregation at blind crest curves.

2.5 Context Sensitive Design

2.5.1 General

Context-Sensitive Design (CSD) provides a significant change from the traditional approach of focusing almost exclusively on mobility to an approach that balances access, safety and environmental preservation with the available funding. The approach provides flexibility to encourage independent designs tailored to particular situations, i.e. the design can deviate when necessary from accepted design criteria provided acceptable standards of safety are achieved at reduced costs. The challenge is to develop a design solution that takes account of the competing alternatives and trade-offs that might be needed, as discussed further in *Appendix.A:.Design.Domain.Concept.*

CSD recognises that, in some cases, exceptions may be required in applying standards. For example, where the provision of an engineered alignment results in excessive earthworks, it may be preferable to accept variable travel speeds in order to reduce costs and minimise social or environmental impacts whilst paying due attention to road safety through the adoption, where necessary, of appropriate countermeasures. An example of this approach is presented below in *Section.2.6.4 – Alignment.Design.*

By applying CSD, the approach to design adopted in this Manual addresses the unique requirements, and recommends appropriate geometric design standards, for LVRs. By so doing, it affords design engineers with the flexibility to adopt appropriate standards that are less restrictive and costly than those generally applied to HVRs. However, where there is a deviation of the normal standard for one element, it is usually required that a higher than normal standard be used for other elements to compensate (e.g. the use of wider pavement where a vertical crest curve of a low standard must be adopted). Thus, the approach discourages unnecessary improvements to the road geometry and the roadside, except where there is site-specific evidence of safety problems where such improvements are likely to provide substantial safety benefits.

The approach outlined above should also consider the potential effects of future development that may affect the function of the road within its design life in terms of changes in traffic volumes, patterns, and operating conditions. Should such changes result in a likely reclassification of the road to a higher class outside of the LVR range, then the standards for higher volume roads should be adopted.

2.5.2 Design and Operating Speed

Design speed is traditionally used in highway design 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 and not faced by 'surprises'. However, the uniform design speed concept should be reconsidered as a basis for the design of LVR for two reasons:

1) Low volume access roads are distinctly different from higher volume mobility roads, for which higher, consistent design and operating speeds are justified.
2) Applying uniform design speeds to LVR designs to obtain a consistent speed environment will inevitably lead to increased earthworks, acquisition of adjacent land and properties for adjustment or horizontal and vertical alignment, and consequently higher project costs.

Operating speed on LVRs will, therefore normally be variable and dictated by the terrain, existing alignment (in case of upgrading) and roadside developments, always accepting the principle of not surprising the driver. Usually, LVRs will accommodate variable operating speeds up to 80 km/h, but some access roads have long open stretches traversing gentle terrain where it may be feasible and desirable to allow for higher speeds without incurring unjustifiable costs, in which case traditional highway standards may be more appropriate.

2.5.3 Road Width and Traffic Safety

In addition to such factors as traffic composition and travel speed, topography/terrain and nature of the roadside development, the number of conflicts (vehicles passing in opposite directions) on a LVR is a key determinant of carriageway width. Table 2-3 shows the average number of interactions/km/hour and time between interactions/km for different directional splits based on uniform traffic distribution over 12-hour travelling day and gives a good indication of the actual situation on LVRs in terms of potential conflicts and accidents.

Table 2-3: Avg. no of interaction/km/hour and time between interactions/km on LVRs

	Average no of interactions/km/hour				Minutes between interactions/km			
ADT	**300**		**100**		**300**		**100**	
Speed km/h	**Traffic directional split**				**Traffic directional split**			
	50/50	**75/25**	**50/50**	**75/25**	**50/50**	**75/25**	**50/50**	**75/25**
40	7.81	5.86	0.43	0.65	7.7	10.2	69.1	92.2
60	5.21	3.91	0.58	0.43	11.5	15.4	103.7	138.2
80	3.91	2.93	0.87	0.33	15.4	20.5	138.2	184.3

The number of interactions/km/hour is independent of the length of the road, and, as indicated in Table 2-3, even on roads with 300 vpd, the number of potential conflicts is very low and considerable periods of time elapse between potentially hazardous meeting situations. It is also apparent from observation that on LVRs, vehicles tend to travel towards the centre of the road even with a road width of 6.0 m which, in principle, allows for segregated lane traffic. With this width, the outer wheel path is usually not clearly defined, but will typically be ≥ 1.0 m from the edge of the road.

In view of the above, it can be concluded that for most of the time and at all traffic levels, LVRs as defined above, are effectively operating as single-lane roads and that this feature can be used to ensure satisfactory levels of service and safety for all road users without resorting to unnecessarily generous and costly standards. A consequence of this is that normal shoulders or additional width to accommodate NMT in a low-speed environment can be omitted except in particularly busy areas within villages, trading areas etc. This would lead to substantially reduced costs compared to current LVR standards, which are more related to HVRs. On this basis, the recommended carriageway widths for five different basic geometric standards (LVR1 – LVR5) are presented in *Chapter.5 – Cross.Section.*

The safe and comfortable accommodation of road users is closely related to the width of the carriageway and the travelling speed of motorised traffic. At high vehicle speeds, more space is needed for other road users to feel safe. Conversely, wide roads tend to encourage high speeds, thereby reducing the level of road safety, both real and perceived. Speed is universally recognised as being closely related to the risk of road accidents, hence the LVR design must aim at keeping travelling speeds relatively low.

The typical traffic situations on a LVR4 road with less than 400 vpd and a low percentage of heavy traffic – typically up to about 25% – are illustrated in Figure 2-3 to Figure 2-6. With these low traffic volumes, vehicles tend to travel towards the middle of the road leaving space for pedestrians and motorcycle/cyclists on either side.

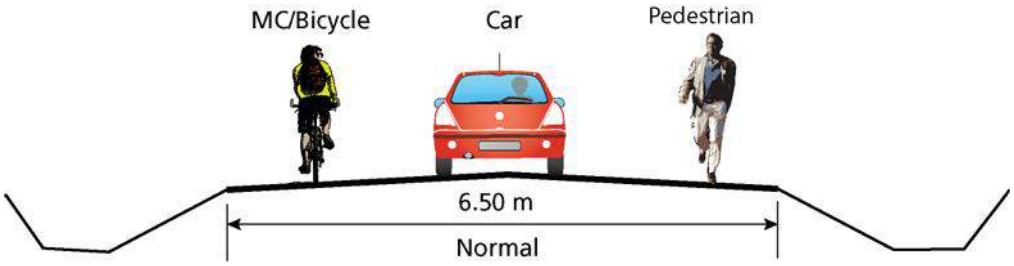

Figure 2-3: Typical traffic situation (LVR4 standard - schematic)

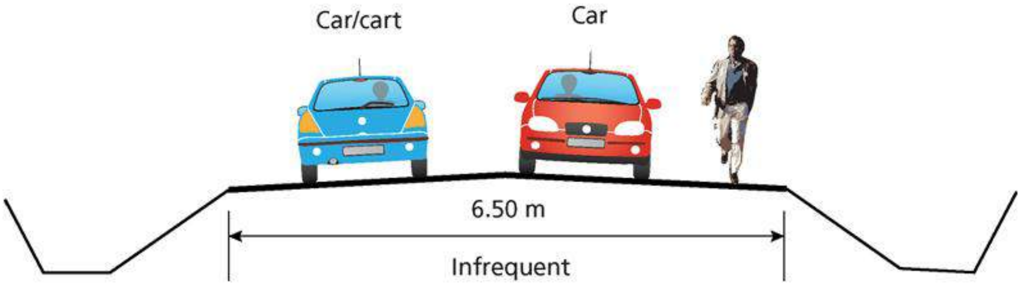

Figure 2-4: Infrequent traffic occurrence (LVR4 standard - schematic)

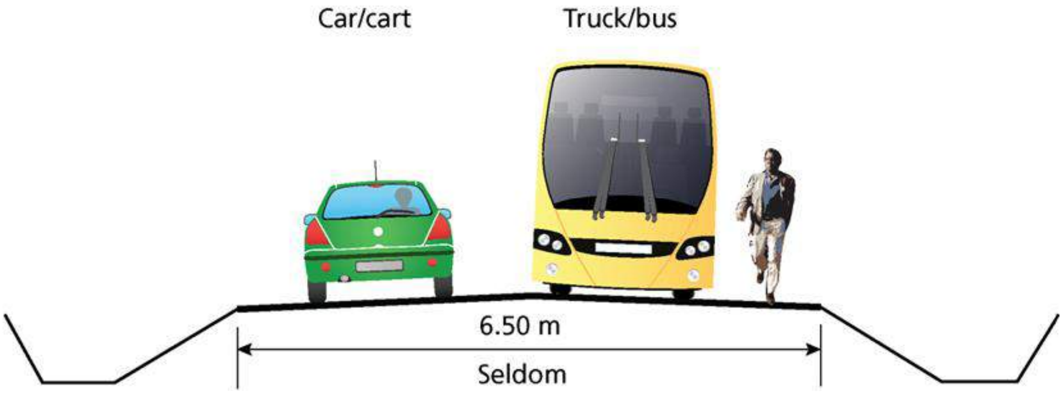

Figure 2-5: Very infrequent traffic occurrence (LVR4 standard - schematic)

Figure 2-6: Rare traffic occurrence (LVR4 standard - schematic)

2.5.4 Alignment Design

There are essentially two types of projects that will be faced by the geometric designer, namely:

1) **Brownfield site:** Is a project site where a road already exists and may influence the geometric design to the extent that the use of normal design approaches may not be economically justified.

2) **Greenfield site:** Is a project site where a new road or section of a road is to be constructed where none existed before.

Designing an alignment for an entirely new road where no road existed before is a considerably more complex process than merely upgrading an existing road because of the many different route alignments that are possible and the relative lack of information available at the beginning of the process. In many cases, a pre-feasibility study may be required to identify possible corridors for the road and to decide whether the project is likely to be viable.

In view of the above, in order to produce economic standards, a careful balance needs to be struck between the cost of improving the existing alignment, both horizontally and vertically, or of widening the road, with the benefits to be derived from so doing. This requires an approach that emphasises the economic aspects of geometric design and which needs to be applied with an appropriate understanding of economic analysis.

There are two main options that may be considered for the design of a LVR alignment as follows:

Option A – Alignment engineered for fulfilling an access function

This option adopts most of the existing alignment except in problem areas where safety may be an issue. The use of this option means that to a large extent, "the existing alignment fixes the travel speed". It will result in variable cross section widths (because the width of most of the existing road need not be changed) and travel speeds but will not incur significant earthworks costs. This option is appropriate in situations where:

- The road is unlikely to change its function over its design life.
- The road is likely to be used mostly by local people and seldom by other users who are not familiar with the characteristics of the alignment.
- Problem areas such as very tight curves, steep grades or other potentially black spots are addressed by sound engineering solutions such as curve widening, lane widening and demarcation, and use of appropriate traffic calming measures.

In many cases, based on the least cost criterion discussed above, Option A is the most economical standard in that it will result in an alignment that is "fit for purpose" and provide an appropriate level of access at minimum costs. Thus, this option is recommended for the geometric design of many LVRs. However, the adoption of this option will require some good engineering judgement to be exercised by a design engineer with experience in LVR design.

The adoption of Option A is supported by research findings, which have shown that:

- In terms of geometry, drivers will choose lower speeds on roads that have rough surfaces, are narrow, winding or hilly, and where the direction of the road and the lane boundaries are not well delineated.
- Roadside environments and objects next to the road can also affect speed. Multiple objects next to the road can increase peripheral visual flow and therefore increase perceived speed, which will lead to reduced actual speed.
- Drivers will also slow down if they feel they are too close to objects on the side of the road, e.g. pedestrians and cyclists, and they feel they are unable to move away.
- Drivers choose lower speeds on roads with multiple access points to prepare for the possible entry of other vehicles and, in visually complex environments, in order to process the higher levels of visual information.

The adoption of Option A would be linked to the following measures:

- Installation of traffic calming measures where required, particularly in areas with a high incidence of non-motorised traffic (NMT), e.g. speed humps, rumble strips, warning and speed limit signs, etc.
- Fully engineered solutions at potentially hazardous spots that can be achieved within reasonable costs (e.g. road widening/lane separation over sharp crests, alignment improvement to straighten out blind curves).

- Adequate advance warning to drivers and speed-reducing measures where potentially hazardous situations cannot be avoided without incurring prohibitive costs.
- Varying road carriageway width dictated by the amount and mix of traffic and terrain.

Option B – Alignment engineered for fulfilling a mobility function

A fully engineered alignment is one in which the design speed, in most cases, determines the alignment. This option uses a consistent cross-section width throughout and a fixed design speed that determines many of the geometric requirements such as passing and stopping sight distances, engineered curvature, both horizontally and vertically, etc. These are the design principles and specifications contained in *Chapter.7 – Design.Standards,* which should be used when Option A is not appropriate.

Whenever an entirely new road is to be designed and constructed on a greenfield site, it is most likely to be in the higher road classes, and Option B is then the natural choice, but elements of Option A could still be applied.

The same principle as applied above for the design of the horizontal alignment of an LVR also applies to the vertical alignment, except where there is site-specific evidence of safety problems for which appropriate countermeasures can be put in place. For example, where sight distances do not comply with those specified for HVRs, mitigating countermeasures should be considered, such as road widening, centre line marking and, where feasible, lane separation at the approach to the vertical curve rather than embarking on earthworks to flatten the crest curve.

2.5.5 Selection of Design Standards

A geometric standard represents a service level that is deemed appropriate for the particular road environment. Typically, this service level increases with traffic and is relatively high for major, highly trafficked roads and has a clear connection with transport efficiency and economic benefits. For LVRs the benefits of a high service level are less tangible in economic terms, and, as a result, a compromise has to be reached between service level and costs in relation to the selected standard. The approach for doing so is based on the CSD concept, as described above, and elaborated on in Appendix A.

There are essentially two types of design standards considered in this Manual, as follows:

(1) Those related to an Option A alignment design that adopts lower-than-normal design standards, as applied to paved and unpaved roads with an ADT <u>less than 400 vpd at mid-life, i.e.</u> road design classes LVR1 to LVR4. These standards would generally be applied in cases where it is impractical to meet the normally applied standards, often because of extremely severe terrain conditions. Under such circumstances, the standards must be relaxed, but not at the expense of road safety for which compensatory countermeasures would be required, including traffic calming measures and road signage and markings.

(2) Those related to an Option B alignment design that adopts normally applied design standards as applied to paved and unpaved roads with an ADT <u>more than 400 vpd at mid-life</u>, i.e. road design class LVR5 and above. These standards are modified for different terrain types with optional inclusion of shoulders based on either a high number of motorcycles and NMTs and/or a high proportion of heavy vehicles. Thus, the designer has a wide range of standards from which to choose, ensuring that a suitable standard is available for almost all situations (see Tables in *Chapter.7 – Design.Standards*).

Ideally, the adoption of either an Option A or an Option B alignment should be made on the basis of a life-cycle cost analysis, as presented in the *Pavement.Design.Manual,.Chapter.12 – Life-Cycle Costing.* However, in practice, the data for undertaking such an analysis is seldom available and, instead, recourse will need to be made to sound engineering judgment.

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Appendix A: Design Domain Concept

The Design Domain concept has been developed internationally as a for the design of upgrading projects, particularly for LVRs, where it will be uneconomical to conform to the normal Design Domain applied for new roads. It places emphasis on developing appropriate and cost-effective designs rather than providing a design that simply meets “standards”. It recognises that there is a range of values which could be adopted for a particular design parameter within absolute upper and lower limits. Values adopted for a particular design parameter within the design domain would achieve an acceptable though varying level of performance in average conditions of safety, operation and economic and environmental consequences. Figure 2-7 illustrates this concept.

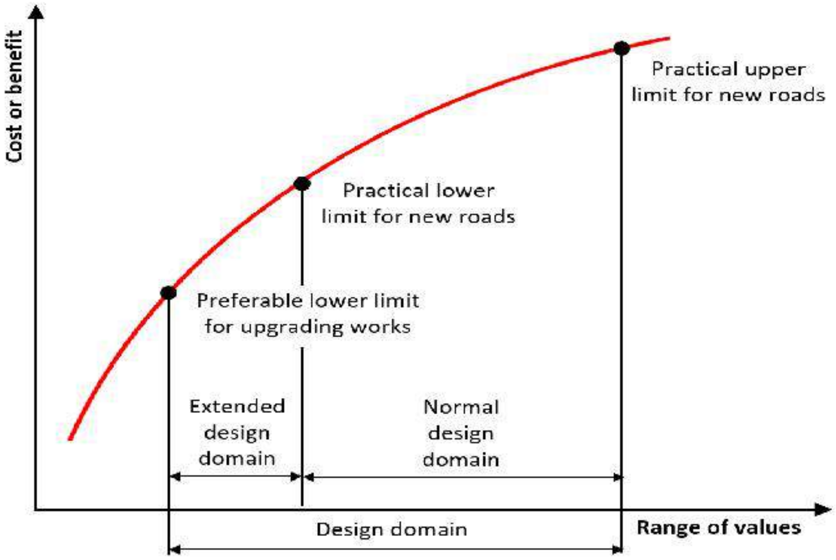


Figure A-1: The design domain concept

Source: Cox and Arndt (2006)

As illustrated in Figure A-1, the Design Domain comprises a Normal Design Domain (NDD) and an Extended Design Domain (EDD). The NDD defines the normal limits for the values of the parameters that have traditionally been selected for new roads. In this domain, the resulting designs are generally safer and more efficient in operation, but may cost more to construct. In contrast, the EDD concept uses values to a limited extent outside those in the NDD range and would generally be considered less safe or less efficient, but usually less expensive than those in the NDD. However, in the context of LVRs, with relatively few head-on meetings per day (see Table 2-3), this approach can generally be justified and defended on engineering and economic grounds and operating experience.

The decision on the design values to adopt in the EDD should be made using objective data on the changes in cost, safety and levels of service caused by changes in the design, together with benefit-cost analysis. Such data may not always be available for LVRs, particularly data that relates changes in the values associated with specific design elements and parameters to safety performance. In such a situation, designers should use sound engineering judgment to qualitatively assess the potential effects of changes for the various design elements involved.

The design domain concept provides the following benefits to the designer:

- It is directly related to the true nature of the road design function and process, since it places emphasis on developing appropriate and cost-effective designs, rather than on those which simply meet standards;
- It directly reflects the continuous nature of the relationship between service, cost and safety and changes in design dimensions. It thus reinforces the need to consider the impacts of 'trade-offs' throughout the domain and not just when a “standards” threshold has been crossed; and

- It provides an implicit link to the concept of 'Factor of Safety' – a concept that is used in other civil engineering design processes where risk and safety are important.

As a general principle, values in the upper part of the Design Domain should be selected when:

- designing new roads, particularly those in green field sites;
- designing roads with relatively high volumes of traffic;
- little additional cost is involved in the use of these values, and
- a significant accident history exists at a particular location.

In contrast to the above, values in the lower part of the Design Domain, i.e. in the Extended Design Domain, should be selected when:

- upgrading existing roads, particularly those on brownfield sites;
- designing roads with relatively low volumes of traffic;
- financial or physical constraints exist, and
- no significant accident history exists at a particular location.

Figure A-2 illustrates how the Design Domain concept might be applied to a single design parameter, for example, shoulder width. In practice, a value for shoulder width might be chosen that optimises the balance between costs and safety. Selection of a value within the domain will depend on a trade-off between various costs and benefits. To a large extent, the Design Domain concept formalises the approach adopted in this Manual to design the various elements of a LVR where the use of fixed standards often cannot be justified on the basis of a benefit-cost analysis.

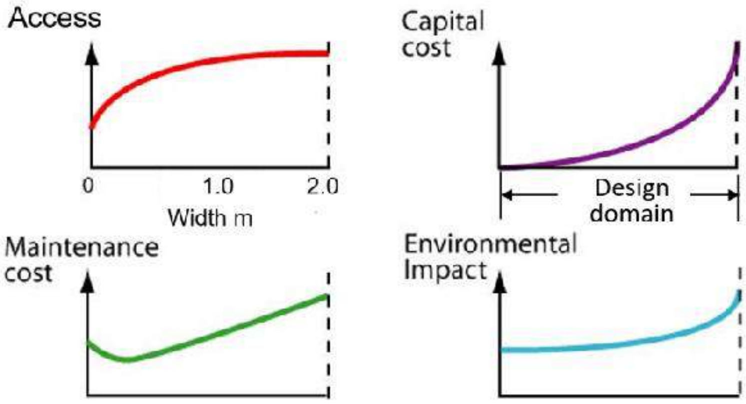


Figure A-2: Example of design domain application - shoulder width

Appendix B: Generic Table of Contents for a Design Report

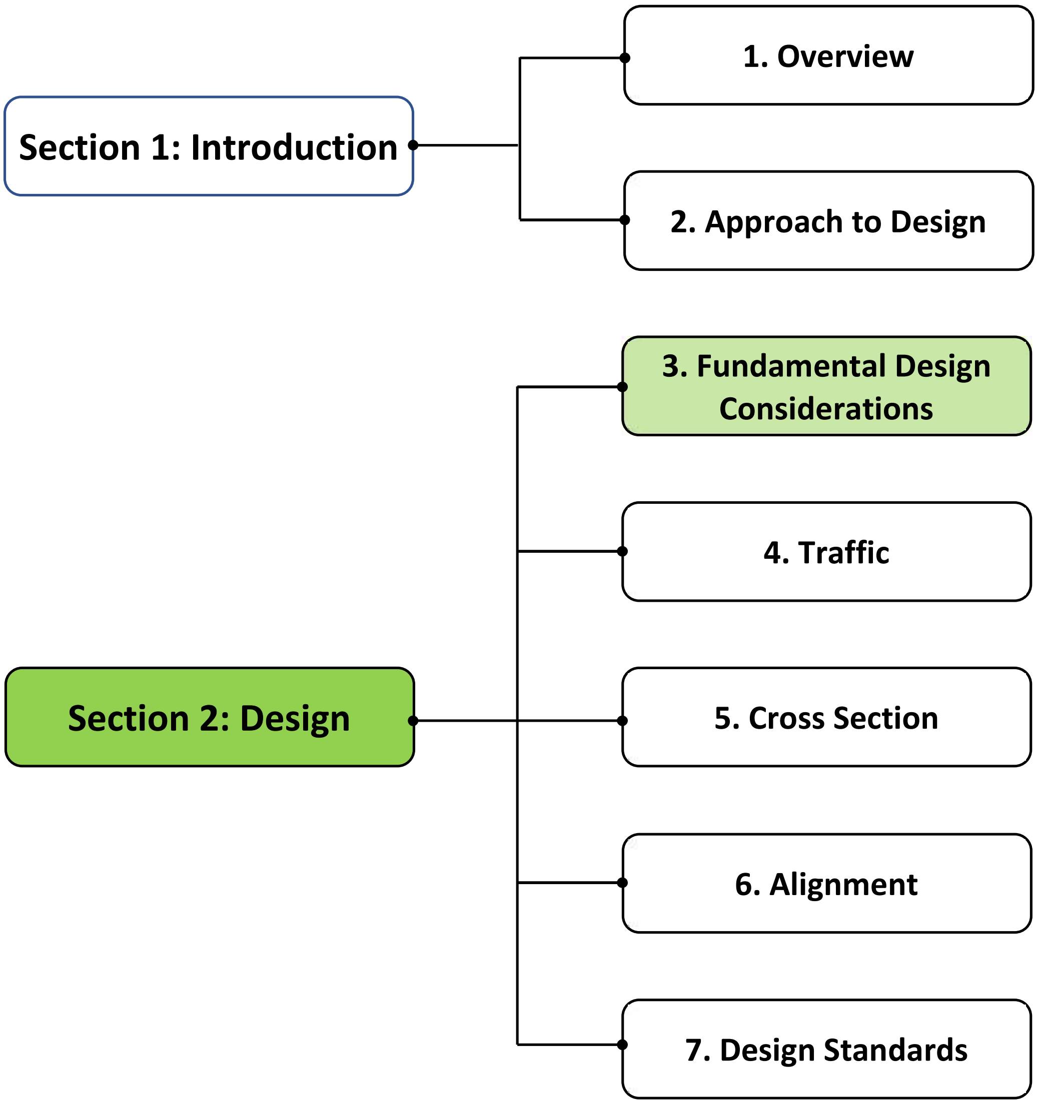
The design report that should be compiled after completing a design should contain the following topics:

1. Title Page and Introductory Information
2. Table of Contents
3. Location Map
4. Background to the Project
5. Brief Summaries of Site Surveys (Specific Detailed Reports of Surveys should exist)
6. Specifications
    - Introduction
    - Objectives
    - Design Policy
    - Design Controls
    - Lane Requirements (if any)
    - Other Conditions
7. Summary of Environmental Issues
8. Horizontal Alignment
9. Vertical Alignment (profile)
10. Alternative Routes Considered
11. Any Co-ordination Aspects of the Horizontal and Vertical Alignment
12. Examples of Curve Designs
13. Cross Sections
14. Drainage
    - Catchment Areas
    - Plan of Ditch and Culvert Layout
15. Details of all Intersections
16. Construction Cost Estimates and Comparisons
17. Economic Analysis (if Appropriate)
18. Summary of Key Technical Issues and Road Safety Considerations

Section 2

Design

Low Volume Roads Manual
Part A – Geometric Design: Rural Roads



Chapter 3 – Fundamental Design Considerations

Contents

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3.1 Introduction

3.1.1 Background

There are a wide variety of factors that affect, and sometimes control, the geometric design of a LVR and impact on the outcome of the design. These factors include consideration of physical, social, financial, engineering, economic and environmental issues that all affect the development of the road. Thus, the design approach needs to be undertaken in a holistic and balanced manner that not only meets the needs of all road users, but does so in a safe, convenient, cost-effective and environmentally sustainable manner. Attainment of this goal requires and understanding of a number of fundamental design considerations, as discussed in this chapter.

3.1.2 Purpose and Scope

This chapter discusses all of the main factors that affect the geometric design of a LVR so that the engineer can take due account of them in the process of undertaking this activity. Although many of the factors are outside the control of the designer, the engineering required to cater for them is the responsibility of the designer. Thus, the purpose of this chapter is to outline the wide range of factors that affect the appropriate design of a LVR and need to be given careful consideration by the designer.

3.2 Design Considerations

3.2.1 General

The range of factors that impact on the appropriate geometric design of a rural road include:

- Cost and Level of service
- Alignment and route controls
- Design vehicle
- Administrative and functional considerations
- Traffic volume and composition
- Terrain
- Design speed
- Roadside population (open country or populated areas)
- Pavement type
- Land use
- Environmental considerations
- Drainage
- Climate including considerations of climate change
- Construction technology
- Soil type and climate
- Safety

The above factors are discussed in the listed order in this chapter.

Since these factors differ for every road, the geometric design of every road could, in principle, be different. It is normal practice to identify the main factors and to adopt geometric standards that fall within the range of values of these key factors.

For urban roads, the principal factors are different and are discussed in Part B of this Manual.

3.2.2 Cost and Level of Service

The basic purpose of any road is to provide or enhance connectivity and economic activity. The safety, convenience and comfort of users are factors which enter into the decisions on the standards to be adopted, but are not ends in themselves. The road is merely an element to be integrated into the physical infrastructure which, taken together with the economic and social order, will facilitate development. It is for this reason that the emphasis is placed on the demand for economic return from investment in roads. Generally, the absolute level of road user costs is low and potential savings, being a relatively small fraction of total user costs, are even lower. The recouping of capital costs through maintenance and user cost savings can be accomplished in a reasonable time only if capital costs are kept low.

In view of the above, the whole-life cost of a LVR is usually the most critical factor affecting its viability. This, in turn, is directly related to the standard of the road which is essentially an index of its ‘service level’. However, ‘service level’ is a rather imprecise term. Its main components include; the speed of travel, safety, comfort, ease of driving, stopping and parking, and reliable trafficability or passability. The chosen service level is directly associated with traffic volume and function and, hence, is not treated as a separate variable. The standards for service level simply increase from the lowest road class to the highest, remaining relatively constant within each class.

3.2.3 Alignment and Route Controls

There are various factors that control the route. Obligatory points consist of two types, namely, points through which the alignment should pass and points through which it should not pass. Some examples are:

- Bridge sites: A bridge can be located only where the river has a straight and permanent path and also where the abutment and pier can be strongly founded. The road approach to the bridge should not be curved and a skew crossing should be avoided if possible. Thus, to locate a bridge, the highway alignment may need to be changed.
- Areas where construction would involve excessive costs: For example, if the alignment must pass through or cross a mountain, the alternatives are to either construct a tunnel or to go around the high points. The suitability of the alternative depends on topography, site conditions and construction and operation cost. If possible, the alignment should also avoid high-quality agricultural land and dense forests.
- The alignments should, as far as possible, pass through, or close to, important towns, groups of villages and places of religious, social, political and commercial importance.
- In general, there are a number of areas where the alignment must not cross. These include religious sites such as burial grounds, areas protected for environmental reasons, and areas designated for military purposes.
- The alignment controls also include the limits of the specifications for the class of road being designed. These include maximum gradients, radii of horizontal curves, sight distances, etc.

3.2.4 The Design Vehicle

The physical and operating characteristics of vehicles using a LVR control specific elements in the geometric design, e.g. tracking of large vehicles on small radius horizontal curves. In principle, the road alignment should permit easy passage of as many vehicle types as possible. However, by virtue of the function of low volume rural roads, primarily provision of access to local communities, there are various types of large vehicles that are not expected to travel on such roads. Thus, the extra expense of catering for such vehicles is not warranted.

The design vehicle is a vehicle with representative weight, physical dimensions, and operating characteristics used to establish design controls for accommodating vehicles in the designated class.

The three general classes of design vehicles adopted by many authorities have the characteristics shown in Table 3-1.

Table 3-1: LVR Design vehicle characteristics

Design vehicle	Code	Height (m)	Width (m)	Length (m)	Front overhang (m)	Rear overhang (m)	Wheel-base (m)	Minimum turning radius (m)
Passenger car	DV1	1.2	1.8	5.0	0.7	1.0	3.1	6.8
Single unit truck	DV3	4.3	2.6	9.1	1.2	1.8	6.1	12.8
Single unit bus	DV4	4.3	2.6	12.3	2.1	2.6	7.6	12.8

Turning templates are essential in ensuring that the kerb lines at intersections accommodate the path that the design vehicle will follow in negotiating left turns and, in the presence of median islands, the right turn. They also have applications in designing the layouts of parking areas and modal transfer stations.

Turning templates for various design vehicles, including specialised vehicles, can be plotted using commercially available computer-aided draughting programs, or can be constructed from the information contained in Table 3-2 if required.

Table 3-2: Minimum turning circle radii at crawl speed (m)

Vehicle	Minimum Turning Radius Outer Wheel Path	Minimum Turning Radius Inner Wheel Path
Passenger car (P)	6.2 m	4.4 m
Single unit truck (SU)	12.8 m	8.64 m
Single unit bus (BUS)	13.1 m	7.8 m
Note: Allow an additional 0.5 m front overhang for P and SU vehicles and 1.0 m for BUS over the outer wheel path when determining clear space required for turning. Refer to Figure 3-4 below for an illustration of such a turning template.		

Should larger vehicles comprise more than 10 % of the traffic mix, which is unlikely in the case of residential and collector streets, it will become necessary to use them as design vehicles for manoeuvrability, in which case reference will have to be made to other appropriate design manuals.

Some typical turning templates are illustrated in Figures 3-1 and Figure 3-2.

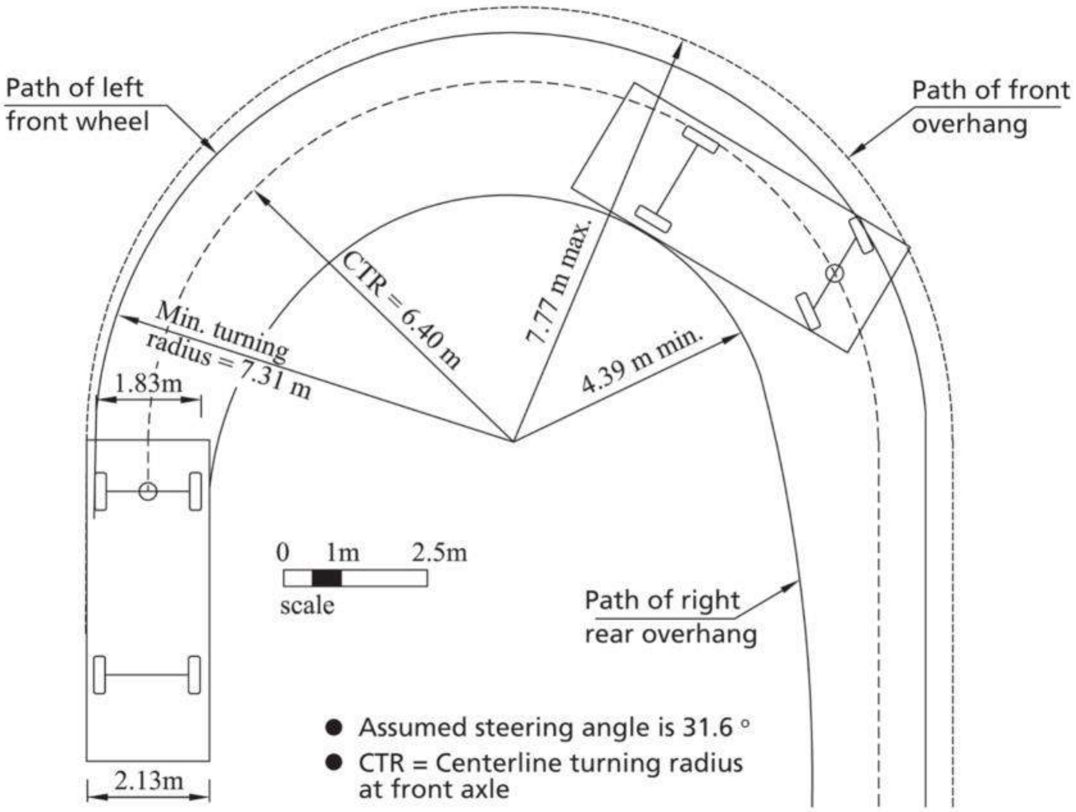

Figure 3-1: Turning template for Passenger Car

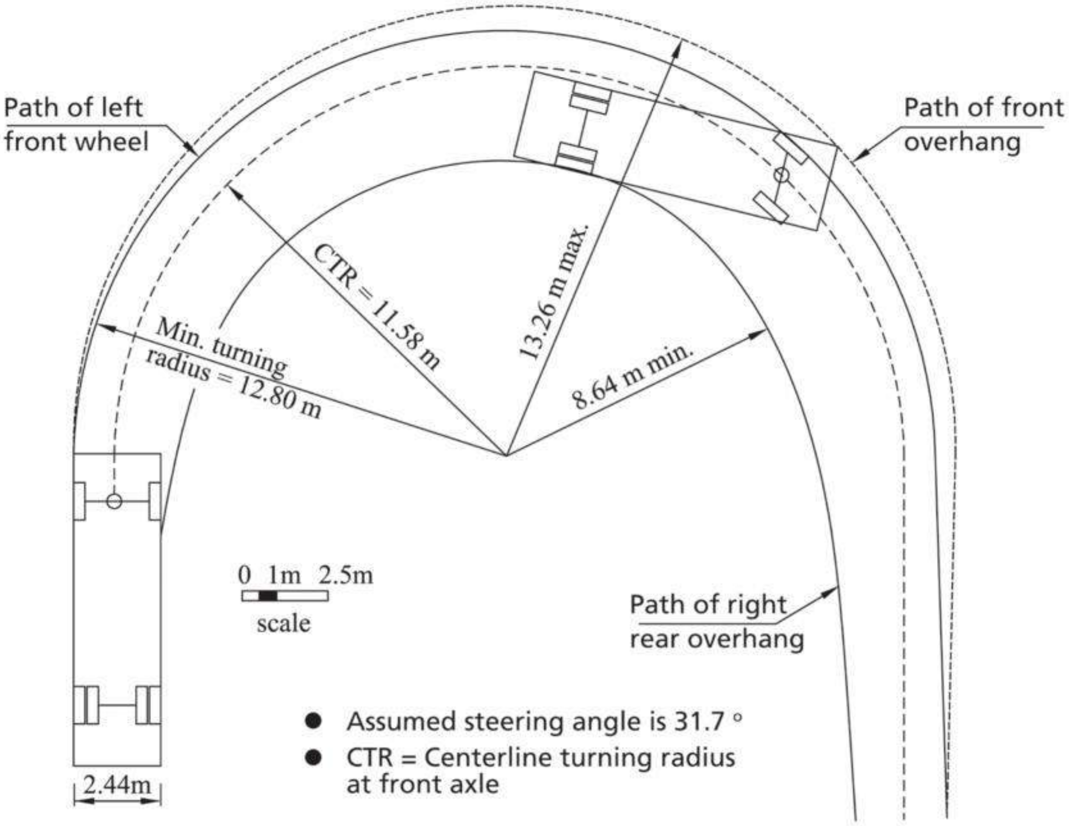

Figure 3-2: Turning template for Single Unit Truck (SU)

3.2.5 Administrative and Functional Considerations

This manual is concerned only with roads that primarily fulfil an access function (Table 2.1) i.e. District and Community roads. These roads are the lowest level in the network hierarchy. Vehicular flows will be very light and will be aggregated in the Secondary road network. Geometric standards may be low and need only be sufficient to provide appropriate access to the rural agricultural, commercial and population centres that they serve. Substantial proportions of the total movements are likely to be by non-motorised traffic and, in many areas, motorcycles may be or become the dominant mode of transport.

District and Community roads have the function of linking traffic to and from rural areas, either directly to adjacent urban centres or to the Secondary and Primary road network. Traffic levels will normally be correlated with road type and increase as traffic moves from Community through District roads to Secondary and Primary roads designed for mobility. Traffic flows and trip lengths for Secondary roads will be of an intermediate level and the need for geometric standards higher than provided by Access roads is therefore important for all mobility roads.

Primary roads are likely to exceed the traffic range for which this guideline is applicable, and users should consult the SATCC Code of Practice for Geometric Design of Trunk Roads (1998) for use on the major road network.

Whilst this hierarchy is shown simplistically in *Chapteri2 – ApproachitoiDesign*, Figure 2-1 and Figure 2-2, in practice there will be many overlaps of function and clear distinctions will not always be apparent in functional terms alone Thus, although functional aspects are usually related to traffic level, there are always exceptions that require special considerations. For example, strategic roads carrying little traffic but are essential for security reasons, and roads servicing specific industrial activities with low traffic but heavy loads e.g. quarrying or mining activities.

This hierarchy should not be confused with the division of administrative responsibilities which may be based on historic conditions.

3.2.6 Traffic Volume and Composition

The AADT of motorised vehicles with two or more axles provides the basic method of defining the different geometric road standards, but these are sometimes modified based on traffic composition. Five standards are defined as summarised in *Chapteri5 – CrossiSection,* Table 5-1. However, as indicated earlier, traffic volume is not the only aspect to be considered in deciding design standards, and the functional classification of the road generally plays a dominant role. It is, nevertheless, important that the designation of a road by functional type should not give rise to overdesign for the levels of traffic actually encountered. The road should be designed based on the task it has to fulfil, primarily the traffic that it has to carry. Details for counting and predicting traffic are provided in *Chapteri4 – Traffic*.

3.2.7 Terrain

The terrain has the greatest effect on the cost of roads; therefore, it is not economical to apply the same standards in all terrains. Drivers using LVRs are normally familiar with this and lower standards are expected in hilly and mountainous terrain. It should be noted that the definition of terrain is exactly that, it is not a description of the eventual alignment of the road. For example, in mountainous terrain, the road alignment may be relatively flat by following contours, but it could be more direct and contain very steep grades.

Three categories have been defined, as shown in Table 3-3.

Table 3-3: Terrain classes

Description	5m contours /km	Characteristics
Level/flat	0 - 5	Largely unrestricted horizontal and vertical alignment. The natural ground slopes perpendicular to the ground contours are generally below 3%. 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.
Rolling	6 - 25	Low hills introducing moderate levels of rise and fall with some restrictions on vertical alignment. The natural ground slopes perpendicular to the ground contours are generally between 3% and 25%. 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.
Mountainous	> 25	Rugged, hilly and mountainous with substantial restrictions in both horizontal and vertical alignment. The natural ground slopes perpendicular to the ground contours are generally above 25%. Higher standard roads will generally require large amounts of cut and fill.

An important aspect of geometric design concerns the ability of vehicles to ascend steep hills. Roads that need to be designed for very heavy vehicles or for animal-drawn carts require specific standards to address this, for example, special climbing lanes. Fortunately, the technology of trucks has improved greatly over the years and, provided they are not grossly overloaded (which is a separate problem) or poorly maintained, they do not usually require special treatment. On the other hand, animal-drawn carts are unable to ascend relatively low gradients, and catering for them in hilly and mountainous terrain is rarely possible. Climbing lanes cannot be justified on LVRs, nor can the provision of very low maximum gradients. The maximum gradients allowable for different road classes are shown in *Chapter 7 – DesigniStandards.*

In mountain areas, the geometric standard for LVRs takes account of the constraints imposed by the difficulty and stability of the terrain, but this design standard may need to be reduced locally in order to cope with exceptionally difficult terrain conditions. Every effort should be made to design the road so that the maximum gradient does not exceed the recommended maximum standards shown in *Chapteri7 – DesigniStandards.* However, where higher gradients cannot be avoided, they should be restricted in length. Gradients exceeding the absolute maxima should not be longer than 200 m, and relief gradients ≤ 6% with a minimum length of 200 m, are required to allow heavy vehicles to regain speed. Horizontal curve radii of less than the minimum specified of 15 m may sometimes be unavoidable, and warning signs will need to be provided sufficiently early to allow vehicles to divert if necessary.

A fourth terrain category is sometimes defined, namely an "*Escarpment*" category, but this is such an extreme terrain that uniform standards for it cannot be easily defined, and each one needs to be considered on its merits.

3.2.8 Design Speed

Minimum horizontal and vertical curvatures are governed by the 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 dependent on an assumed design speed.

Within this guide, the adopted design speeds are explicitly stated and, as shown in *Chapter 7 – DesigniStandards,* 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.

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 increases and generally support higher standards with more direct and shorter routes.

3.2.9 Roadside Population (Open Country or Populated Areas)

When a road passes through a village, town, or other populated or market area, safety must be a primary consideration. Pedestrian footpaths are required on both sides of the road and should preferably not be the road shoulder. Extra width may also be required in each direction for parking and for passenger pick-up, but such a wide section of road encourages drivers to increase speed; therefore, speed reduction or containment methods should be employed (refer to *PartiC – RoadiSafety*).

In built-up areas, the problem is one of deciding the safety measures that are justified based on the size of the area or length of road that is affected. The following data is useful for making such decisions, but no precise guidelines have been developed hence engineering judgement and consultation with the local community is required:

- How many shops/traders are there?
- How many people use the area on market days?
- What development and increases are likely to happen in the next ten years?

In practice, a basic standard is specified, as indicated above, combined with some elements of traffic calming as described in *PartiC – RoadiSafety*. These standards are not justified for the lower traffic levels of LVR1 and LVR2, unless the road passes through a particularly well-populated area. In such circumstances, the shoulders should be widened as appropriate for the extent of the populated area.

3.2.10 Pavement Surfacing Type

The friction factors for paved and unpaved roads are significantly different, and this affects the distance required to stop safely and the safe speed for negotiating curves. Thus, the geometric standards differ according to the type of surface (*Chapter 7 – DesigniStandards*).

3.2.11 Land Use and Physical Features

Land use influences the design of the drainage features of a road and access to the road. Dealing with water run-off and potential erosion, for example, forms an important aspect of design, much of which is geometric in nature. These aspects are dealt with in *Chapteri6 – Alignment*.

3.2.12 Environmental Considerations

Road construction affects the environment in many ways that can be detrimental but can also be positive. It is, therefore, important to fully consider the impact of these effects at the design stage of the project. Mitigation measures for addressing a range of environmental and social impact issues are addressed in the Pavement Design Manual, *Chapteri13 – PracticaliConsiderations*. Moreover, local environmental protection measures and regulations are well-founded in Malawi and should be followed in all road construction work.

3.2.13 Drainage

Consideration of issues associated with drainage of the road and surrounding land can significantly affect the geometry and cross section of the road whilst the choice of the drainage system can affect the cross section or formation width. Thus, a cohesive design requires that drainage issues are considered at the earliest stage of the design process to ensure that geometric design decisions are informed by, and supportive of drainage design. The main elements of drainage design are addressed in the Pavement Design Manual, *Chapteri8 – DrainageiandiErosioniControl.*

3.2.14 Construction Technology

In a labour-abundant economy, it is usually beneficial to maximise the use of labour rather than rely predominantly on equipment-based methods of road construction. In such a situation, the choice of technology affects the geometric standards that can be achieved, especially in hilly and mountainous areas. This is because:

1. Maximum cuts and fills must be small.
2. Economic haul distances are limited to those achievable using wheel-barrows.
3. Mass balancing is achieved by transverse rather than longitudinal earth movements.
4. Maximum gradients follow the natural terrain gradients.
5. Horizontal alignments may be less direct.

The standards in hilly and mountainous terrain are always lower than in flat terrain, but this reduction in standards need not necessarily be greater where labour-based methods are used. Following the contour lines more closely will make the road longer, but the gradients and earthworks can be less severe. Every effort should be made to preserve the same standards in the particular terrain encountered irrespective of the construction method.

3.2.15 Climate and Soil Type

Varying standards of geometric design do not exist to cater specifically to climate and soil type. However, it is important that these factors are taken into account in the design of the drainage features of the road, and these affect the road cross-section, thereby contributing to the geometric design. Engineering adaptations to climate change are addressed in the Pavement Design Manual, *Chapteri13 – PracticaliConsiderations.*

3.2.16 Safety

The mix of traffic, including relatively old, slow-moving and often overloaded vehicles, a large number of pedestrians, animal-drawn carts and, possibly, motorcycle-based forms of transport; plus, poor driver behaviour and poor enforcement of regulations means that methods to improve safety through engineering design assume paramount importance. These are dealt with at appropriate places throughout the Manual and in *PartiC – RoadiSafety*.

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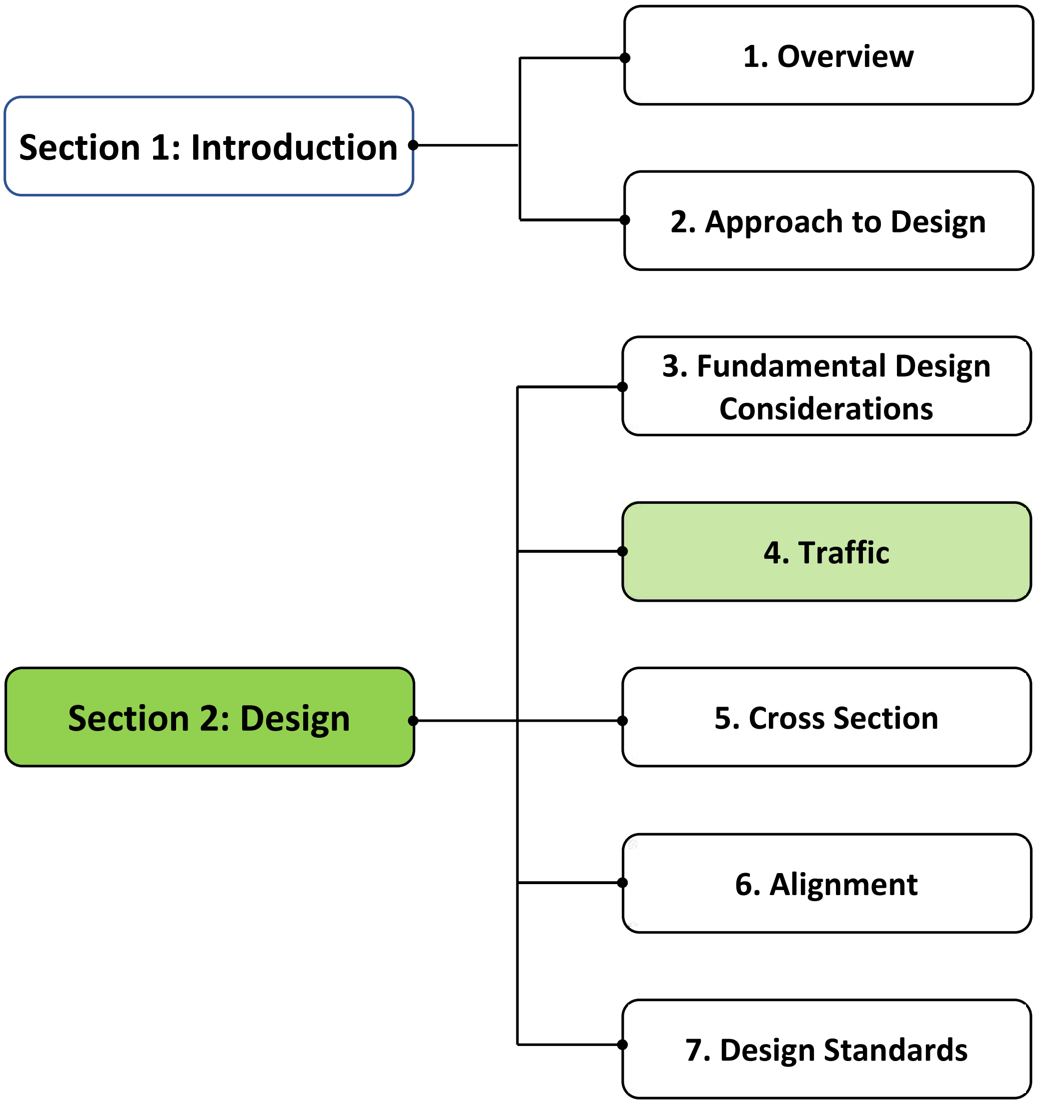

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4.1 Introduction

4.1.1 Background

Roads should be designed based on the function that they have to fulfil, which is primarily to carry the estimated traffic volumes over their design lives safely, comfortably and efficiently. Thus, reliable data on traffic volumes and characteristics are essential for geometric design as well as for pavement structural design and for assisting in the planning of road safety measures, as summarised below:

- **Geometric design**: The volume and composition of traffic, both motorised and non-motorized, influence the design of the cross-section (carriageway and shoulders). The geometric design standards (refer to *Chapter 7 – Design Standards*) must cater adequately for the traffic volumes expected on LVRs. These standards need to be modified based on the characteristics of the traffic using the road, such as different traffic mixes, including numbers of NMTs, motorcycles, large vehicles, and pedestrians.
- **Pavement design**: The deterioration of the pavement is influenced by both the magnitude and frequency of individual axle loads. For the structural design of LVRs, a range of Traffic Load Classes (TLC) are defined based on the traffic loading calculated in terms of cumulative equivalent standard axles carried in the specified design life. Thus, each TLC is applicable over a range of traffic levels.
- **Road safety**: The volume, type and characteristics of the traffic using the road all influence the type of road safety measures required to ensure a safe road environment.

In view of the above, reliable estimates of the existing (base line) and future traffic volumes are required.

4.1.2 Purpose and Scope

The purpose of this chapter is to provide procedures for counting base line traffic and predicting future traffic for determining the traffic volume as a basis for designing the geometric components of the road. The procedures are essentially very similar to those required for pavement structural design, as described in *Volume 1 – Pavement Design*, except that information about axle loads, is not required. Information about the volumes of light traffic, motorcycles and NMTs (cyclists, pedestrians and animal-drawn carts) that have no influence on the structural design are all required for geometric design and for road safety considerations.

The chapter considers types of surveys that provide the inputs for determining the design traffic. This requires the data to be sufficiently accurate to attain a reliable forecast of the future traffic volumes. The chapter considers various ways that such forecasts can be achieved, bearing in mind that all methods of forecasting traffic are subject to errors of estimation. Thus, several methods should be used, and a sensitivity analysis should be carried out to select the most likely result based on “engineering judgement”.

4.2 Design Life

The design life of paved LVRs is usually set at 10 or 15 years. The traffic for which a road is designed should be such that it is not significantly under-designed at the end of its design life or overdesigned at the beginning. Thus, the traffic at mid-life is used for geometric design. This requires a prediction of traffic growth as described in Section 4.4 below. However, the most important property for geometric design is usually the capacity of a road, but this is not a major issue for LVRs because the traffic level is generally too low for congestion to be a problem (ref. *Chapter 2 – Approach to Design, Sections 2.5.3*).

Reliable traffic estimation is required to determine the appropriate geometric design standards and also the road safety measures for the various classes of road. Higher-standard roads are based on relatively higher design speeds, which relate to wider carriageways, larger radii of minimum curvature and possibly lower maximum gradients as shown in the various design tables in

Chapter 7 – Design Standards. Although the boundaries between one road class and another in terms of AADT are based on the best evidence available, they should be treated as approximate in the light of the uncertainties inherent in traffic estimation.

4.3 Traffic Surveys

4.3.1 General

Traffic surveys are required for geometric design, as well as for planning purposes, in terms of evaluating economic benefits derived from the construction of LVRs. For these purposes, it is necessary to ascertain the volume and composition of current and future traffic in terms of all vehicle classes, motorcycles, and, importantly, NMT.

The following types of traffic surveys are typically carried out in the road project area:

- Classified Traffic Surveys
- Origin-Destination Surveys

4.3.2 Survey Methods

The most common types of surveys for counting and classifying the traffic in each class are:

- Manual and Automatic Traffic Survey
- Moving Observer Methods

Although the methods of traffic counting may vary, the objective of each method remains the same, essentially to obtain an estimate of the Annual Average Daily Traffic (AADT) using the road, disaggregated by vehicle type. Prediction of such traffic is notoriously imprecise, especially where the roads serve a predominantly developmental or social function and when the traffic level is low.

4.3.3 Reducing Errors in Estimating Traffic for LVRs

Increasing the count duration

The accuracy of traffic counts can be improved by increasing the count duration or by counting in more than one period of the year. Improved accuracy can also be achieved by using local knowledge to determine whether there are days within the week or periods during the year when the flow of traffic is particularly high or low.

Figure 4-1 shows the possible errors in AADT estimates for traffic counts of varying duration. The figure illustrates two important points; 1) that short duration traffic counts in low traffic situations can lead to large errors in traffic estimation, and 2) that there is little scope for improving accuracy by counting for more than 7 days. Thus, the duration of traffic surveys should be given careful consideration in terms of striking a balance between cost and accuracy.

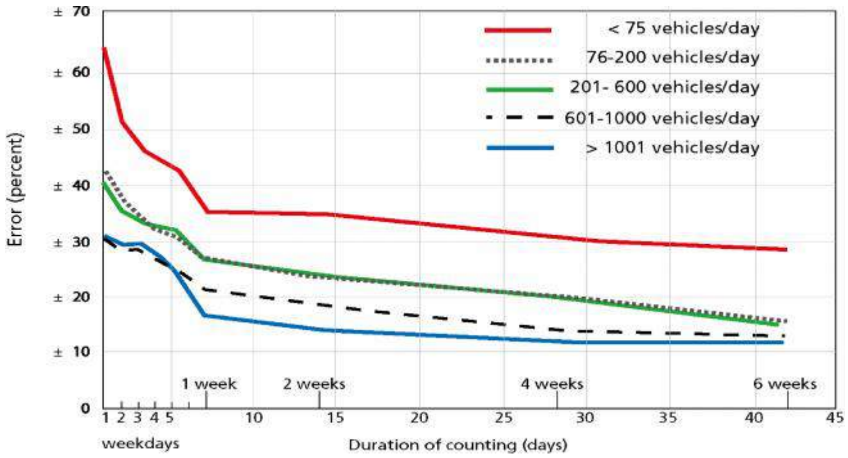

Figure 4-1: Possible errors in ADT estimates from random counts of varying duration

(Source: Howe 1972)

Errors in estimating traffic can be reduced by carrying out a **Classified Traffic Count** as follows:

- Counting for seven consecutive days.
- On some days counting for a full 24 hours, preferably with one 24-hour count on a weekday and one during a weekend; on other days, 16-hour counts (typically 06.00 – 22.00 hours) should be made and expanded to 24-hour counts using a previously established 16:24 hour conversion ratio.
- Avoiding counting at times when road travel activity increases abnormally; for example, just after the payment of wages and salaries, or at harvest time, public holidays or any other occasion when traffic is abnormally high or low. However, if the harvest season is during the wet season (often the case, for instance, in the timber industry), it is important to obtain an estimate of the additional traffic typically carried by the road during these periods.

Adjustments for season

Usually, motorised traffic volumes will decrease in the wet season to, typically, 80% of their dry season level. However, on poor quality roads, this difference can be even more marked, and the wet season traffic can decrease to as much as 35% of dry season traffic levels as shown in Figure 4-2. For the purposes of this Manual it can be assumed that roads have trafficability problems when wet season traffic levels fall below about 60% of dry season levels. It is also possible that dry season traffic may be lower than wet season traffic, e.g. in areas where sands tend to become loose and less traversable in the absence of ground moisture.

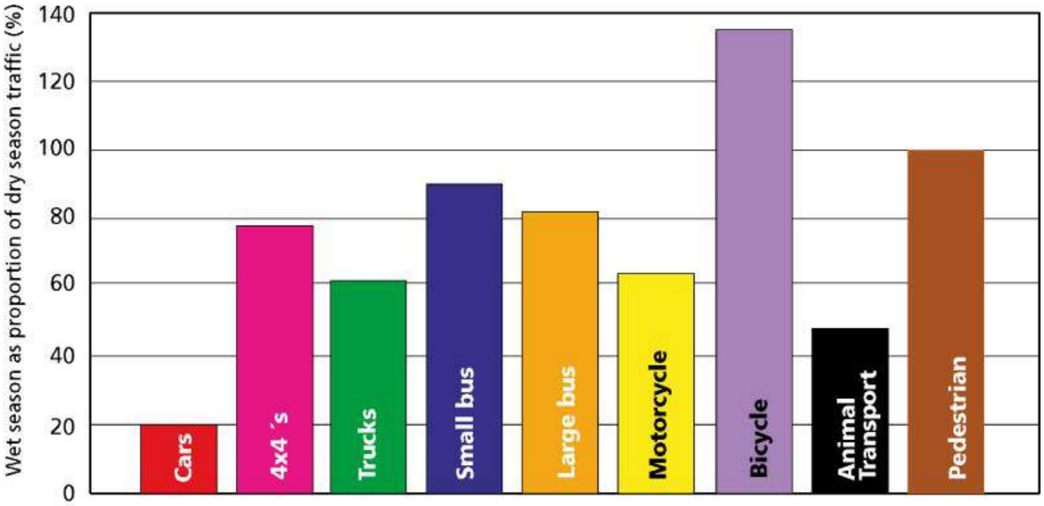

Figure 4-2: Difference in wet season and dry season traffic levels on poor quality roads

(Source: Parsley and Ellis, 2003)

An appropriate, weighted average adjustment will need to be made according to the season in which the traffic count was undertaken and the length of the wet and dry seasons, as illustrated in Figure 4-3. The Classified Traffic Count may, therefore, have to be repeated at least twice throughout the year.

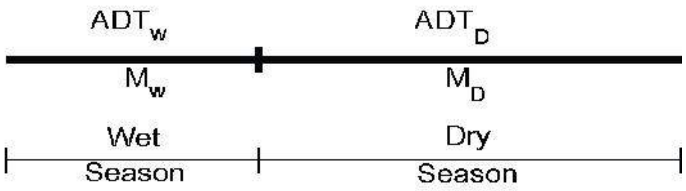

Figure 4-3: Basis for traffic count adjustment in relation to seasonal characteristics

The weighted average of the traffic count in relation to the seasonal characteristics of the region in which the counts were undertaken is obtained, as shown below.

$$Weighted\ Average\ ADT = \frac{ADT_w \times M_w}{12} + \frac{ADT_D \times M_D}{12}$$

Where: ADT_W = Average daily traffic count in wet season
ADT_D = Average daily traffic count in dry season
M_W = Number of months comprising the wet season
M_D = Number of months comprising the dry season

Location of census points

Care should be exercised in selecting appropriate locations for conducting the traffic counts to ensure a true reflection of the traffic using the road and to avoid under- or over-counting. Thus, locations such as within villages or market places should be avoided.

If any major junctions occur along the road length, counts should also be conducted before and after the junctions.

Origin-Destination surveys

While the Classified Traffic Counts will provide information on the current traffic using the road, Origin-Destination (O-D) surveys may be required to facilitate the estimation of diverted traffic from alternative routes once the road has been improved or upgraded. Such diversion may occur due to drivers wishing to travel on a quicker or cheaper route, although this may not be the shortest. When combined with other estimates of traffic growth following a road improvement, it allows the total traffic flow to be estimated as illustrated in Figure 4-5 (page 4-8).

Origin-Destination (O-D) surveys can be undertaken using a variety of survey techniques, but are generally quite costly and may require the assistance of Traffic Police. Thus, for individual LVR projects it may not be feasible to undertake an O-D survey.

4.4 Traffic Growth

To determine the future traffic in each traffic class and in each direction, a forecast of future traffic must be made based on the current traffic. For many LVRs, a simple estimate based on local precedent or recent experience should be sufficient, but each situation should be reviewed because traffic growth can be high and more comprehensive analysis may be warranted. Such an analysis will require an estimate of the initial traffic when the road is completed. The initial traffic should include the normal, generated and diverted traffic, as illustrated in Figure 4-2. For geometric design purposes, it is necessary to count non-motorised and intermediate means of transport including pedestrians, bicycles, motorcycles, tractors and trailers and, possibly, animal transport. Growth rates for each traffic class may differ, with motorcycles growing faster than other vehicles.

1) **Normal traffic.** Traffic that would pass along the existing road or track even if no new geometry were provided. This increases naturally by virtue of normal social and economic growth.
2) **Diverted traffic.** Traffic that changes from another route (or mode of transport) to the project road because of the improved pavement, but still travels between the same origin and destination. Diverted traffic should be considered when a totally new road is to be provided or when an existing road is to be improved. To estimate the volume of diverted traffic origin-destination surveys of all junctions that adjoin to the project road are usually required, but this is usually unnecessary for LVRs. A pragmatic approach is simply to assume that traffic will take the quickest route if the standard of the road is acceptable and not a route that provides a rough ride even if it is shorter.
3) **Generated traffic.** Additional traffic which occurs in response to the provision or improvement of the road. This is traffic generated by any extra economic growth resulting from the road. It is likely to be greater than the increase expected from normal regional economic growth. The initial volume of generated traffic can be obtained by conducting

interviews with the existing road users. The interviews must focus on understanding whether upgrading the road would lead to an increased number of trips immediately. Other planning factors must also be considered. For example, if a farm is likely to increase its crop outputs as a result of improved road conditions, the extra trips generated as a result should be considered in determining the generated traffic.

There are several methods for estimating the traffic growth and each has its advantages and disadvantages, as summarised in Table 4-1. However, most are based on national statistics and a general growth figure is usually provided by the central government. The problem is that overall trends may not reflect what is likely to happen on specific LVRs; hence the methods will not all give robust and reliable figures, and so some degree of judgement about the quality of the data will be required to obtain the best estimate. Local recent historical knowledge should always be used if available.

Table 4-1: Methods of estimating traffic growth

Method	Details
Local historic precedent	In some cases, annual traffic data for nearby roads, collected for a number of years might be available. The traffic data can be used to compute the traffic growth rate. The growth rate on the project road will likely be very similar to that of the adjacent or nearby roads.
Vehicle registry	The central or regional government maintains a registry of the number of vehicles registered annually therefore the annual traffic growth rate can be estimated from these data. However, regional or zonal data is more relevant to the project since nationwide data may not be representative of the specific project.
Weighbridges	The annual number of trucks weighed at weighbridges offers a method to estimate the growth rate related to various truck categories.
Fuel consumption trends	The government's customs department maintains records of fuel imports. Fuel imports are related to the demand, which is in turn related to the traffic growth rate.
Economic growth estimation	Traffic growth is closely related to the growth of the economy measured in terms of Gross Domestic Product (GDP). Economic growth rates can be obtained from government plans and government-estimated growth figures. The growth rate of traffic should preferably be based on regional growth estimates because there can be large regional differences.
Population trends	Local population trends can also provide useful information about possible traffic growth.

4.5 Traffic Categories

4.5.1 Vehicle Classification

Table 4-2 shows the vehicle classification system used for compiling the results of the traffic survey described above.

Table 4-2: Vehicle classification system

Class	Type	Axles	Description	Use
A	Car	2	Passenger cars and taxis	Capacity analysis for geometric design
B	Pick-up	2		
C	4-wheel drive	2		
D	Minibus	2	≤ 28 seats	
E	Medium bus	2	28 – 40 seats	Capacity and axle load analysis for pavement design
F	Large bus/coach	2	> 40 seats	
G	Light Goods Vehicle (LGV)	2	≤ 3.0 tonnes empty weight	
H	Medium Goods Vehicle (MGV)	2 - 5	>3.0 tonnes empty weight	
I	Heavy Goods Vehicle (HGV)	> 6	>3.0 tonnes empty weight	
J	Tractor			Capacity analysis for geometric design and road safety considerations
K	Motorcycles, motor cycle taxis			
L	Bicycles			
M	Animal carts			
N	Pedestrians			

The geometric design standards are modified based on the proportion of heavy vehicles in the traffic stream. The modifications depend on the road class and are described in the notes to the Tables of Standards in *Chapter 7 – Design Standards.*

4.5.2 NMT and Motorcycles

Non-motorised traffic (NMT) includes pedestrians, bicyclists and animal-drawn carts. The combined number of NMTs and motorcycles is assessed in terms of the effective road space that they occupy, as measured in terms of the Car Equivalent (CE) values presented in Table 4 3. It is important to note that, in the context of LVRs, the use of this concept is not concerned with traffic congestion effects as such problems do not occur on LVRs. Rather it is concerned with deciding whether the volume of these traffic categories warrants widening the carriageway or shoulders for safety reasons.

The CE concept is similar to, but not the same as, the Passenger Car Unit (PCU), which is normally used to obtain a measure of the congestion effects of NMT and motorcycles in urban/peri-urban environments.

A typical situation sometimes encountered in practice is the approach to a village or any other area that attracts people, for example, a village market. In such a situation, a dedicated pedestrian footpath is an ideal solution for improving road safety. However, the ever-growing numbers of motor cycles can present a safety problem when NMTs and motorcycles are mixed with 4 wheeled motorised traffic. The daily volumes of NMTs and motorcycles are measured using the total daily CE value. If this exceeds 300 (approximately 1200 motorcycles or 2000 pedestrians), it is recommended to consider including or widening the shoulders to improve road safety (see *Chapter 7 – Design Standards).*

Table 4-3: Car Equivalent (CE) values for mixed traffic

Vehicle	Car Equivalent Factor
Pedestrian	0.15
Bicycle	0.20
Motor cycle	0.25
Bicycle with trailer	0.35
Motor cycle with trailer	0.45
Ox-drawn cart	0.70
All based on a passenger car = 1.0	

4.6 Determination of Design Traffic

4.6.1 General

The procedure for determining the traffic for geometric and pavement design purposes is essentially the same as summarized in and explained below. The traffic analysis for pavement design cannot be separated from the analysis for geometric design since the geometric design requirements and, ultimately, the selection of a road class and cross-section width will influence the traffic load lane distribution. The analysis for geometric and pavement design purposes should, therefore, always be carried out together.

4.6.2 Procedure

The procedure for determining the mid-life traffic and selection of road class is confined to Steps 1 to 4 as illustrated in Figure 4-4 and described below.

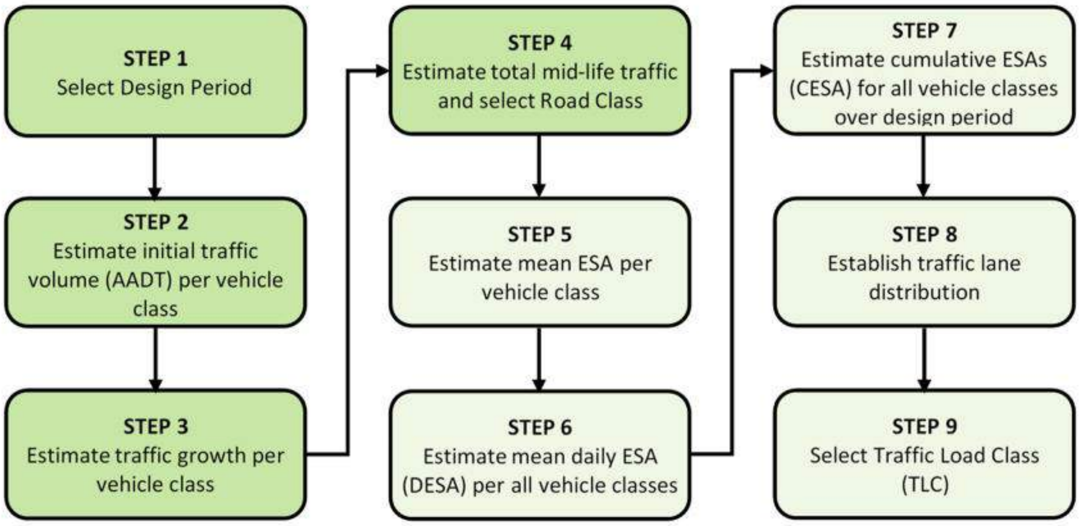

Figure 4-4: Procedure for selection of road class

Step 1: Select Design Period

The design period of the LVR provides the basis for estimating the mid-life traffic volume for geometric design purposes.

Step 2: Estimate Initial Traffic Volume per Vehicle Class

Based on the traffic surveys described in Section 4-3, the initial traffic volume for each vehicle class can be determined. For structural design purposes, it is only the commercial vehicles in classes D to K inclusive (refer to Table 4.2) that will make any significant contribution to the total number of equivalent standard axles. However, in contrast, for geometric design purposes, it is necessary to count all traffic, including motorcycles, tractors and trailers etc., as well as and non-motorised traffic including bicycles, animal-drawn carts, and pedestrians.

Step 3: Estimate Traffic Growth per Vehicle Class

Following the establishment of the baseline traffic, further analysis is required to establish the total design traffic based on the forecast of traffic growth in each vehicle class. To forecast such growth, it is first necessary to sort traffic in terms of the following categories as described previously in Section 4.4:

- Normal traffic
- Diverted traffic
- Generated traffic

Estimating traffic growth over the design period is very sensitive to economic conditions and prone to error. It is, therefore, prudent to assume low, medium and high traffic growth rates as an input to a traffic sensitivity analysis for geometric design purposes as described below.

The growth rate of each vehicle class may differ considerably. Traffic by Light Goods Vehicles, for example, are usually growing at a faster rate than that of Heavy Goods Vehicles, and this should be taken into account when estimating the traffic loading.

There are several methods for estimating traffic growth, as presented in Table 4-1.

It should be born in mind that both geometric design classes and structural design classes are quite wide in terms of traffic range, typically a range of 100% or more, hence the precision required of traffic estimation is not high. A common method of choosing the design traffic is simply to estimate the initial traffic, including diverted and generated traffic and to accommodate traffic growth by choosing the next higher road class for both geometric and structural design. As shown in Table 2-2 in *Chapter 2 – Approach to Design*, going up one LVR Class is equal to a doubling of the AADT. As indicated in Figure 4-6, this is equivalent to increasing the traffic by a factor of about two or a traffic growth rate of about 8%.

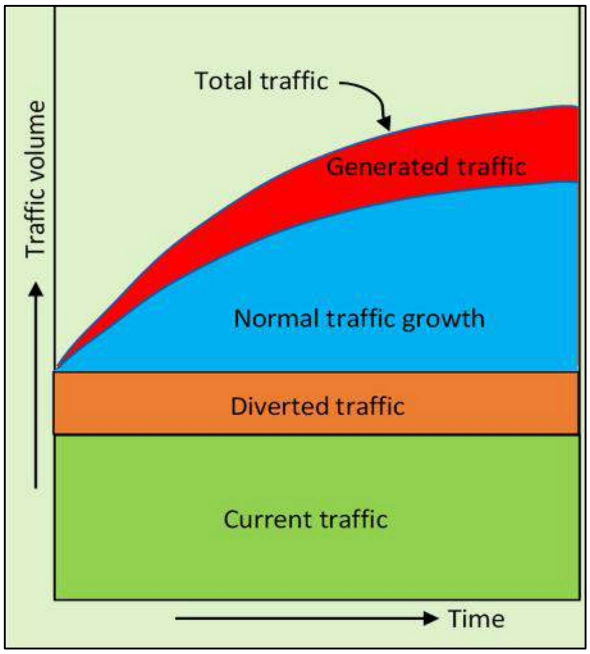

Figure 4-5: Traffic development on an improved road

Step 4: Estimate total mid-life traffic and select Road Class

The AADT in both directions in the first year of analysis consists of the current traffic plus an estimate of the generated and diverted traffic. Thus, if the total traffic is denoted by AADT and the general growth rate is **r** per cent per annum, then the traffic in any subsequent year, **x**, is given by the following equation:

$$AADT_X = AADT_0 \times \left(1 + \frac{r}{100}\right)^X$$

This is illustrated in Figure 4-6, which shows the multiplier for the AADT in the first year of analysis to obtain the AADT in any other year.

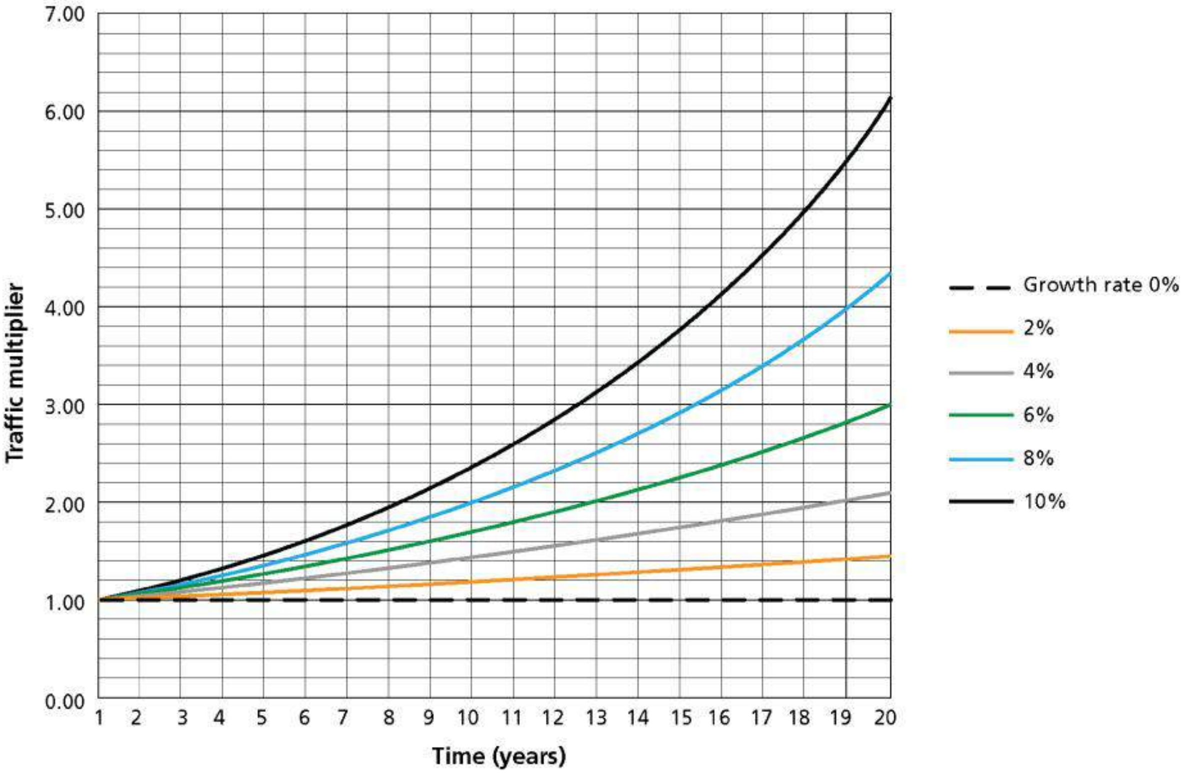

Figure 4-6: Multiplier to obtain AADT in any year for different growth rates

Sensitivity analysis: For the final selection of the Road Class, it is prudent to carry out a sensitivity analysis in order to cater for:

- Different traffic growth rate scenarios.
- The likelihood of future developments in the area, e.g. new industry, mining operations, agricultural development, new road projects etc., which have not already been accounted for in the traffic growth estimates.

If the estimated mid-life traffic, based on the current assumptions, is close to the upper boundary of LVR class, and the sensitivity analysis indicates that the upper boundary may be exceeded, it may be prudent to assume the next higher road class and to assess the impact of this on the geometric design. This impact may be negligible if the required material quality is readily available, or significant if the higher TLC would require longer haulage distances or modification of the materials available in the vicinity of the road.

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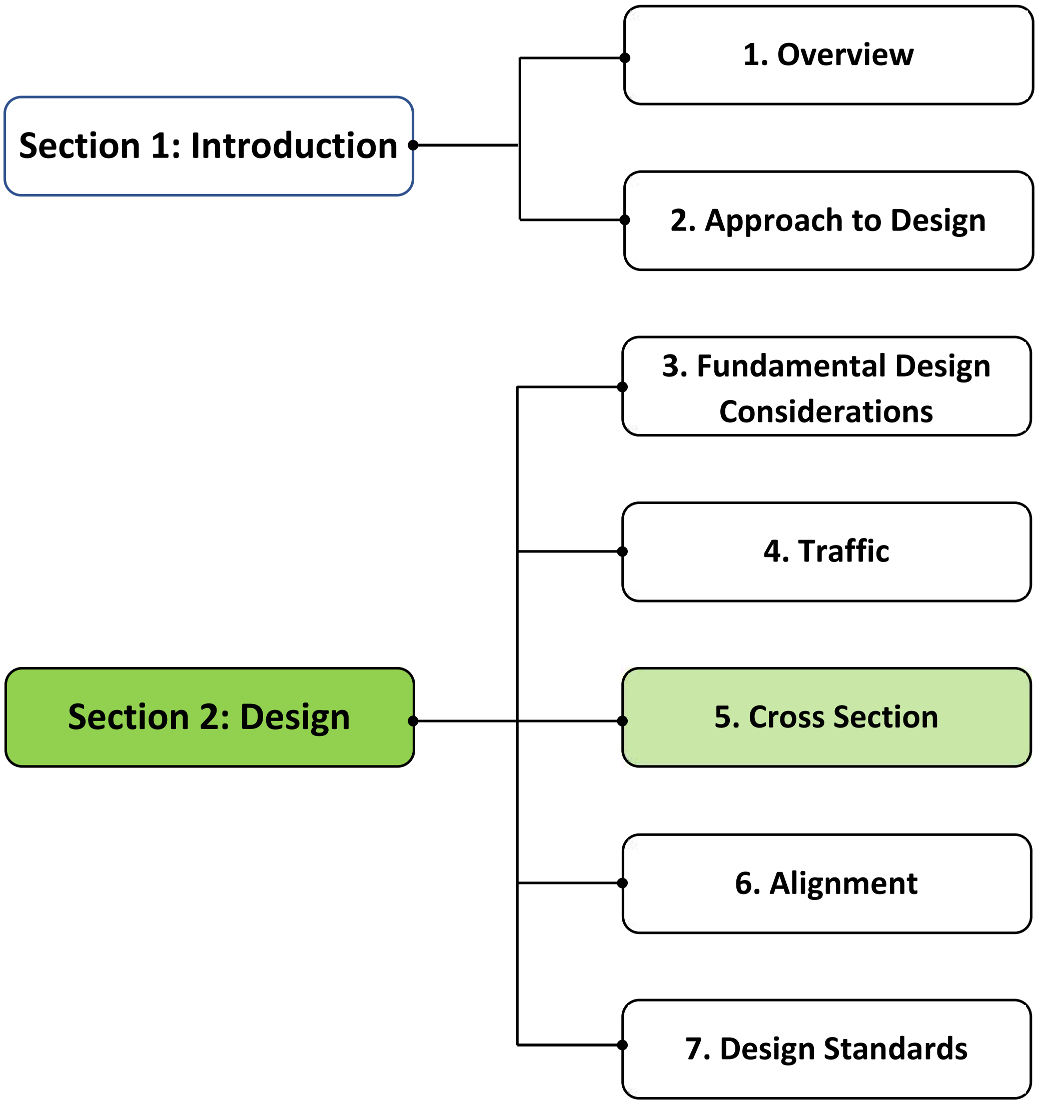

Chapter 5 – Cross Section

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5.1 Introduction

5.1.1 Background

The cross-sectional dimensions of a road, particularly it's carriageway and shoulder widths, have a significant impact on construction costs and, in the context of LVRs, should be minimised subject to operational and safety considerations. Generally, widths are closely related to the classification of the road and are influenced by the controls and criteria described in *Chapter-3 – Fundamental Design Considerations.* This means that the cross section may vary over a particular route because the controlling factors may vary.

As discussed in *Chapter 2 – Approach to Design,* Section 2.5.3 and illustrated in Figures 2-3 to 2-6, on LVRs there is a relatively small probability of vehicles meeting, and the manoeuvres can be undertaken at very reduced speeds. Thus, it would not be cost-effective to adopt cross section widths that are typically used on HVRs with a much higher incidence of vehicles passing each other in opposite directions.

Of particular importance to LVRs is the issue of catering simultaneously for the requirements of motorised as well as non-motorised traffic and pedestrians. In some circumstances, it is necessary to consider cost-effective ways of segregating these various types of road users within an appropriately designed cross section. For example, relatively wide shoulders might need to be considered in some mixed traffic situations.

5.1.2 Purpose and Scope

The purpose of this chapter is to provide guidelines for the selection of the various elements that comprise the cross section of a LVR in order to attain the overall objectives of providing “fit-for-purpose” rural access roads at reasonable cost as stated in Chapter 2.

Each road should be designed in accordance with its specific requirements, and no designs will be exactly the same. Thus, instead of prescribing exact design parameters, guidelines are given on ranges within which acceptable designs can normally be accommodated. This provides the required flexibility to adapt the design to the different traffic volumes and compositions and terrains as well as the provision of access with limited budgets.

This chapter addresses all the cross-sectional elements of a typical LVR including carriageway and shoulder, right-of-way, camber and crossfall, side slopes and low embankments.

5.2 Cross-section Elements

5.2.1 Terminology

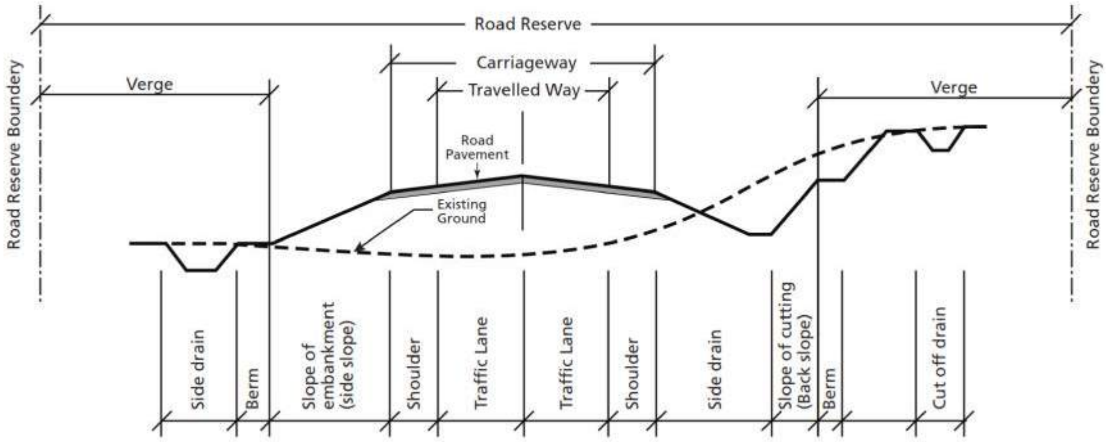

Figure 5-1: Elements of road cross section

Note: Where there are no shoulders the Travelled Way = Carriageway

5.2.2 Road Width

The LVR Road Classes and the associated basic cross-section parameters are summarised in Table 5-1 and take account of the following factors:

- **Classification of the road**: The higher the class of road, the higher the level of service expected and the wider the road will need to be.
- **Traffic**: As the traffic volumes increase from Class LVR1 to Class LVR5, there will be more frequent passing manoeuvres, and therefore, the vehicles will be further from the centreline of the road. As a consequence, the carriageway needs to be wider.
- **Vehicle speeds**: As speeds increase, drivers have less control of the lateral position of vehicles, reducing the required clearances, and so a wider carriageway is needed.

Full details of the design parameters are shown in the Tables in *Chapter 7 – Design Standards*.

Table 5-1: LVR Road Classes and associated basic design parameters

Label	Design Criterion	Design Classes				
		LVR 1	LVR 2	LVR 3	LVR 4	LVR 5
	Mid-life traffic (AADT)	<50	50-100	100-200	200-400	>400
A	Travelled way width[1] (m) (minimum)	3.5	3.5-4.5	4.5-5.5	5.5-6.5	6.5
B	Shoulder width (m), unpaved	0.50[2]	0.50[2]	n/a	n/a	n/a
	Shoulder width (m), paved, CE>300	n/a	n/a	0.5[3]/1.0-2.0[4]	1.0- 2.0[4]	1.0-2.0[4]
	Camber/crossfall (%) (Paved/Unpaved)[5]	3.0/5.0				
	Shoulder crossfall (%) (Paved/Unpaved)	3.0/5.0				
D	Back slope of drain (v:h ratio)	See Table 5-2				
E	Side slope of drain (v:h ratio)	See Table 5-2				
F	Depth of side drain (m)	Varies				
G	Side slope (v:h ratio)	See Table 5-2				
H	Crown height (m)	Desirable minimum = 0.75; Decreased if grade >1.0% and/or if drain is lined (see PD manual Table 8-3)				
J	Cleared width (m)	Desirable A + 2xB +6 (Figure 5-1)				
K	Embankment toe (m)	Varies				
L	Drain width (trapezoidal drain) (m)	Minimum 0.60, varies according to required hydraulic capacity				
	Right of way	As per Public Roads Bill				

Notes:

1. The widths of the travelled way and shoulders in Table 5-1 are not prescriptive in that:
    a. They provide ranges within which the designer can select the most appropriate width according to terrain type and difficulty of construction (see Tables in *Chapter 7 – Design Standards*).
    b. In flat/rolling terrain the larger widths will normally be provided whereas in steep and mountainous terrain the narrower widths may be used in combination with local widening or passing bays, if so required.
2. On road classes LVR1 and LVR2, where passing bays are not provided, the minimum width of the Carriageway will be 4.5 m comprising a Travelled Way of 3.5 m and 2 x 0.50 m unpaved shoulders.
3. On road class LVR3, when a 4.5 m travelled way width is adopted, 2 x 0.50 m paved shoulders should be considered on curves and at other appropriate locations to provide a Carriageway width of 5.5 m which will accommodate the occasional passing of large vehicles.
4. On road classes LVR4 and LVR5, the Travelled Way widths recommended are adequate for accommodating mixed traffic with a Car Equivalency (CE) < 300 (see Chapter 4, Table 4.3). Paved shoulders of varying width (depending on particular circumstances) are required when the CE > 300.
5. A camber of 3.0% is recommended on paved roads. Although steeper than traditional requirements, it facilitates more efficient shedding of rainwater on relatively narrow carriageways, accommodates construction tolerances of ±0.5% (taking into account the skills and experience of small-scale contractors and LBM of construction), and does not adversely affect driving conditions on LVRs.

The typical cross-sections for each terrain type are essentially the same for both paved and unpaved roads, the only difference being that the surfacing indicated on the Figure 5-2 to Figure 5-5 will not be there on the unpaved roads (Table 5-1 explains the symbols).

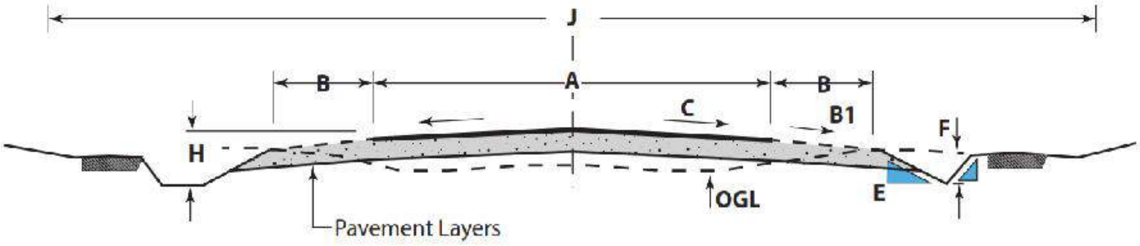

Figure 5-2: Typical cross section in flat terrain

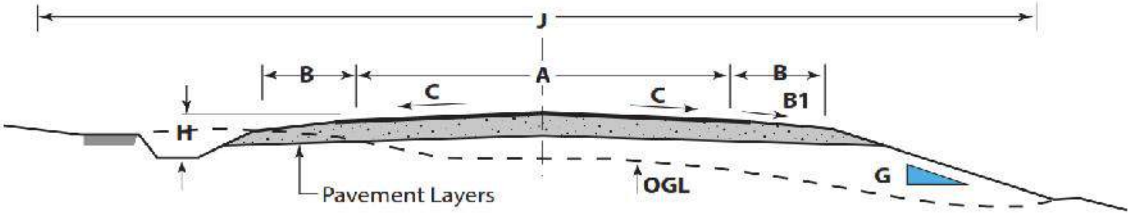

Figure 5-3: Typical cross section in rolling terrain

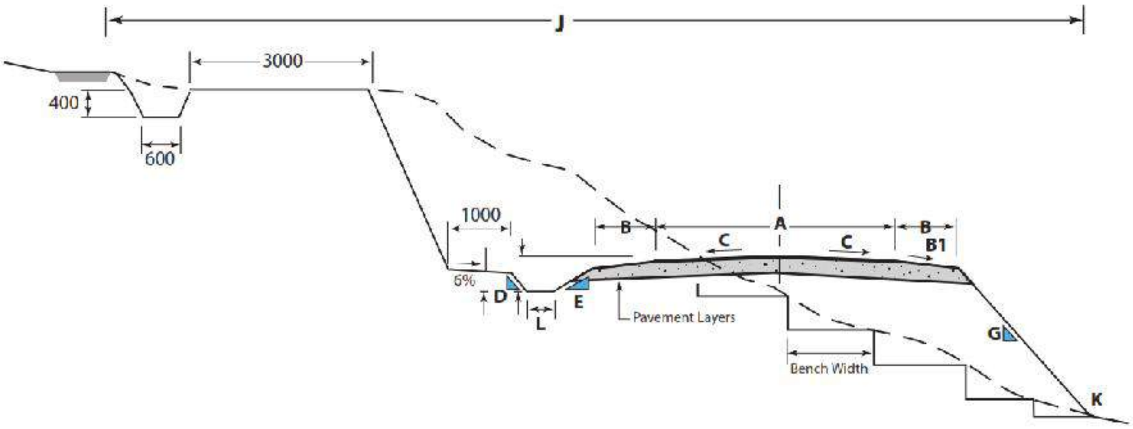

Figure 5-4: Typical cross section in mountainous terrain

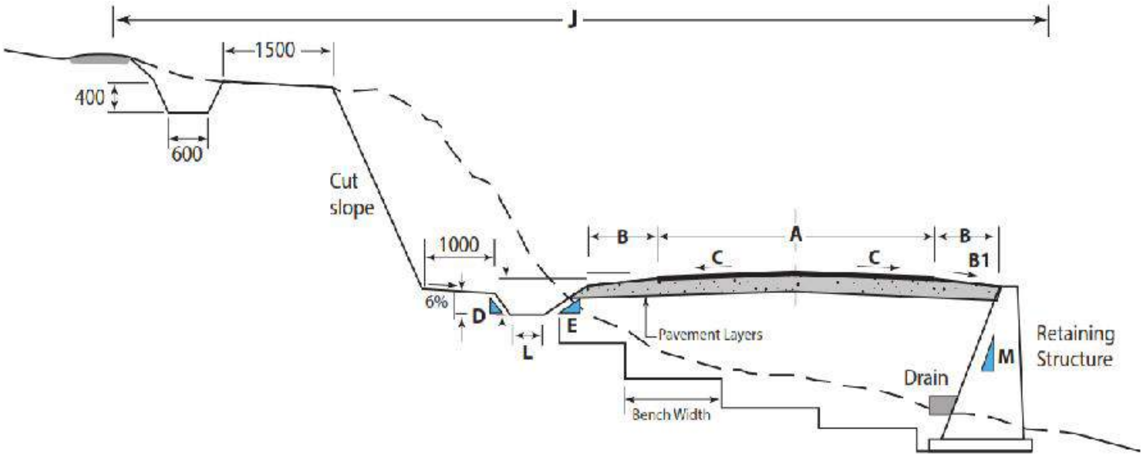

Figure 5-5: Typical cross section for escarpment terrain

Notes to Figure 5-4 and Figure 5-5:

1. For cut slopes refer to Table 5-2.
2. For details on the use of interceptor and cut-off drains see the Pavement Design Manual, *Chapter 8 – Drainage and Erosion Control*.
3. Cross-sections can be in either full fill, full cut or a combination of the two in varying proportions as determined by topography, alignment and underlying geology. Retained full fill is shown here for convenience.

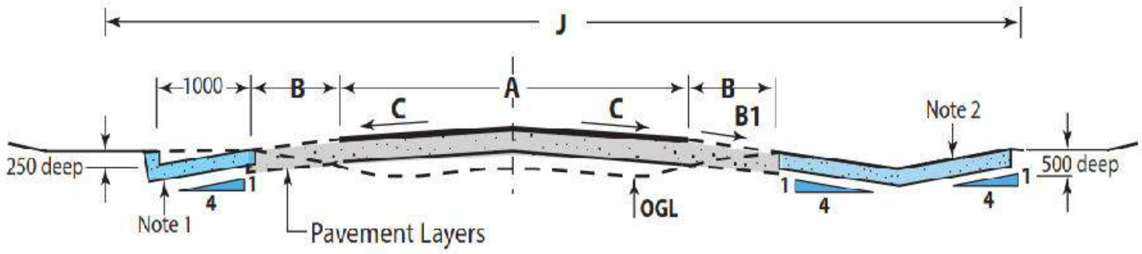

Figure 5-6: Typical cross section for populated areas

Notes to Figures 5 and 6:

1. Open channel Type A – 250 mm thick mortared stone pitching.
2. Open channel Type B – 250 mm thick mortared stone pitching.
3. Choice of open channel dependent on local conditions.
4. Surfacing of shoulder required on paved roads if the side drains are lined.
5. Provide lined channels only where maintenance of road surface and camber at original levels is guaranteed.

5.2.3 Right-of-way

Right-of-way (or the road reserve) is provided to:

- accommodate road width and the drainage requirements;
- provide space for services (water, electricity etc.);
- provide space for self-recovery of run off-road incidents
- enhance safety;
- improve the appearance of the road;
- provide space for non-road travellers; and
- provide space for upgrading and widening in the future.

The width of the right-of-way given in Table 5-1 is stipulated by the current Public Roads Bill. It is important that the right-of-way is strictly enforced to avoid problems in the future when space may be required for upgrading and widening.

5.2.4 Side Slopes and Low Embankments

Side slopes should be designed to ensure the stability of the roadway and, on low embankments, to provide a reasonable opportunity for recovery if a vehicle goes out of control across the shoulders.

Figure 5-7: Details of road edge elementsillustrates the general cross section and defines the various elements. The position of the side drain invert should be a reasonable distance away from the road to minimise the risk of infiltration of water into the road pavement structure when the drain is full for any length of time.

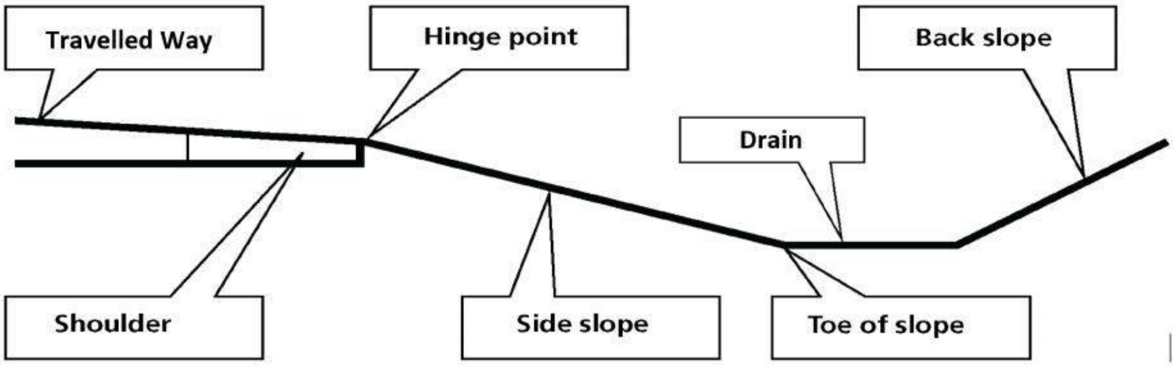

Figure 5-7: Details of road edge elements

The side slope is defined as 'recoverable' when drivers can generally recover control of their vehicles should they encroach over the edge of the roadway. Side slopes of 1:4 or flatter are recoverable. Research has also shown that rounding at the hinge point and at the toe of the slope is also beneficial.

A non-recoverable slope is defined as one that is traversable but from which most drivers will be unable to stop safely or return to the roadway easily. Vehicles on such slopes can be expected to reach the bottom. Slopes of between 1:3 and 1:4 fall into this category.

A critical slope is one on which the run-off road vehicle is likely to overturn, and these will have slopes of greater than 1:3.

The selection of side slope and the back slope is often constrained by topography, embankment height, the height of cuts, drainage considerations, right of way limits and economic considerations. For rehabilitation and upgrading projects, additional constraints may be present such that it may be very expensive to comply fully with the recommendations provided in this manual.

Slope dimensions for the various conditions are summarised Table 5-2.

Table 5-2: Slope dimensions for cross-sections (ratios are vertical: horizontal)

Material	Height of slope (m)	Side slope		Back slope	Safety classification(3)
		Cut	Fill		
Earth	0.0-1.0	1:4	1:4	1:3	Recoverable
	1.0-2.0	1:3	1:3	1:2	Not recoverable
	>2.0	1:2(1)	1:2(1)	1:1.5	Critical
Rock	Any height	Dependent on costs			Critical
Expansive clays(2)	0-2.0	n/a	1:6		Recoverable
	>2.0	n/a	1:4		

Notes to Table 5-2:

1. Certain soils may be unstable at slopes of 1:2. Geotechnical advice required.
2. The side drains should be moved away from the embankment.
3. If critical and non-recoverable side slopes cannot be avoided, it is often appropriate to install 'guard posts' at critical locations.

5.2.5 Side Drains

Detailed information concerning side drains is provided in the Pavement Design Manual *Chapter 7 – Hydrology and Drainage Structures*.

Depending on the method of construction, the side drains may be either v-shaped or trapezoidal. Trapezoidal drains are preferable because they have a greater hydraulic capacity and tend to scour less than v-drains.

Substantial side drains should be avoided when the road traverses areas of expansive clays, with a preference for the roadway to be constructed on a low embankment. Water should be discharged uniformly along the road. Where side drains cannot be avoided, they should be a minimum distance of 4 m from the toe of the embankment and should be shallow and trapezoidal in shape.

5.2.6 Shoulders, Flush Kerbs and Edge Beams

The functions of shoulders include:

- Providing structural support to the carriageway.
- Allowing wide vehicles to pass one another without causing damage to the carriageway or shoulder.
- Providing extra room for temporarily stopped or broken-down vehicles.
- Allowing pedestrians, cyclists and other vulnerable road users to travel in safety.
- Limiting the penetration of water into the pavement.

On paved roads the whole roadway width should normally be sealed, whether shoulders are provided or not.

Gravel shoulders tend to be badly maintained and can pose a serious danger to traffic (edge drop) and trap water that will penetrate into the pavement layers. The level of maintenance available, to a large extent, will determine whether shoulders are to be paved or not.

As much as provision of shoulders may be desirable, it may not always be economically feasible and strictly warranted in very low traffic situations. Other than in populated areas with high CE values, shoulders are generally not recommended on LVRs. Where shoulders are not provided, other means of providing extra lateral support, as well as protection to the edge of the sealed surface, must be provided.

It is good practice to ensure even and proper compaction right to the edge of the roadway. To achieve this, it is necessary to initially construct it slightly wider than the specified width and to trim the side slope off with a rounded shape over, say, the first 1.0 m from the edge of the seal. This assists in reducing erosion of the side slope.

Other means of giving lateral support and protecting the edge of the surfaced area include a method that has been used extensively in the past, namely to provide flush kerb stones which may be set in mortar or just properly embedded in the top of the side slope (Figure 5-8). Such protection should always be provided where vehicles would regularly turn off a paved surfacing onto the shoulder.

Severe edge breaks constitute a major maintenance problem, and selective use of kerbs or edge beams will thus contribute to reduced maintenance requirements and enhanced road safety.

Where minor accesses join the road or on sections with frequent “off carriageway” driving or parking occurs, concrete edge beams or flush kerb stones should be used to protect the edge of the surfacing.

Experience has shown that severe edge breaks also occur where commonly used footpaths cross the road. When these are clearly defined at the time of construction, short kerbed sections or edge beams will prevent this from happening.

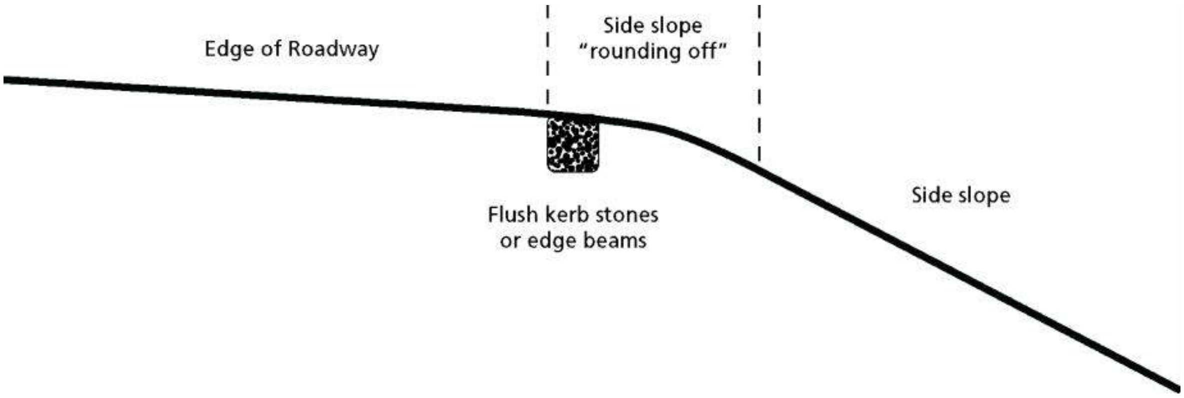

Figure 5-8: Side slope "rounding off" and location of flush kerb stones or edge beams

5.2.7 Single-lane Roads and Passing Bays

Single lane roads are commonly used on very low volume roads (Road Design Class LVR1, ADT < 50 vpd) where it would not be economically justifiable to provide a higher standard facility. Such roads permit two-way traffic but are not wide enough in most places to allow vehicles to pass one another. However, a single-lane operation is adequate as there will only be a small probability of vehicles meeting, and the few passing manoeuvres can be undertaken at reduced speeds using either passing bays or local widening, especially at bends.

The recommended single lane travelled way width is 3.5 m. Where feasible, 0.50 m unpaved shoulders may be considered to provide a carriageway of 4.5 mm which is sufficient to cope with the expected traffic and occasional meeting occurrences on these roads. Alternatively, passing bays, as illustrated in Figure 5-9, may be provided~~.~~ The combined width of the carriageway and passing bay shall be 5.5 m over a length of 5 m (or 10 m where likely to be used by buses or single-axle trucks). 5 m tapers should be provided at each end of the passing bay. Local widening at bends must be determined on a case-by-case basis.

Figure 5-9: Single lane road with passing bay

Passing bays should normally be provided every 300 m to 500 m depending on the terrain and geometric conditions. Care is required to ensure good sight distances and the ease of reversing to the nearest passing bay, if required. Passing bays should be provided at the most convenient/ practicable places rather than at precise intervals provided that the distance between them does not exceed the recommended maximum. Ideally, there should be a clear view from one passing bay to the next.

The same approach for dealing with LVR1 roads, as discussed above, is also recommended for LVR2 roads, where local widening to achieve a carriageway width of 4.50 m at selected, conveniently located sections of about 25 m will adequately accommodate the relatively few vehicle interactions.

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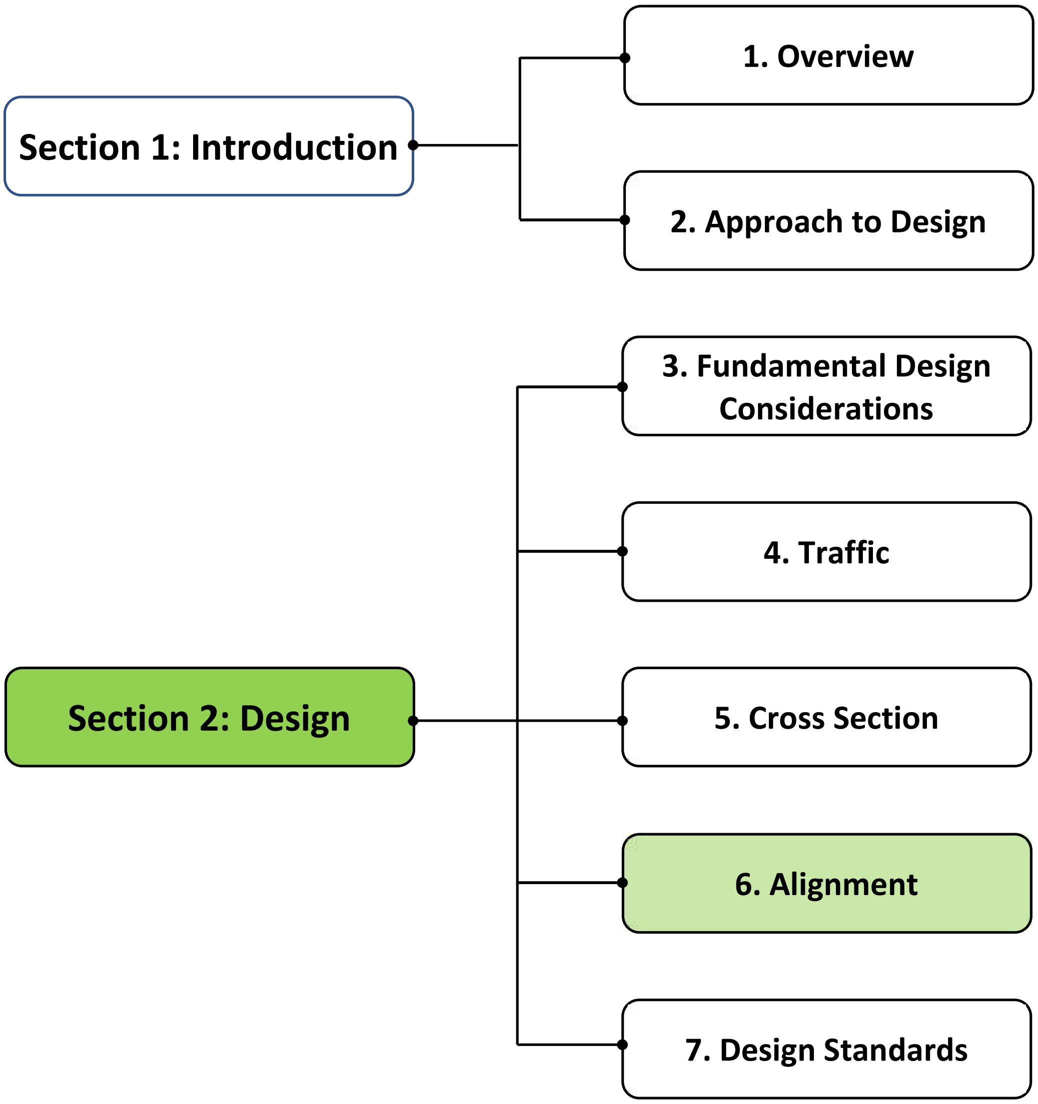
Low Volume Roads Manual
Part A – Geometric Design: Rural Roads



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6.1 Introduction

6.1.1 Background

The design of the road alignment is concerned with selecting the parameters of the geometric features of the road so that they provide a safe, comfortable and efficient means for transporting people and goods. The principal components are the horizontal alignment, which is essentially the road in plan, and the vertical alignment, which is the road in longitudinal profile. Thus, designing the road alignment is primarily concerned with the application of methods of achieving safety and efficiency in the road transport system.

However, for LVRs designed for access rather than mobility, speed and efficiency are not the primary concerns. For the Option A design method described in *Chapter 2 – Approach to Design*, whereby an existing alignment is used as much as possible provided that safety concerns are fully addressed, the primary criterion is to provide an all-weather road that is safe.

If the Option B design is selected, the relationships between safe speed and geometry become very important. Design speed controls many aspects of the alignment and the resulting design standards are driven primarily by safety requirements. Although the calculations required for the Option B design are not specifically required for Option A, an understanding of the safety issues is also essential for Option A because every element of the alignment must be checked for safety. For example, adequate sight distances are required for both Option A and Option B designs, but sight distance requirements can be reduced with the installation of appropriate speed reducing and other measures to avoid costly re-alignments.

6.1.2 Purpose and Scope

The purpose of the chapter is to discuss the application of horizontal and vertical alignment principles to form, together with cross-sectional elements, safe and efficient LVRs. The vertical slopes and horizontal curves of the road must satisfy certain criteria based on how vehicles and humans interact with them. Some of these are specific to either horizontal or vertical alignment while some are common to both.

The scope of the chapter is to cover the various criteria and how they should be applied. Once the criteria have been defined, they are used to design the horizontal and vertical alignments.

6.2 Design Speed and Geometry

6.2.1 General

Design speed has been introduced in *Chapter 3 – Fundamental Design Considerations*, Section 3.2.8. It is defined as the maximum safe speed that can be maintained over a specified section of road when conditions are so favourable that the design features of the road govern the speed. In practice, this comes down to the 85th percentile of operating speeds, as observed for the particular design speed.

The concept of design speed is most useful because it allows the key elements of geometric design to be selected for each road standard in a consistent and logical way. For example, design speed is relatively low in mountainous terrain to reflect the necessary reductions in standards required to keep construction costs to manageable proportions. The speed is higher in rolling terrain and higher still in flat terrain.

In practice, the speed of motorised vehicles on many roads in flat and rolling terrain will only be constrained by the road geometry over relatively short sections, but it is important that the level of constraint is consistent for each road class and set of conditions.

In view of the mixed traffic that occupies rural roads and the cost-benefit of selecting lower design speeds, it is prudent to select values of design speed towards the lower end of the internationally acceptable ranges. The recommended values are shown in the Tables in *Chapter 7 – Design Standards*.

Changes in design speed, for whatever reason, should be made over distances that enable drivers to change speed gradually. Thus, changes should never be more than one design step at a time and the length of the sections with intermediate standards (if there is more than one change) should be long enough for drivers to realise there has been a change before another change in the same direction is encountered. Where this is not possible, warning signs should be provided to alert drivers to the changes.

6.2.2 Stopping Sight Distance

In order to ensure that the design speed is safe, the geometric properties of the road must meet certain minimum or maximum values to ensure that drivers can see far enough ahead to carry out normal manoeuvres, such as overtaking another vehicle or stopping if there is an object in the road.

The distance a vehicle requires to stop safely is called the stopping sight distance (SSD). It mainly affects the shape of the road on the crest of a hill (vertical alignment), but if there are objects near the edge of the road that restrict a driver's vision on the approach to, or in a bend, SSD requirements also affect the horizontal curvature.

The driver must be able to see any obstacle on the road, hence the stopping sight distance depends on the size of the object and the height of the driver's eye above the road surface (Table 6-1).

Table 6-1: Parameter values used for calculating sight distances

Characteristic	**Value**
Car driver's eye height	1.05 m
Truck drivers eye height	1.8 m
Height for Stopping Sight Distance for general objects in the road	0.2 m
Height for Stopping Sight Distance for flat objects in the road (e.g. potholes, wash-out)	0.0 m
Height for Stopping Sight Distance for vehicle in the road	0.6 m
Object height for Passing Sight Distance (e.g. roof of car)	1.3 m
Object height for Decision Sight Distance	0.0 m
Driver's reaction time	2.5 s
The maximum deceleration rate for cars	3.0 m/s^2
The maximum deceleration rate for trucks	1.5 m/s^2
Friction between tyres and road surface	Appendix A1-3
Gradient of the road	Appendix A1-3

The driver needs time to react, and then the brakes of the vehicle need time to slow the vehicle down, hence stopping sight distance is extremely dependent on the speed of the vehicle. The surface characteristics of the road also affect the braking time, so the values for unpaved roads differ from those of paved roads, although the differences are small for design speeds below 60 km/h.

The stopping distance also depends on the gradient of the road as it is harder to stop on a downhill gradient than on a flat road because the momentum of the vehicle acts down the gradient in the opposite direction to the frictional forces that are attempting to stop the vehicle.

Full adherence to the required sight distances is essential for safety reasons. Thus, on the inside of horizontal curves, it may be necessary to remove trees or other obstacles in the road reserve to ensure adequate lines of sight. If this cannot be done, the alignment must be changed. In rare cases where it is not possible, a change in design speed is necessary, and adequate and permanent signage must be provided. Lines of sight should never go outside the road reserve and preferably should remain between the shoulder breakpoints, because vegetation grows back and maintenance teams are often unaware of clearances for sight distance purposes.

Recommended stopping sight distances for paved and unpaved roads in flat terrain and at different design speeds are shown in Table 6-2, as derived from Equation A1.1 and Table A1-2, and in the detailed design Tables in *Chapter 7 – Design Standards.*

Table 6-2: Stopping sight distances (m)

Design speed (km/h)	20	30	40	50	60	70	80
Unpaved roads (1)	20	30	50	70	95	125	160
Paved roads (1)	20	30	45	65	85	110	135

Note: (1) In rolling and mountainous terrain these distances should be increased by 10%.

6.2.3 Stopping Sight Distance for Single Lane Roads (Meeting Sight Distance)

For single-lane roads, adequate sight distances must be provided to allow vehicles travelling in the opposite direction to see each other and to stop safely, if necessary. This distance is normally set at twice the stopping sight distance because two vehicles travelling in opposite directions are involved. An extra safety margin of 20-30 m is usually added because of the serious consequences of a head-on collision.

Although a vehicle is a much larger object than is usually considered when calculating stopping distances, these added safety margins are used partly due to the very severe consequences of a head-on collision, and partly because it is difficult to judge the speed of an approaching vehicle, which could be considerably greater than the design speed. However, single-lane roads will have a relatively low design speed, hence meeting sight distances should not be too difficult to achieve.

6.2.4 Intersection Sight Distance

Intersection sight distance is similar to stopping sight distance except that the object being viewed is another vehicle that may be entering the road from a side road or crossing the road at an intersection. The required safe sight distance for trucks, measured in metres, is about 3 times the vehicle speed in km/hr. On straight sections of road, many vehicles will exceed the road's design speed but, since the road is straight, sight distances should be adequate.

6.2.5 Passing Sight Distances

Factors affecting the safe sight distances required for overtaking are more complicated because they involve the capability of a vehicle to accelerate and the length and speed of the vehicle being overtaken. Assumptions are usually made about the speed differential between the vehicle being overtaken and the overtaking vehicle, but many road authorities have simply based their standards on empirical evidence.

For single-lane roads, overtaking manoeuvres are not possible and passing manoeuvres take place only at the designated passing places (laybys). On the lower classes of 2-lane roads, passing sight distances (PSD) are based on providing enough distance for a vehicle to safely abort a passing manoeuvre if another vehicle is approaching. The recommended values are shown in Table 6-3.

Table 6-3: Passing sight distances (m)

Design speed (km/h)	30	40	50	60	70	80
Recommended values	115	135	155	180	210	240

6.2.6 Passing Opportunities

Passing Sight Distance is a desirable requirement for two-lane single carriageway roads. Sufficient visibility for passing increases the capacity and efficiency of a road and should be provided for as much of the road length as possible within financial limitations. Ideally, passing opportunities should be available based on the road hierarchy, as indicated in Table 6-4. The percentage is the percentage length of road that provides sufficient passing opportunities at the design speed. For example, since the PSD at 80 km/h is 550 m, an alignment giving a 50% passing opportunity means that one passing opportunity will occur every 1100 m on average. If these percentages cannot be physically or economically achieved in a particular stretch of road, its level of service should be locally evaluated to verify whether special provision (e.g. a passing or climbing lane) should be provided.

Table 6-4: Minimum provision of passing sight distance (%)

Design Standard	Percent Passing Opportunity and Terrain				
	Flat	**Rolling**	**Mountainous**	**Escarpment**	**Urban/Peri-Urban**
LVR5	50	50	25	0	20
LVR4		33			
LVR3	25	25	15		

6.2.7 Control of Sight Distance

Sight distances should be checked during design and adjustments made to meet the minimum requirements. The values shown in the paragraphs above should be used for the determination of sightlines. Details of crest and sag curve design are provided in Section 6.4.

On the inside of horizontal curves, it may be necessary to remove buildings, trees or other sight obstructions or widen cuts to obtain the required sight distance as indicated in Figure 6-1. The distance labelled M in the diagram must be clear of obstruction to allow a clear view along the sightline shown.

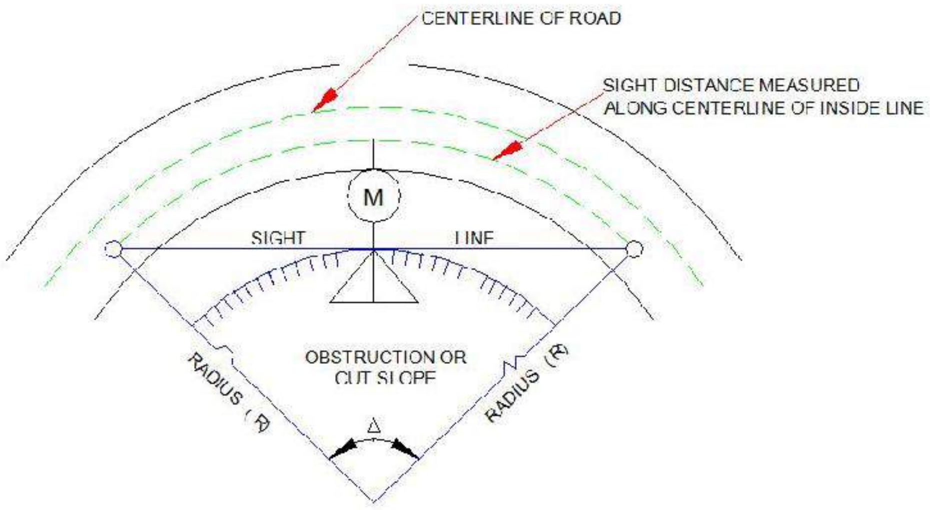


Figure 6-1: Sight Distance for Horizontal Curves

Relevant formulae are as follows:

Length of Sight Line (S) = 2R sin($\Delta/2$) where Δ = Deflection angle (°)

Length of Middle Ordinate (M) = R (1-cos ($\Delta/2$)

Example:

Radius = 1000 m, $\Delta = 20^0$;

S = 2R sin(Δ/2)	M = R (1 – cos(Δ/2)
= 2(1000) (sin(10°))	= 1000(1- cos(10°))
= 347.0 m	= 15.2 m

6.3 Components of Horizontal Alignment

6.3.1 General

The horizontal alignment consists of a series of straight sections (tangents) connected to circular curves. The horizontal curves are designed to ensure that vehicles can negotiate changes in direction safely. The alignment design should be aimed at avoiding sharp changes in curvature, thereby achieving a safe uniform driving speed. Transition curves between straight sections of road, and circular curves whose radius changes continuously from infinity (tangent) to the radius of the circular curve (R), are used to reduce the abrupt introduction of centripetal acceleration that occurs on entering the circular curve. They are not required when the radius of the horizontal curve is large and where the design speed is 80 km/h or greater, and therefore they are normally not required on LVRs.

6.3.2 Circular Curves

In order for a vehicle to move in a circular path, an inward radial force is required to provide the necessary centripetal acceleration or, in other words, to counteract the centrifugal force. This radial force is provided by the sideways friction between the tyres and the road surface assisted by the cross-fall or super-elevation.

The sideways friction coefficient is considerably less than the longitudinal friction coefficient. Its value decreases as speed increases, but there is considerable disagreement about representative values, especially at the lower speeds. For paved roads, it ranges from between 0.18 and 0.3 at 20 km/h down to between 0.14 and 0.18 at 80 km/h. For unpaved roads, it can be considerably less.

For both sealed and unsealed roads, there are also constraints on the maximum cross-fall, as described below. These constraints translate directly into minimum values of horizontal radii of curvature.

6.3.3 Camber and Crossfall

Achieving proper camber and crossfall is essential to ensure rapid shedding of water off the carriageway and to prevent moisture ingress into the pavement from the top.

On paved LVRs, a camber of 3% is recommended, as shown in Figure 6-2. Although steeper than traditional specifications, it does not cause problems for drivers in a low-speed environment. It also accommodates a reasonable construction tolerance of ± 0.5%, taking into account the skills and experience of small-scale contractors and labour-based construction, and provides an additional factor of safety against water ingress into the pavement should slight rutting occur after some time of trafficking.

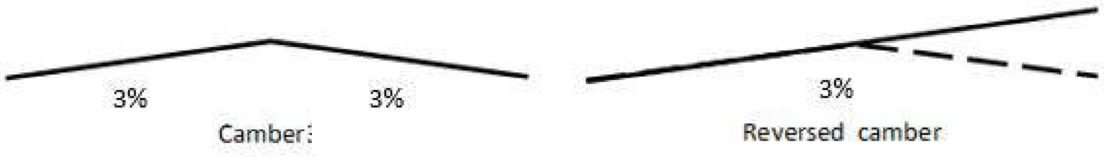


Figure 6-2: Camber and reverse camber

6.3.4 Adverse Cross-fall/Camber

The need for removing adverse camber arises on the outside of curves when the cross-fall or camber causes vehicles to lean outwards when negotiating the curve. This affects the cornering stability of vehicles, thereby affecting safety and is uncomfortable for drivers. The severity of its effect depends on vehicle speed, the horizontal radius of curvature of the road and the side friction between the tyres and the road surface. A side friction factor of 0.07 is considered reasonable and has been used to determine suitable minimum radii below which adverse camber should be removed (Table 6-5). Values for unpaved roads are based on a 6% 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 6-5: Adverse crossfall/camber to be removed if radii are less than shown

Design speed (km/h)	Minimum radii (m)	
	Paved	Unpaved
<50	500	700
60	700	1000
70	1000	1300

To remove adverse cross-fall, the basic cambered shape of the road is gradually changed as the road enters the curve until it becomes simply cross-fall in one direction at the centre of the curve as shown in Figure 6-3, with the cross-fall being the same as that of the inner side of the cambered two-lane road (usually 3% for sealed roads). The removal and restoration of adverse cross-fall should take place over similar distances to super-elevation as described in Section 6.3.5.

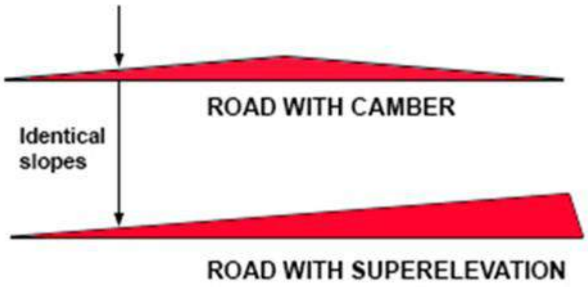


Figure 6-3: Camber and superelevation

The values shown in Table 6-5 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 shown, should be treated in a similar manner in the design.

For sealed roads, the removal of adverse camber may not be sufficient to ensure good vehicle control when the radius of the horizontal curve becomes too small. In such a situation, additional cross-fall may be required. This is properly referred to as superelevation, but it has become common practice to refer to all additional elevation as super-elevation, and this convention will be used here.

6.3.5 Superelevation

Superelevation on narrow, unpaved LVRs is not necessary. This is because it is recommended that adverse crossfall or camber is always removed on horizontal curves below 1000 m radius. Since the recommended crossfall or camber is 6%, the effective ‘superelevation’ when adverse cross-fall is removed will also be 6%, and this, therefore, determines the minimum radius of horizontal curvature for each design speed in the same way as for genuine superelevation. In practice, it may not be possible to maintain such a value of crossfall during the life of an unsealed road and therefore it is recommended that minimum radii are based on the lower level of 4% crossfall.

For sealed roads, the removal of adverse cross-fall will result in an effective superelevation of 3% and this should be used to determine minimum radii of curvature for such roads. However, if these radii are difficult to achieve, genuine superelevation of up to 7% (or, in exceptional circumstances, up to 10%) can be used with a resulting decrease in horizontal radius of curvature.

The change from a normal cross section on straight sections of the road to a super-elevated section should be made gradually (Figure 6-4). The length over which superelevation is developed is known as the superelevation development length. Two-thirds of the development length should be provided before the curve begins. The development length depends on design speed, as shown in Table 6-6. Between 50% and 75% of the superelevation should be achieved by the tangent point (66% is usually used).

Table 6-6 Superelevation development lengths

Design speed (km/h)	Development length (m)
30	25
40	30
50	40
60	55
70	65
80	80

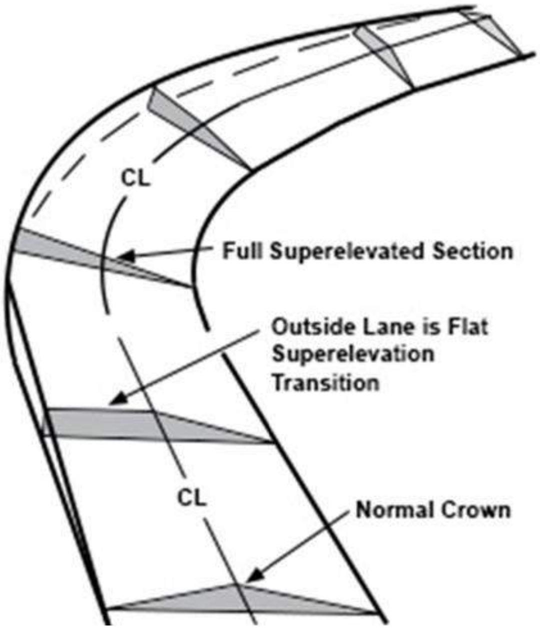


Figure 6-4: Development of superelevation

6.3.6 Recommended Minimum Horizontal Radii

The recommended minimum values of horizontal curvature were derived on the basis of sideways friction factors (see *Appendix: Characteristics of Horizontal and Vertical Alignment*) and superelevation and are shown in Table 6-7, Table 6-8 and in the Tables in *Chapter 7 – Design Standards*. The use of a higher value of superelevation makes it possible to introduce a smaller horizontal curve based on the same design speed. This can be used for paved roads but not for unpaved roads.

In some situations, 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.

Where only small numbers of large 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.

Table 6-7: Recommended minimum horizontal radii of curvature: Paved roads (m)

Design speed (km/h)	20	30	40	50	60	70	80
Minimum horizontal radius for SE = 4%	15	30	55	95	150	220	300
Minimum horizontal radius for SE = 6%	15	27	53	85	135	190	265

Table 6-8: Recommended minimum horizontal radii of curvature: Unpaved roads (m)

Design speed (km/h)	20	30	40	50	60	70	80
Minimum horizontal radius for SE = 4%	15	35	65	115	175	255	355
Minimum horizontal radius for SE = 6%	15	30	60	100	155	215	300

6.3.7 Consistency and Multiple Curves

Horizontal alignment design involves connecting curves and tangents. Under normal circumstances, sections of road will contain many curves whose radii are larger than the minimum radii specified in the design standards.

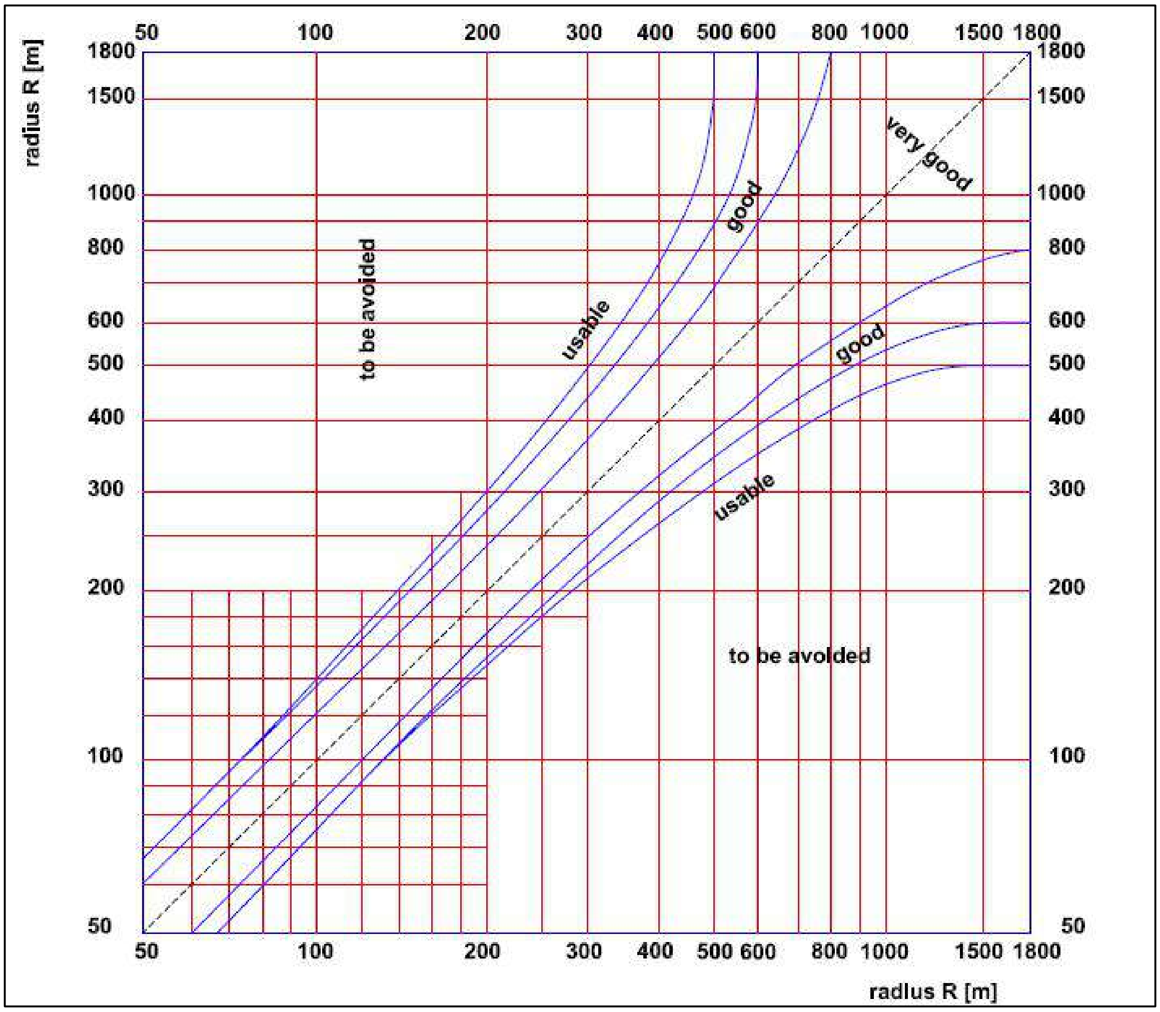
In hilly and mountainous terrains, horizontal curves are required more frequently and have small radii because the design speeds are low. The tangent sections become shorter, and a stage can be reached where successive curves can no longer be dealt with in isolation. In cases of reverse curves, broken back curves and compound curves it is often possible to connect curves and tangents that do not fit well together according to normal design standards and in terms of meeting driver expectation and comfort.

6.3.8 Compound Curves

Compound horizontal curves are defined as curves where the distance between the end of one and the beginning of the next consecutive curve is less than the radius of the larger curve. These can be useful in fitting the road to the terrain, but in some circumstances, they can be dangerous. Drivers do not usually expect to be confronted by a change in radius whilst in a curve, and therefore in design speed. Hence, for reasons of safety and driver comfort, it is not advisable for two consecutive curves to differ in radius by a large amount even though they are both greater than the minimum.

Figure 6-5 shows the required ratio of radii for consecutive curves. The best result will be achieved when the two radii are similar (labelled 'very good' in the diagram). If the ratio of radii falls outside the 'good' category but inside into the 'useable' category, some discomfort or inconvenience will be felt because of the increase in centripetal force when entering the tighter curve. For high-speed roads, such situations can be potentially dangerous and should be avoided. However, for LVRs the design speed is lower, and it is rarely necessary to modify the alignment for these reasons other than for curve widening. Nevertheless, if the situation can be avoided, it is obviously best to do so unless it is considered too costly.

However, it is not merely the ratio of curve radii that affect consistency. In particular, the length of connecting tangents and the friction between the tyre and the road surface are also important because these affect speed. Thus, for consistency, all the various design elements must be combined in a balanced way, avoiding the application of minimum values for one or a few elements at a particular location when other elements are considerably above the minimum requirements.



Source: German Road and Transportation Research Association, Cologne, Germany (1973). *Guidelines for the design of rural roads (RAL), Part II*.

Figure 6-5: Ratio of radii of consecutive horizontal curves

6.3.9 Reverse Curves

A reverse curve is one which is followed immediately by a curve in the opposite direction. In this situation, it is difficult for the driver to keep the vehicle in its proper lane. It is also difficult for the designer to accommodate the required superelevation within the space available. If it is not possible to realign then warning signs should be provided.

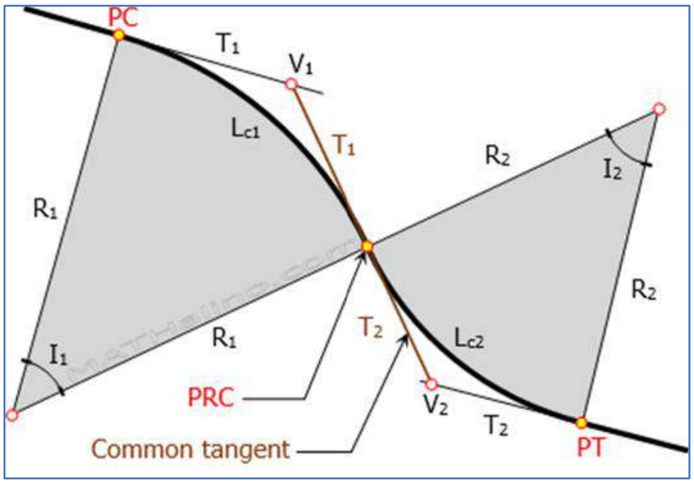


Figure 6-6: Illustration of reverse curves

6.3.10 Broken-back Curves

This is the term used to describe two curves in the same direction connected by a short tangent. Drivers do not usually anticipate that they will encounter two successive curves close to each other in the same direction. There can also be problems fitting in the correct superelevation in the space available. If it is not possible to realign then warning signs should be provided.

6.3.11 Isolated and Long Curves

An isolated curve close to the minimum radius connected by long straight sections is inherently unsafe. Irrespective of the design speed, actual speeds on long straight sections will be relatively high, and therefore a curve of minimum radius will require a significant reduction in speed for most vehicles. It is good practice to avoid the use of minimum standards in such situations. An added bonus is that, provided no extra cutting or filling is required, the use of a larger radius of curvature results in a shorter and less expensive road. Curve widening can help to alleviate this problem if a higher radius curve cannot be used.

6.3.12 Curve Length

For reasons of safety and ease of driving, curves near the minimum for the design speed should not be used at the following locations:

- On high fills, because the lack of surrounding features reduces a driver's perception of the alignment.
- At or near vertical curves (tops and bottoms of hills) because the unexpected bend can be extremely dangerous, especially at night.
- At the end of long tangents or a series of gentle curves, because actual speeds may exceed design speeds.
- At or near intersections and approaches to bridges or other water crossing structures.

There are conflicting views about curve lengths, depending on how straight the road could be. Normally, for LVRs, the horizontal alignment should maximise the length of road where adequate sight distances are provided for safe overtaking. Overtaking is difficult on curves of any radius and hence the length of curved road should be minimised. This requires curve radii to be relatively close (but not too close) to the minimum for the design speed to maximise the length of straight sections. This view is the currently accepted best practice for roads except in very flat terrain, but care should be exercised to ensure the curves are not too tight.

However, very long straight sections should also be avoided because they are monotonous and cause headlight dazzle at night. A safer alternative is obtained by a winding alignment with tangents deflecting 5 to 10 degrees alternately from right to left. Some authorities recommend that straight sections should have lengths (in metres) less than 20 x design speed in km/h. However, such 'flowing' curves restrict the view of drivers on the inside of the carriageway and reduce safe overtaking opportunities. Thus, such a winding alignment should only be adopted where the straight sections are very long. In practice, this only occurs in very flat terrain. The main aspect is to ensure that there are sufficient opportunities for safe overtaking and therefore, provided the straight sections are long enough, a semi-flowing alignment can be adopted at the same time. If overtaking opportunities are infrequent, maximising the length of the straight sections is the best option.

For small changes of direction, it is often desirable to use a large radius of curvature. This improves the appearance and reduces the tendency for drivers to cut corners. In addition, it reduces the length of the road segment and therefore the cost of the road provided that no extra cut or fill is required.

6.3.13 Curve Widening

Widening of the carriageway where the horizontal curve is tight is usually necessary to ensure that the rear wheels of the largest vehicle remain on the road when negotiating the curve; and, on two-lane roads, to ensure that the front overhang of the vehicle does not encroach on the opposite lane. Widening is, therefore, also important for safety reasons. Any curve widening that is considered should only be applied on the inside of the curve.

Vehicles need to remain centred in their lane to reduce the likelihood of colliding with an oncoming vehicle or driving on the shoulder. Sight distances should be maintained as discussed above. The levels of widening shown in Table 6-9 are recommended except for roads carrying the lowest levels of traffic (LVR1). Widening should be applied on the inside of the curve and introduced gradually.

Widening on high embankments is often recommended for the higher classes of road. The steep drops from high embankments unnerve some drivers and the widening is primarily for psychological comfort, although it also has a positive effect on safety. Such widening is not recommended for LVRs.

Table 6-9: Widening recommendations (m)

Parameter	Single-lane roads				Two-lane roads			
Curve radius	20	30	40	60	<50	51-150	151-300	301-400
Increase in width	1.5(1)	1.0	0.75	0.5	1.5	1.0	0.75	0.5

Notes: (1) See Section 6.4.5 dealing with hairpin stacks

6.3.14 Road Junctions

Unlike road junctions on high volume roads, on LVRs they do not pose a significant problem. Where two roads have to cross each other, a simple cross junction is adequate for LVRs. However, where possible, it is safer to provide two staggered T-junctions as illustrated in Figure 6-7, rather than one X-cross junction, provided there is no cost penalty in doing so. The most heavily trafficked road is retained as a direct through route. The minor road is then split so that traffic has to enter the major road by making a right turn onto the major road and then a left turn to exit the traffic stream and re-enter the minor road. This method halves the number of possible manoeuvres where the traffic from the minor road has to cross the traffic stream on the major road. The entry points of the two arms of the minor road should be spaced about 100 m apart.

The result of an accident is likely to be that one or more vehicles will leave the road. Hence, where possible, a safe 'run-off' environment should be created and good sight distances provided. Intersections should therefore not be located on high embankments, near to bridges or other high-level water crossings, on small radius curves or on super-elevated curves. To ensure good visibility, vegetation should be permanently cleared from the area surrounding the junction.

It is also advisable to avoid having intersections on gradients of more than 3% or at the bottom of sag curves. This is because:

- Stopping sight distances are greater on downhill descents and drivers of heavy vehicles have more difficulty in judging them.
- It is advantageous if heavy vehicles are able to accelerate as quickly as possible away from the junction.

The ideal angle that intersecting roads should meet is 90° because this provides maximum visibility in both directions, but visibility is not seriously compromised as long as the angle exceeds 70°.

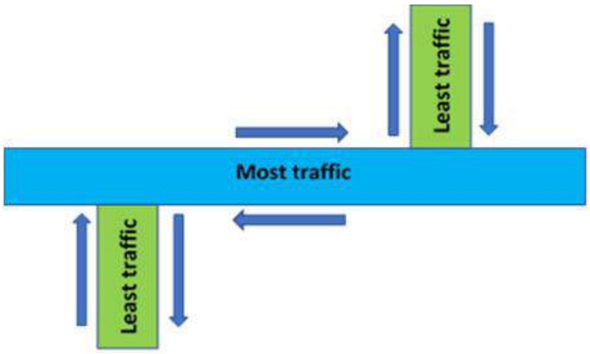


Figure 6-7: Preferred intersection design

6.4 Vertical Alignment

6.4.1 General

The two major elements of the vertical alignment are the gradient, which is related to vehicle performance and level of service, and the vertical curvature, which is governed by safe sight distances and comfort criteria.

The vertical alignment of a road seems more complicated than the horizontal alignment, but this is simply because of difficulties in presentation due to the inclusion of the algebraic difference in gradient (A %) between the uphill and downhill sides. In addition, the equation of the vertical curve is a parabola rather than a circle, because the parabola provides a constant rate of change in grade along the vertical curve and hence eases passenger comfort.

The required sight distance for safety is the basic stopping sight distance.

6.4.2 Crest Curves

The minimum length of the curve (L metres) over the crest of the hill between the points of maximum gradient on either side is related to A and the stopping-sight distance, therefore, to the design speed. Note that although drivers would like to overtake on hills, the required sight distance for safe passing on crests is much too large to be economical on LVRs.

The minimum value of the L/A ratio (K-value) can be tabulated against the stopping sight distance and therefore also the design speed, to provide the designer with a value of L for any specific value of A. The international comparisons give the values shown in Table 6-10.

Table 6-10: Minimum K-values for crest curves

Design speed (km/h)	30	40	50	60	70	80
Sealed roads	2	4	7	12	21	37
Unsealed roads	3	6	11	19	34	58

6.4.3 Sag Curves

Sag curves are the opposite of crest curves in that vehicles first travel downhill and then uphill. In daylight, the sight distance is normally adequate for safety, and the design criterion is based on minimising the discomforting forces that act upon the driver and passengers when the direction of travel changes from downhill to uphill. On rural roads, such considerations are less important than road safety issues. However, at night-time, the problem on sag curves is the illumination provided by headlights to see far enough ahead. This depends on the height of the headlights above the road and the angle of divergence of the headlight beams.

The provision of vertical sag curvature that allows the driver to see sufficiently far ahead using headlights while driving at the design speed at night is usually too expensive for LVRs. In any case, the driving speed should be much lower at night on such roads. As a result of these considerations, it is recommended that the minimum length of the curve is determined by the driver discomfort criterion. The results are shown in Table 6-11.

Table 6-11: Minimum K-values for sag curves

Design speed (km/h)	30	40	50	60	70	80
Sealed and unsealed roads	0.7	1.3	2.2	3.5	4.8	7.5

6.4.4 Gradient

For four-wheel drive vehicles, the maximum traversable gradient on paved roads is about 18%. Two-wheel drive trucks can cope with gradients of 15%, except when heavily laden. Bearing in mind the likelihood of heavily laden small trucks, international rural road standards have a general recommended limit of 12%, but with an increase to 15% for short sections (< 250 m) in areas of difficult terrain. Slightly higher standards are recommended for LVR4 with a preferred maximum of 10% and an absolute maximum of 12% on escarpments where relief gradients of less than 6% are required for a distance of 250 m following a gradient of 12%.

For driving consistency, and hence safety, in terrains other than mountainous terrains and escarpments, limiting values of the gradient are also often specified. Thus, in flat terrain, a maximum gradient of 7% is recommended whilst in rolling terrain, a maximum of 10% is recommended.

On gravel roads a maximum gradient of 7% is recommended as, above this value, travel becomes difficult due to lack of sufficient traction on the road surface, as well as for pavement maintenance reasons.

6.4.5 Hairpin Stacks

Climbing sections on mountain and escarpment roads are often best designed using hairpin stacks. The advantages are that the most favourable site for ascending the escarpment can be selected and a more direct and therefore shorter route will often be possible. However, there are several problems with this approach.

The limited space to construct cut and fill slopes necessitates either a reduction in geometric standards or more expensive retaining structures. For LVRs, the former solution should be adopted.

Lack of suitable sites for the disposal of spoil and access problems for the plant can pose difficulties during construction.

If there are problems of instability, they may extend from one loop to another and so the advantage of attempting to choose the most stable section of the escarpment is lost.

Storm run-off will, of necessity, become very concentrated, so although the number of drainage structures and erosion controls may be reduced, their capacity will need to be increased. The risk associated with failure of the drainage is therefore correspondingly high and minimising this risk adds to the costs. If the topography allows, some of the problems of stacked hairpins can be reduced by creating several stacks that are offset from each other and staggered across the slope (i.e. not immediately above or below each other). This will reduce drainage problems and limit the danger of instability to fewer hairpin loops.

The key aspect of their geometric design is that the curves should be as flat as possible, and the tangents should be used to achieve the ascent. This is because vehicle traction is much more efficient when the vehicle is travelling in a straight line. The maximum gradient through the hairpin curve itself should be 4% for LVR4 and LVR3 but could be up to 6% for LVR2 and LVR1.

Considerable curve widening will be required where the curve radius is small to ensure that large vehicles can negotiate the bends. Widening is also required for safety reason and, if space allows, to provide a refuge area if a vehicle breaks down.

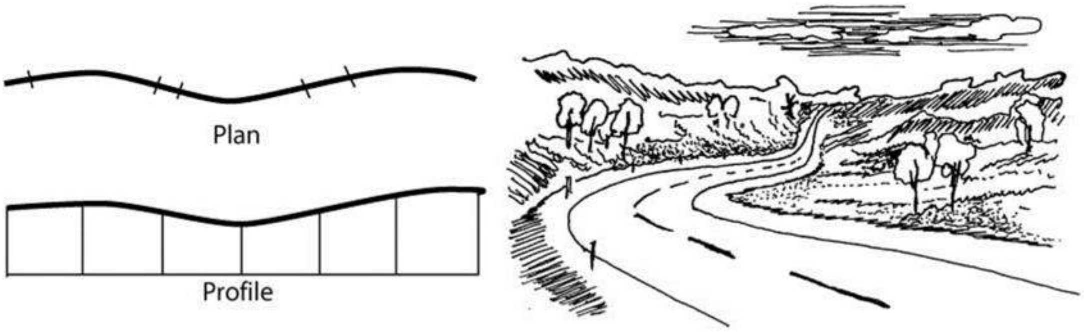
For LVRs, it is recommended that the curves should be designed to allow the passage of the design vehicles shown in *Chapter 3 – Fundamental Design Considerations*, Section 3.2.4. This means that the curve radius at the centre line of the road should be an absolute minimum of 13 m.

6.5 Coordination of Horizontal and Vertical Alignment

The alignment design must ensure that all the design elements are complementary to each other. There are a number of design situations that could produce unsatisfactory combinations of elements, despite the fact that the design standards have been followed for the particular class of road in question. These are designs that could provide surprises for drivers by presenting them with unfamiliar conditions. They are, therefore, comparatively unsafe.

Avoiding such designs is more important for the higher classes of the road because design speeds are higher, traffic volumes are much greater and, consequently, any accidents resulting from poor design are likely to be more severe and more frequent. However, in many cases, avoidance of such designs does not necessarily impose a significant cost penalty and, therefore, the principles outlined below should be applied to roads of all classes.

The horizontal and vertical alignment should not be designed independently. Hazards can be concealed by inappropriate combinations of horizontal and vertical curves and, therefore, such combinations can be very dangerous. Some examples of good and poor phasing are illustrated in Figure 6-7.



Above: Example of a good alignment design – a smooth-flowing appearance results when vertical and horizontal curves coincide.

Below: Example of a poor alignment design – uncoordinated horizontal and vertical

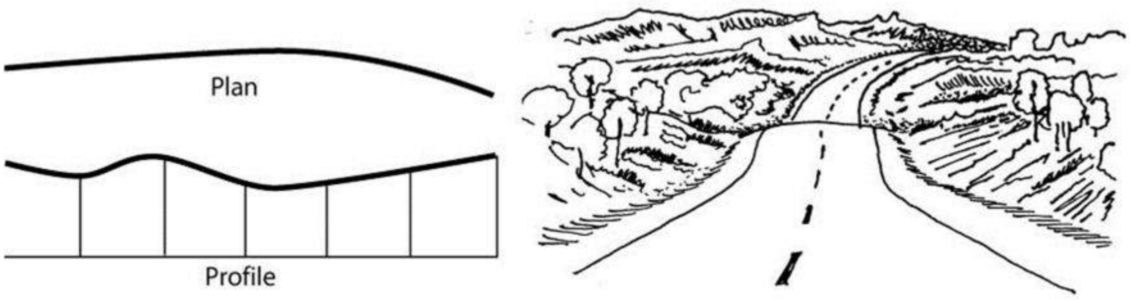


Figure 6-8: Examples of good and poor combinations of horizontal and vertical alignment

6.6 Balance

It can be seen that there are several competing factors in providing the optimum horizontal alignment. Smaller radii curves, still meeting design requirements, maximise the length of straight sections and optimise overtaking opportunities. This should be the controlling factor where the terrain is such that overtaking opportunities are infrequent and actual speeds are close to the design speeds. However, in more gentle terrain where overtaking is less of a problem and vehicles generally travel at speeds higher than the design speed, the use of larger radius curves is preferred for the reasons outlined previously.

In summary, engineering choice plays a part in the final design, which should aim to achieve a balance between competing requirements.

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Appendix: Characteristics of Horizontal and Vertical Alignment

A1-1 Introduction

This Appendix describes the calculations for computing the principal parameters for the alignment of the road that are based on the physical properties of the road, vehicle and drivers. The results of these calculations comprise the contents of some of the Tables in *Chapter 6 - Alignment* but the methodology is presented here so that the user can compute the alignment details for other combinations of the variables e.g. friction, speed, gradient etc.

A1-2 Sight Distances

Drivers must be able to see objects in the road with sufficient time to either stop or to manoeuvre round them. There are several situations requiring different sight distances i.e.:

- Stopping sight distance
- Intersection sight distance
- Decision sight distance
- Passing sight distance

Each depends on the initial speed of the vehicle and the factors listed in Table A1-1.

Table A1-1: Parameters Values Used for Calculating Sight Distances

Characteristic	Value
Car driver's eye height	1.05 m
Truck driver’s eye height	1.8 m
Height for Stopping Sight Distance for general objects in the road	0.2 m
Height for Stopping Sight Distance for flat objects in the road (e.g. potholes, wash-outs)	0.0 m
Height for Stopping Sight Distance for vehicle in the road	0.6 m
Object height for Passing Sight Distance (e.g. roof of car)	1.3 m
Object height for Decision Sight Distance	0.0 m
Driver’s reaction time	2.5 s
The maximum deceleration rate for cars	3.0 m/s^2
The maximum deceleration rate for trucks	1.5 m/s^2
Friction between tyres and road surface	Section A1-3
Gradient of the road	Section A1-4

A1-3 Friction between Tyres and Roadway

The coefficient of friction in the longitudinal direction between the vehicle tyres and the road surface is the ratio of the frictional force on the vehicle and the component of the weight of the vehicle perpendicular to the frictional force. Longitudinal friction depends on:

- vehicle speed;
- type, condition and texture of the roadway surface;
- weather conditions; and
- type and condition of tyres.

Its value decreases as speed increases and there are considerable differences between studies, especially at the lower speeds, because of the wide range of conditions that are encountered. Thus, it is difficult to select representative values because of variations in tyre wear (worn tyres are common), as well as variations in the climate from wet to arid with the time of year. Gravel roads can have particularly low friction characteristics.

Side friction coefficients are also dependent on vehicle speed, type, condition and texture of the road surface, weather conditions, and type and condition of tyres.

The coefficient of friction values considered most suitable for LVR design are shown in Table A1-2 using representative results of friction tests. The values allow a reasonable safety factor to cater for the wide range of conditions. For unpaved roads, a systematic reduction in the values used for paved roads has also been used.

Table A1-2: Friction factors

Friction Type	Road Type	Design speed (km/h)									
		30	40	50	60	70	80	90	100	110	120
Longitudinal friction	Paved	0.40	0.37	0.35	0.33	0.32	0.305	0.295	0.285	0.28	0.28
	Unpaved	0.32	0.30	0.28	0.26	0.25	0.24	0.235	0.23	0.23	0.23
Side friction	Paved	0.21	0.19	0.17	0.16	0.14	0.13	0.12	0.10	0.10	0.095
	Unpaved	0.165	0.15	0.135	0.125	0.12	0.11	0.10	0.095	0.09	0.09

A1-4 Stopping Sight Distance

The Stopping Sight Distance is the distance a vehicle, travelling at design speed, requires to stop safely after the driver has spotted a stationary object or other dangerous situation on the road ahead. This mainly affects the design of vertical curves, e.g. shape of the road over the crest of a hill, but if there are objects near the edge of the road that restrict a driver's vision on approaching a bend, then it also affects the horizontal curvature. The stopping sight distance is given by the following formula:

$$d = (0.278)(t)(V) + \frac{V^2}{(254(f+g/100))} \qquad \text{Equation A1.1}$$

where:

d = stopping distance (m)
t = driver reaction time (sec)
V = initial speed (km/h)
f = longitudinal coefficient of friction between tyres and roadway
g = gradient of road as a percentage (downhill is negative)

For speeds above 50 km/h, the gradient of the road makes a significant difference and must be taken into account in establishing safe sight distances. On a flat road, the value of g is zero. At 80km/hr on a 10 % gradient, the stopping sight distance is nearly 28 percent longer than on a flat road.

Table A1-3 applies to cars and trucks with anti-lock braking systems. Trucks with conventional braking systems require longer stopping distances. Although the driver's eye height is greater than that of a car driver, hence the driver can see objects sooner, this does not always compensate for the poorer braking system. However, separate stopping sight distances for trucks and passenger cars are not generally used in highway design.

Table A1-4 is for unpaved roads where the coefficients of friction are lower and much more variable, depending on the properties of the gravel or soil.

It is important to note that the values in the tables are for dry weather conditions. Stopping sight distances can be much longer in unfavourable wet conditions but are not generally used in design, it being assumed that drivers would drive slower under such circumstances. Driving at the design speed with worn tyres in very wet conditions is fortunately not a common activity. Most drivers slow down until they feel safe, but accident rates do increase in wet weather.

Table A1-3: Minimum Stopping Sight Distances for Paved Roads

Design Speed (km/h)	Coefficient of Friction (f)	Stopping Sight Distance (m)		
		g = 0	g = -5%	g = -10%
20	0.42	18	18	18
25	0.41	23	24	25
30	0.40	30	31	33
40	0.37	45	47	50
50	0.35	65	70	75
60	0.33	85	95	105
70	0.32	110	120	140
80	0.30	140	155	180
85	0.29	155	175	205
90	0.29	170	195	230
100	0.28	205	235	280
110	0.28	245	285	340
120	0.28	285	335	405

Table A1-4: Minimum Stopping Sight Distances for Unpaved Roads

Design Speed (km/h)	Coefficient of Friction (f)	Stopping Sight Distance (m)		
		g = 0	**g = -5%**	**g = -10%**
20	.34	19	19	20
25	.33	23	24	25
30	.32	32	34	37
40	.30	49	55	60
50	.28	70	80	90
60	.26	95	110	130
70	.25	125	145	175
80	.24	160	190	235
85	.24	180	215	270
90	.235	200	240	305
100	.23	240	290	370

A1-5 Stopping Sight Distance for Single Lane Roads (Meeting Sight Distance)

Meeting Sight Distance (sometimes called Barrier Sight Distance) is the distance that needs to be provided on a single-lane road to allow vehicles travelling in the opposite direction, usually because one vehicle is executing a passing manoeuvre, to see each other and to stop safely if necessary.

It is measured for an object height of 1.3 m (i.e. the height of an approaching passenger car) and an eye height of 1.05 m. This distance is normally set at twice the stopping sight distance for a vehicle that is stopping to avoid a stationary object in the road. An extra safety margin of 20-30 m is also sometimes added

It is particularly important to check Meeting Sight Distance on existing roads that have a poor vertical alignment that may contain hidden dips that restrict sight lines. However, single lane roads have a relatively low design speed, hence meeting sight distances should not be too difficult to achieve.

A1-6 Intersection Sight Distance

Intersection sight distance is determined from the point of view of a driver of a vehicle on the cross road that wants to cross or merge with traffic on the “main” road. Intersection sight distances are longer than stopping sight distances.

On straight sections of road, many vehicles will exceed the road’s design speed but, being straight, sight distances should be adequate for vehicles that are travelling straight through the junction on the major road. The situation is quite different for vehicles that may need to slow down or stop at the junction. This is because the time required to accelerate again and then to cross or turn at the junction is now much greater, hence longer sight distances are required.

A1-7 Decision Sight Distance

Stopping sight distances are usually sufficient to allow reasonably competent drivers to stop under ordinary circumstances. However, these distances are often inadequate when drivers need to make complex decisions or when unusual or unexpected manoeuvres are required. The driving task is constrained or limited by the human factors involved.

Decision sight distance, sometimes termed ‘anticipatory sight distance’, is the distance required for a driver to:

- detect an unexpected or otherwise ‘difficult-to-perceive’ information source or hazard in a roadway environment that may be visually cluttered;
- recognize the hazard or its potential threat;
- select an appropriate speed and path; and
- complete the required safety manoeuvre safely and efficiently.

Although it is not likely to be a common problem for LVRs, some critical locations where errors are likely to occur are included here for completeness. It is desirable to provide decision sight distance in the following locations:

- Areas of concentrated demand where sources of information such as roadway elements, opposing traffic, traffic control devices, advertising signs and construction zones, compete for attention (i.e. visual noise);
- Approaches to interchanges and intersections;
- Railway crossings, bus stops, bicycle paths, entrances of villages and towns;
- Newly upgraded road sections or the change of road hierarchy;
- Changes in cross-section such as at toll plazas and lane drops; and
- Design speed reductions.

The minimum decision sight distances that should be provided for such situations are shown in Table A1-5. If it is not feasible to provide these distances because of horizontal or vertical curvature, or if relocation is not possible, special attention should be given to the use of suitable traffic control devices for advance warning.

It may be noted that although a sight distance is shown in the Table A1-5 for the right side (off-side) exit, exiting from the right side, except on LVRs, is undesirable because, to be safe, crossing a fast-moving traffic stream requires traffic control; the efficiency of the junction is thus severely reduced. Furthermore, a right-side exit is also in conflict with the expectancy of most drivers and this further compromise safety. The reason for providing this value is to allow for the possibility that an off-side (right side) exit might be necessary sometimes, usually with traffic control.

In measuring decision sight distances, the 1.05 m eye height and 0 mm object height have been adopted.

Table A1-5: Decision Sight Distances for Various Situations (m)

Design Speed km/h	Situations				
	Junctions/interchanges.		Lane, merge	Lane shift	Intersections.
	Sight distance to nose		Sight distance to taper area	Sight distance to beginning of shift	Sight distance to turn lane
	Near-side exit	Off-side exit			
50	NA	NA	150	85	150
60	200	275	200	100	200
80	250	340	250	150	250
100	350	430	350	200	350
120	400	500	400	250	400

A1-8 Passing Sight Distance (PSD)

The minimum sight distance required by a vehicle to overtake or pass another vehicle safely on a two-lane single carriageway road is the distance which will enable the overtaking driver to pass a slower vehicle without causing an oncoming vehicle to slow below the design speed. The manoeuvre is one of the most complex but important driving tasks. It is also relatively difficult to quantify for design purposes because of the various stages involved, the large number of relative speeds of vehicles that are possible and the lengthy section of road needed to complete the manoeuvre.

A driver finding that he has insufficient distance after initiating the passing manoeuvre can choose to abort the manoeuvre. The Minimum Passing Sight Distance is then the sight distance required on a two-lane road to enable the passing manoeuvre to be aborted. The recommended minimum PSDs are shown in Table A1-6 and summarised in Table 6-3.

Table A1-6: Passing Sight Distances

Design Speed (km/h)	Minimum PSD allowing driver to abort (m)[1]	Recommended PSD (m)[2]
30	115	195
40	135	275
50	155	345
60	180	420
70	210	485
80	240	550
90	275	615
100	310	670
110	350	730
120	395	780
130	440	830

Source: Manual on Uniform Traffic Control Devices (MUTCD) and Harwood et al. (2008). NCHRP Report 605.

A1-9 Headlight Sight Distance

Headlight sight distance is used to design the rate of change of gradient for sag vertical curves (Section 6.4.3). Where the only source of illumination is the headlamps of the vehicle, the illuminated area depends on the height of the headlights above the road and the divergence angle of the headlight beam relative to the grade line of the road at the position of the vehicle on the curve. For cars, a headlight height of 0.6 m and a beam divergence of 1 degree are usually used for calculation purposes. At speeds above 80 km/h, only large, light coloured objects can be perceived at the generally accepted stopping sight distances.

A2 Design of Horizontal Alignment

A2-1 Introduction

The horizontal alignment consists of a series of straight sections (tangents), circular curves and transition curves (spirals) between the tangents and the circular curves.

In order for a vehicle to move in a circular path, an inward radial force is required to provide the necessary centripetal acceleration or, in other words, to counteract the centrifugal force. This radial force is provided by the sideways friction between the tyres and the road surface assisted by the superelevation.

The objective is to provide a safe road which can be driven at a reasonably constant speed. Therefore, sharp changes in the geometric characteristics of both horizontal and vertical alignments must be avoided. A transition curve whose radius changes continuously between a straight section of road and a circular curve is used to reduce the abrupt introduction of centripetal acceleration that occurs on entering the circular curve. Transition curves are not required when the radius of the horizontal curve is large and are not normally used on the lower classes of road.

A2-2 Horizontal Radius of Curvature

The minimum horizontal radius of curvature, R_{min}, for a particular design speed is:

$$R_{min}=VD^2/127(e+f) \qquad \text{Equation A2.1}$$

where:

VD = design speed (km/h)
e = maximum superelevation as a fraction (%/100)
f = side friction coefficient (Section 4.3.2)

The minimum radii of curvature for different design speeds and degrees of superelevation based on this formula and pragmatic coefficients of friction are shown in Table A2-1 for paved roads and Table A2-2 for unpaved roads. For convenience, they are also included in the summary of specifications for each` road class in the Tables in *Chapter 7 – Design Standards*. As the radius increases, the accident rate decreases hence the minimum values should be used only under the most critical conditions and the deviation angle of each curve should be as small as the physical conditions permit.

Table A2-1: Minimum Radii for Horizontal Curves for Paved Roads (m)

Design speed (km/h)	30	40	50	60	70	80	85	90	100
Side Friction Factor (f)	0.21	0.19	0.17	0.16	0.15	0.13	0.13	0.12	0.11
Superelevation = 4%	30	55	95	150	220	300	350	400	520
Superelevation = 6%	27	53	85	135	190	265	305	350	455
Superelevation = 8%	25	50	80	120	175	240	280	320	415
Superelevation = 10%	25	50	75	110	155	210	245	285	370

For unpaved roads, the friction is usually considerably less than on paved roads. In these calculations, it has been assumed that it is 80% of the value for paved roads but this is dependent on a tightly knit and dry surface of good quality gravel with no loose stones; in other words, a surface on which the design speed can be maintained. A poorly bound surface with many loose particles has a very low value of friction and it must be assumed that vehicles will be driven on such a surface at a speed that is much lower than the nominal design speed dictated by the sight distances and radii of curvature.

Table A2-2: Minimum Radii for Horizontal Curves for Unpaved Roads (m)

Design speed (km/h)	20	30	40	50	60	70	80	85	90	100
Side Friction Factor	0.19	0.165	0.15	0.14	0.12	0.12	0.10	0.10	0.10	0.09
Superelevation=4%	15	35	65	115	175	255	355	415	475	610

A3 Design of Vertical Alignment

A3-1 Introduction

On LVRs, as on high-speed roads, a smooth grade line is required rather than a series of successive short lengths of grades and vertical curves. Vertical alignment is the combination of parabolic vertical curves and tangent sections of a particular slope designed to achieve this objective. Thus, the design of vertical alignment is concerned with gradients, crest and sag curves. A crest curve is a convex vertical curve. A sag curve is a concave vertical curve, as shown in Figure A3-1 and Figure A3-2, respectively.

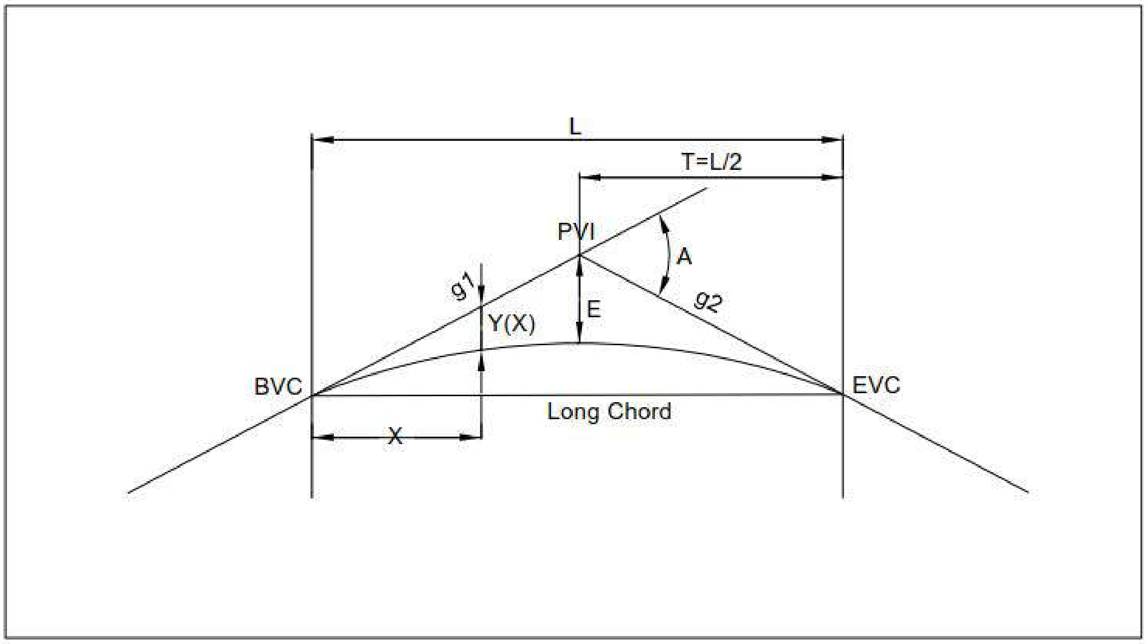


Figure A3-1: Crest curve

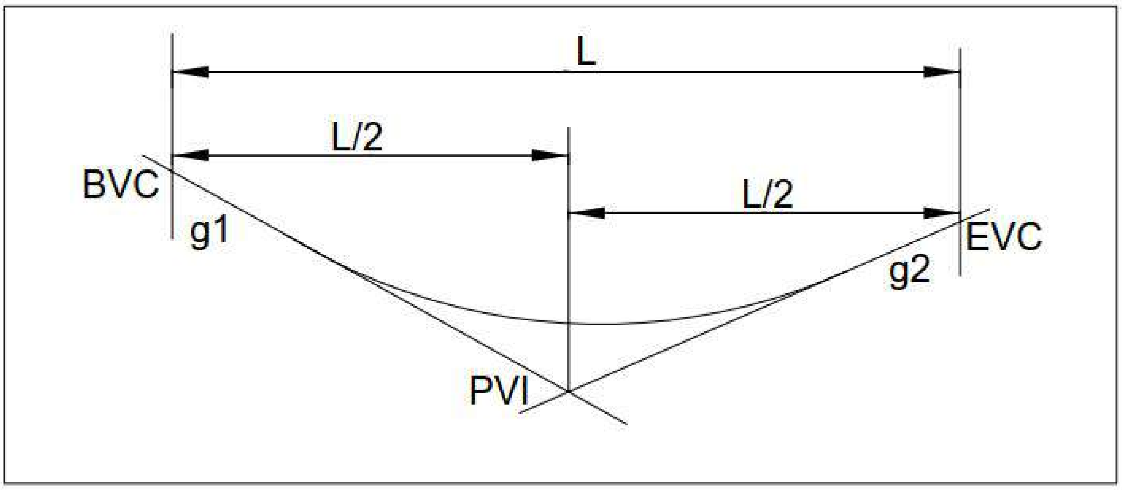


Figure A3-2: Sag curve

A3-2 Vertical Curve Formula

Vertical curves are required to provide smooth transitions between consecutive gradients. The parabola is specified for vertical curves, because the parabola provides a constant rate of change of curvature and, hence, acceleration and visibility, along its length. Equations relating the various aspects of the vertical curve (both crest and sag) are as follows:

$$Y(x) = r \times \frac{x^2}{2} + X \times \frac{g1}{1} + Y_B \qquad \text{Equation A3.1}$$

$$r = \frac{(g2 - g1)}{L} = \frac{G}{L} = \frac{1}{K} \qquad \text{Equation A3.2}$$

where:

BVC = Beginning of the vertical curve.
EVC = End of the vertical curve.
Y(x) = Elevation of a point on the curve (m)
x = Horizontal distance from the (BVC) (m)
g1 = Starting gradient (%),
g2 = Ending gradient (%),
r = Rate of change of grade per section (%/ m),
L = Length of curve (horizontal distance) in m,
G = g2 – g1 (%),

Useful relationships are:

Equation of tangent g1:

$$Y(x) = Y(0) + \frac{g1 \times x}{1} \qquad \text{Equation A3.3}$$

Equation of tangent g2:

$$Y(x) = Y(L) + \frac{g2 \times (x - L)}{1} \qquad \text{Equation A3.4}$$

The y coordinate of the EVC:

$$Y(L) = \frac{(g1 - g2) \times L}{2} + Y(0) \qquad \text{Equation A3.5}$$

The Vertical Point of Intersection (VPI) always occurs at an x coordinate of 0.5L hence, from equation 6.1, the elevation is always;

$$Y(V\quad) = Y\left(\frac{L}{2}\right) = Y(0) + \frac{g1 \times x}{1} = Y(0) + \frac{g1 \times L}{2}$$

Example:

For the crest curve shown in Figure A3-1, the two tangent grade lines are +6% and -3%. The Beginning of the Vertical Curve is at chainage 0.000 and its elevation 100.0 m. The length of the vertical curve is 400 m. Compute the End of the Vertical Curve and the coordinates of the Intersection Point.

The y coordinate of the EVC is Y(L) = (g1+g2)L/200 + Y(0)

= (6 - 3) x 400/200 + 100.0 = 106.0

The x coordinate of the EVC is X(L) = 400.0

The coordinates of the VPI are X(IP) = L/2 = 200.0 and

Y(VPI) = Y(0) + 6.400/200 = Y(0) + 12 = 112m

A3-3 Crest curves

Two possible situations could present themselves when considering the minimum sight distance criteria on vertical curves. The first is where the required sight distance (S) is less than the length of the vertical curve (L), and the second is where sight distance required 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 (the most common situation in practice):

$$L_m = \frac{G \times S^2}{\left[2 \times \left(h_1^{0.5} + h_2^{0.5}\right)^2\right]} = K \times G \qquad \text{Equation A3.6}$$

where

L_{min} = minimum length of vertical crest curve (m)

S = required sight distance (m)

h_1 = driver eye height (m)

h_2 = object height (m)

K = is a constant for given values of h1 and h2 and stopping sight distance (S) and therefore speed and surface friction.

For S > L:

$$L_m = 2 \times S - \frac{\left[2 \times \left(h_1^{0.5} + h_2^{0.5}\right)^2\right]}{G} \qquad \text{Equation A3.7}$$

On computation it will be found that the differences in curve lengths require to meet these conditions are minimal and hence a single set of K values have been selected for use in this Manual, where K= L/G.

Minimum values of K for crest curves are shown in Table A3-1 and Table A3-2 for stopping sight distances, distinguishing between different object heights, as well as passing sight distances. The eye height has been taken as 1.05 m

Table A3-1: Minimum Values of K for Crest Vertical Curves (Paved Roads)

Design Speed (km/h)	K for Stopping Sight Distance (g = 0%)			K for Minimum Passing Sight Distance
	h_2 = 0 m	h_2 = 0.2 m	h_2 = 0.6 m	
25	3	1	1	30
30	5	2	1	50
40	10	5	3	90
50	20	10	7	130
60	35	17	12	180
70	60	30	20	245
80	95	45	30	315
85	115	55	37	350
90	140	67	45	390
100	205	100	67	480
110	285	140	95	580
120	385	185	125	680

Table A3-2: Minimum Values for Crest Vertical Curves (Unpaved Roads)

Design Speed (km/h)	K for Stopping Sight Distance			K for Minimum Passing Sight Distance
	h_2 = 0 m	h_2 = 0.2 m	h_2 = 0.6 m	
25	3	1	1	30
30	5	2	2	50
40	11	6	4	90
50	25	11	8	135
60	45	20	15	185
70	75	35	25	245
80	120	58	40	315
85	150	72	50	350
90	185	90	60	390
100	270	130	88	480

It may be noted that high values of K are required to meet passing sight distance requirements (Table A3-1 and Table A3-2) and therefore, to achieve the passing sight distance, the volume of earthworks required may also be large. Although as much passing sight distance as possible should be provided along the length of the road, it may be impossible to achieve passing sight distance over the crest curve itself. Encouraging drivers to overtake when sight distances have not been fully achieved is dangerous, hence shortening the crest curve, but still meeting stopping sight distance requirements, in order to increase the lengths of the grades on either side is a better option.

Where a crest curve and a succeeding sag curve have a common end and beginning of curve, the visual effect created is that the road has suddenly dropped away. In the reverse case, the illusion of a hump is created. Either effect is removed by inserting a short length of straight grade between the two curves. Typically, 60 m to 100 m is adequate for this purpose.

A3-4 Sag Curves

During daylight hours or on well-lit streets, sag curves do not present any problems concerning sight distances. For such situations, it is recommended that sag curves are designed using a driver comfort criterion of vertical acceleration. A maximum acceleration of 0.3 m/s^2 is often used. This translates into:

$$K > V^2/395$$

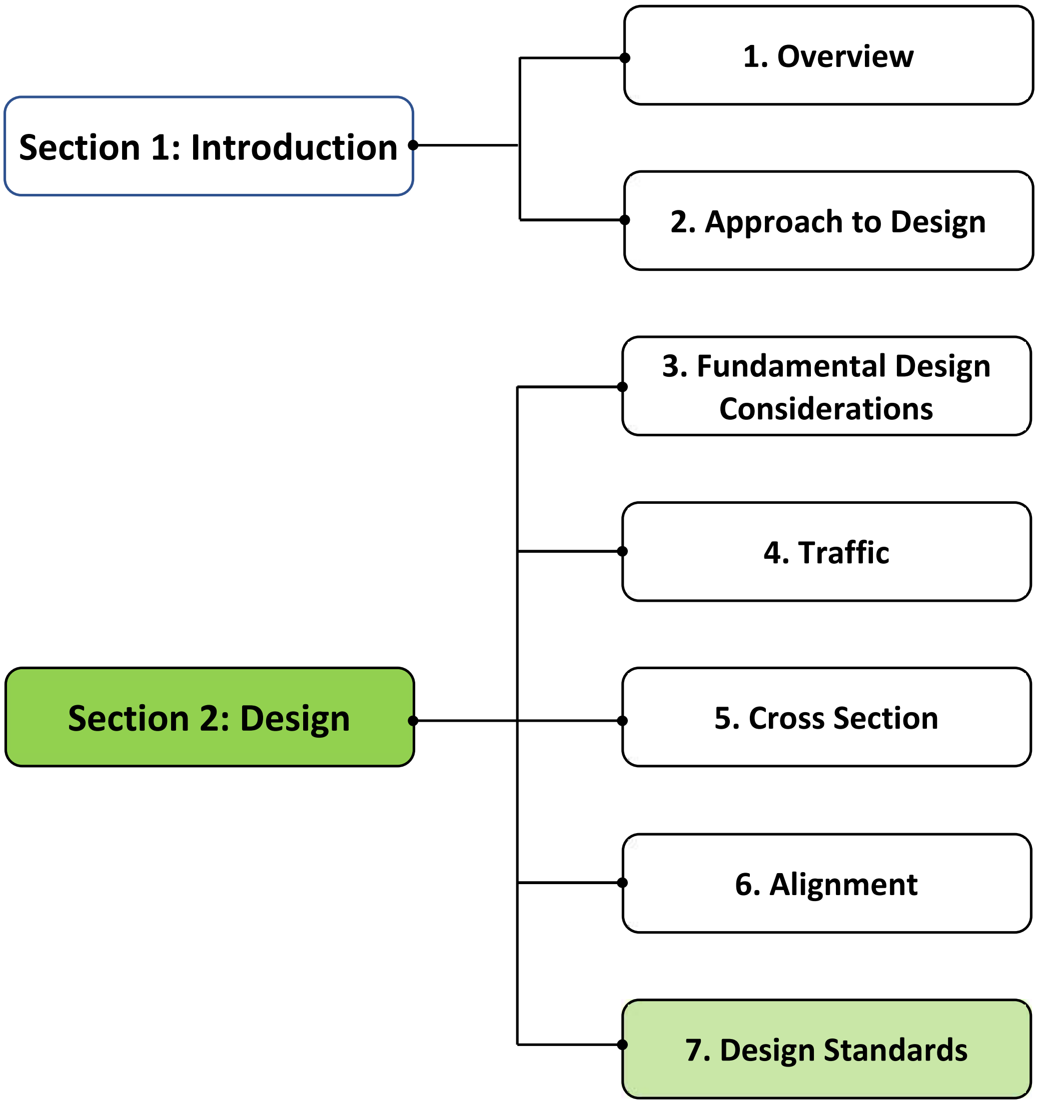
Where V is the speed in km/h.

Where the only source of illumination is the headlamps of the vehicle, the illuminated area depends on the height of the headlights above the road and the divergence angle of the headlight beam relative to the grade line of the road at the position of the vehicle on the curve. Using a headlight height of 0.6 m and a beam divergence of 1°, the values of K are approximately twice the values obtained from the driver comfort criterion which should be used for design. The resulting K values for both situations are shown in Table A3-3.

Table A3-3: Minimum Values of K for Sag Curves

Design Speed (km/h)	K for driver comfort	K for headlight distance
20	1.0	2
25	1.5	3
30	2.5	5
40	4	9
50	6.5	14
60	9	19
70	12	25
80	16	32
85	18	36
90	20	40
100	25	50
110	30	60
120	36	70

Low Volume Roads Manual
Part A – Geometric Design: Rural Roads



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7.1 Introduction

7.1.1 Background

A national 'standard' is not a specification, although it could, and often is, incorporated into specifications and contract documents. Rather, a standard is a specific level of quality that should be achieved at all times and nationwide. Amongst other things, this ensures consistency across the country. For the geometric standards, this means that road users know exactly what to expect. Drivers, for example, are not 'surprised' by unexpected changes in quality. Thus, they will not unexpectedly find that a road is too narrow, or that they have to alter their speed drastically to avoid losing control of their vehicle. Thus, standards provide a guarantee of a particular level of quality and, for roads, this is vital for reasons of safety.

The problem of safety is closely related to traffic volumes and design speed. Thus, for high volume roads designed for speed and mobility, safety takes on an extremely vital role and has an enormous impact on the costs of the facility. In contrast, the traffic volume on a LVR is very low, and it is now very apparent that the likely number of interactions between vehicles is also surprisingly small (see Table 2-3 in *Chapter 2 – Approach to Design*). Coupled with the fact that the design speed on LVRs is also quite low, such roads are generally quite safe, and many of the strict engineering rules of geometric design that are based on safety considerations for high volume roads have little relevance to LVRs. That is not to say that safety is not an issue for LVRs - it is just that the items that are important differ substantially from the considerations of high mobility roads. The approach to the design of LVRs in this Manual allows the incorporation of safety without incurring high costs.

7.1.2 Purpose and Scope

The purpose of this chapter is to provide a summary of the design standards that have been discussed in previous chapters, but with all components or elements for each road class brought together in tabular form to provide a quick look-up system for each one. The Option B design also provides a method of identifying where along a road the Option A design is not satisfactory and where modifications are required. A summary of the decisions and information required for designing an LVR of the appropriate standard is also provided. Important differences exist between paved and unpaved roads because of the different friction values between the tyres and the road. These differences are highlighted.

7.2 Basic Methodology

7.2.1 General

The Manual contains two basic approaches for the geometric design of LVRs. The preferred Option A design approach for upgrading an existing LVR or track is recommended for traffic classes LVR1 to LVR4. However, elements of this approach can also be used for LVR5 roads.

The Option A approach utilises the existing alignment as much as possible and is, therefore, based on existing operating speeds. Such speeds may vary along the length of the road and so it is important to identify any sections that warrant either improvement or modification. Such improvements include:

- ensuring adequate sight distances along the entire road;
- controlling traffic speeds using traffic calming methods;
- minor alignment improvements to ensure a more uniform traffic speed; and
- controlling traffic by means of warning signs.

In considering Option A, the above improvements are only required when the components of the existing alignment that affect safety differ by a significant amount from those of a safe alignment designed for higher traffic levels. However, the outcome of the design process must demonstrate that the recommended measures are defendable with adequate documentation. Given that the number of vehicle interactions on a LVR is quite low (*Chapter 2 – Approach to Design*, Table 2.3), a LVR is inherently quite safe provided that vulnerable road users are protected, especially by controlling traffic speeds.

At present, there are no golden rules for identifying and ranking areas of poor safety on LVRs because road accident data is insufficient for such a detailed analysis. Thus, it is suggested that if the Option A road parameters differ by more than 25 % from the values that would be obtained using a full Option B engineering design, then consideration should be given to either improvement or modification locally as listed above.

7.2.2 Large Vehicles

In the specification tables, 'large vehicles' are defined as trucks with three or more axles and gross vehicle mass greater than 10 tonnes.

7.2.3 Flexibility

Sometimes there will be cases where it is impossible to meet some of the standards, mainly due to severe terrain conditions. Under such circumstances, the standards must be relaxed at the discretion of the Engineer and suitable permanent signage used to warn road users and possible traffic calming measures installed to slow traffic if that is also an appropriate part of the solution. For example, alignment design in severe mountainous terrain can sometimes be difficult. A minimum curve radius of 70 m to 85 m suitable for a design speed of 50 km/h might not be possible without massive earthworks and potential problems of slope instability, disposal of spoil and environmental damage. In such terrain, the design speed can be reduced with the associated alterations in the alignment standards that can be achieved more easily and less expensively. Each situation should be treated on its merits. The tables provide specifications for design speeds from 20 km/h to 80 km/h, but if the specifications for the proper design class need to be changed, the approval of the client is usually required.

7.3 Selection of Design Standards

7.3.1 General

It is important to note that there is no reason why a higher standard than the standard appropriate to the traffic and conditions should not be used in specific circumstances. For example, for reasons of national and international prestige or for strategic or military reasons, a road may be built to a higher standard than would normally be justified, e.g. a road to an international sports facility (where the traffic is very low for most of the time but can be quite high for short periods), the road to an airport, and roads to military establishments. Thus, higher standards can be used if required, but lower standards should not be used except in exceptional circumstances, for example, in particularly difficult terrain.

The decisions and actions that are required for the final design are summarised in Figure 7-1. The steps illustrated and explained below are not usually carried out in the sequence shown. Indeed, some of the decisions will have been made at the planning stage, some following a feasibility study, whilst others cannot be made until most of the information has been obtained.

7.3.2 Procedure

Step 1 – Traffic Volume: The first step is to determine the basic traffic level because this defines the road class (*Chapter 2 – Approach to Design, Table 2-2*). This, in turn, determines possible design speeds and overall level of service, but subject to modification depending on the other controlling factors. At this point, the proportion of heavy vehicles in the traffic stream is also determined. This step is not specific to the geometric design and will usually have been carried out by the time it is necessary to determine the detailed geometric characteristics of the road. However, more details of the traffic are required for the geometric design in terms of the other road users such as pedestrians, bicycles, motorcycles, motorcycle taxis and animal-drawn carts. These are taken into account in Steps 2, 6 and 7.

Step 2 – Road Class: The numbers and characteristics of all the other road users are considered (*Chapter 4 – Traffic*, Section 4.6). It is here that the road layout may be altered and additional widths provided for safety and to improve serviceability for all road users (e.g. reduce congestion caused by slow-moving vehicles).

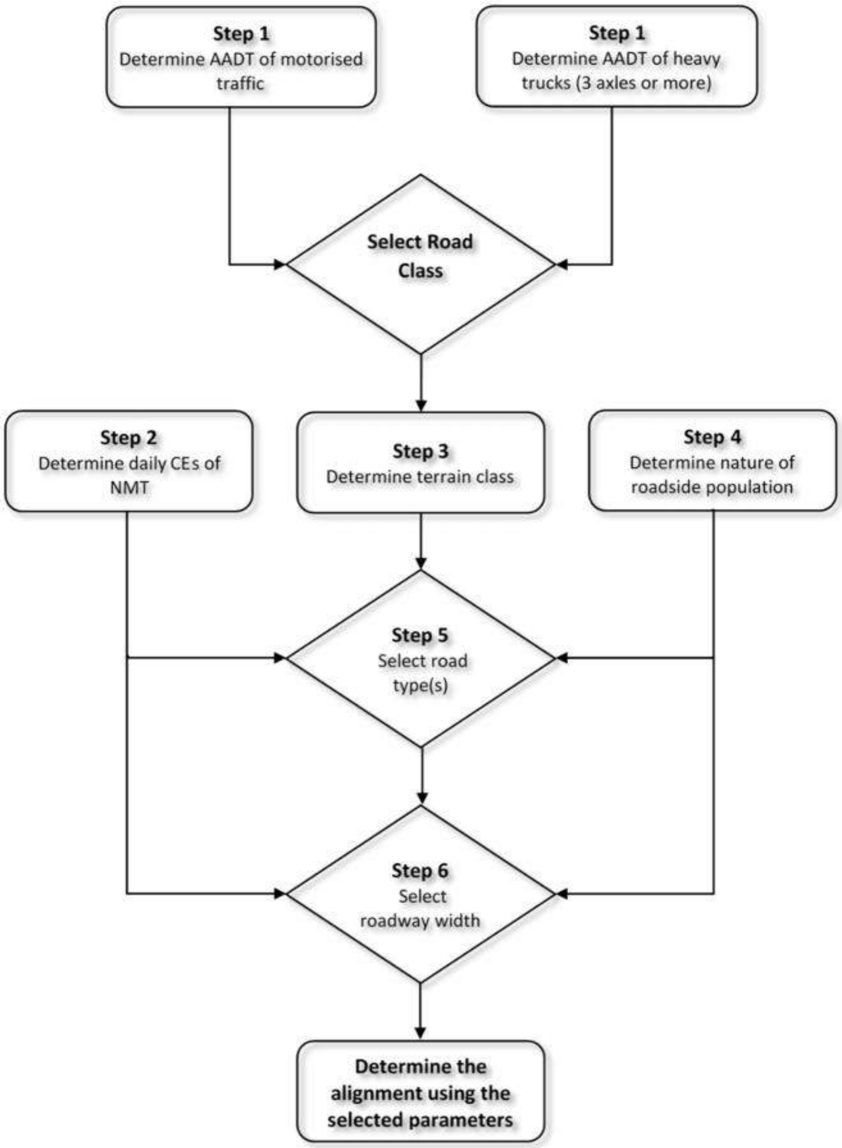

Figure 7-1: Procedure for selecting final design standard

Step 3 – Terrain Class: Flat, rolling, mountainous and escarpment (*Chapter 3 – Fundamental Design Considerations*, Section 3.2.7).

Step 4 – Roadside development: The 'size' of the villages through which the road passes is evaluated to determine whether they are large enough to require parking areas and areas for traders (*Chapter 3 – Fundamental Design Considerations*, Section 3.2.9).

Step 5 – Road Type (paved or unpaved): For most road classes, there are options for road type, and therefore, the next step is to decide which type will be built. In many cases, the adoption of a flexible policy might mean that different parts of the road may be designed with a different surfacing. The choice of road type is described in *Chapter 3 – Fundamental Design Considerations*, Section 3.2.10, and the details are discussed in subsequent chapters.

Step 6 – Road Width: The widths of the carriageway and shoulders should be determined (*Chapter 5 – Cross Section*). At this stage, additional factors that affect the geometric standards are also considered, such as additional road safety features and the construction technology to be employed. Opportunities for the relaxation of standards should also be identified.

Step 7 – Alignment: 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 further design and assessment prior to selecting the final engineering design.

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. This is the safest option for LVRs. An alignment of flowing curves may reduce real overtaking opportunities, thus encouraging injudicious driver behaviour. On two-lane roads, the provision of adequate overtaking opportunities may be particularly important because of the proportions of slow-moving vehicles.

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.

7.4 Design Standards

7.4.1 General

The geometric standard of individual elements of a road will vary with the terrain. It is necessary to identify elements of lower geometric standard the could potentially result in unacceptable hazards. 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.

7.4.2 Option A Alignments

As discussed in *Chapter 2 – Approach to Design*, Section 2.5.4, this option provides for the adoption of an alignment that primarily fulfils an access function by making maximum use of the existing alignment, even though the curvature may not comply fully with formal requirements. This option provides a very economical standard for road classes LVR1, LVR2, LVR3 and LVR4, and in appropriate circumstances, may even be considered for LVR5. However, if it is required to adopt a more formal approach to the alignment design of such roads, then recourse should be made to the adoption of the Option B approach, as discussed below.

7.4.3 Option B Alignments

In this option, the alignment is designed to fulfil a mobility and access function in accordance with the requirements of the particular design speed.

7.4.4 Choice of Standard

Table 7-1 and Table 7-2 summarise the values of all the alignment design variables that can be used to check whether the actual values on the existing alignment are acceptable. In this regard, stopping sight distances are probably the most significant. If the differences between the tabled values and what can be achieved following an Option A approach are greater than about 25%, then Option B would be appropriate. However, if they are less than about 25%, then Option A should be the first choice.

For greenfield sites, and when fully engineered designs are required, the detailed design standards for each design class are shown in Tables 7-3 to 7-7 for paved roads and Tables 7-8 to 7-12 for unpaved roads. The terrain classes in these tables are given for guidance only as there may be sections in both mountainous and escarpment terrain that allow for higher design speeds than those indicated for the respective terrain class, in which case the geometric design parameters for the relevant design speed should be applied.

Table 7-1: General design variables - Paved roads

Design Speed		km/h	100	90	80	70	60	50	40
Minimum Stopping Sight Distance	g = 0%	m	205	170	140	110	85	64	45
	g = 5%	m	235	195	155	120	95	68	47
	g = 10%	m	280	230	182	140	105	75	50
Minimum Passing Sight Distance		m	310	275	240	210	180	155	135
% Passing Opportunity		%	50	50	50	50	33	33	25
Minimum Horizontal Curve Radius(2)	SE = 4%	m	520	400	300	220	150	95	55
	SE = 6%	m	455	350	265	190	135	85	50
	SE = 8%	m	415	320	240	175	120	80	50
Transition curves required			Yes	Yes	Yes	Yes	Yes	No	No
Maximum Gradient (desirable)		%	4	5	6	6	7	7	7
Maximum Gradient (absolute)		%	6	7	8	8	9	9	9
Minimum Gradient		%	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Maximum Super-elevation		%	6	6	6	6	6	6	6
Minimum Crest Vertical Curve - K		m/%	100	67	45	30	17	10	5
Minimum Sag Vertical Curve - K, Comfort criterion		m/%	25	20	16	12	9	7	4
Minimum Sag Vertical Curve - K, Headlights criterion		m/%	50	40	32	25	19	14	9
Normal Camber/Crossfall		%	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Table 7-2: General design variables - Unpaved roads

Design Speed		**km/h**	**80**	**70**	**60**	**50**	**40**	**30**
Minimum Stopping Sight Distance	g = 0%	m	160	125	95	70	50	32
	g = 5%	m	190	145	110	80	55	35
	g = 10%	m	235	175	130	90	60	37
Min. Passing Sight Distance to abort		m	240	210	180	155	135	115
Min. Horizontal Radius with 4 % Superelevation (SE)		m	355	255	175	115	65	35
Max. Gradient (desirable)		%	6	6	6	6	6	6
Max. Gradient (absolute)		%	8	8	8	8	8	8
Min. Gradient		%	0.5	0.5	0.5	0.5	0.5	0.5
Max. Superelevation		%	6	6	6	6	6	4
Min. Crest Vertical Curve K			58	35	20	11	6	2
Min. Sag Vertical Curve K Comfort criterion			16	12	9	7	4	2.5
Min. Sag Vertical Curve K Headlights criterion		m	32	25	19	14	9	5
Normal Camber/Cross-fall		%	5	5	5	5	5	5

Table 7-3: Paved LVR 5 geometric parameters (AADT > 400)(1)

Design Element		**Unit**	**Flat**	**Rolling**	**Mountain(7)**
Design Speed		km/h	80	70	60
Width of Carriageway		m	6.5		
Width of Shoulders (high CE only)(2) (Table 5-1)		m	1.0 – 2.0		
Minimum. Stopping Sight Distance	g = 0%	m	140	110	85
	g = 5%	m	155	120	95
	g = 10%	m	180	140	105
Minimum Passing Sight Distance		m	240	210	180
Minimum Horizontal Curve Radius (3)	SE = 4%	m	300	220	150
	SE = 6%	m	265	190	135
Maximum Gradient (desirable)		%	4	6	7
Maximum Gradient (absolute)		%	6	9	10
Minimum Gradient(5)		%	0.5	0.5	0.5
Minimum Crest Vertical Curve (6)		K	45	30	10
Minimum Sag Vertical Curve		K	16	12	7
Normal camber/Cross-fall		%	3	3	3
Shoulder Cross-fall		%	3	3	3

Notes

1 If there are more than 80 Large Heavy Vehicles, then the specifications for the classification of the next traffic level should be used.
2 In urban and peri-urban areas parking lanes and footpaths may be required.
3 On hairpin stacks, the minimum radius may be reduced to a minimum of 15 m.
4 If the number of Large Heavy Vehicles <10 this can be increased to 12%.
5 In some circumstances in very flat terrain, this can be reduced to 0.3%.
6 These values are based on an object height of 0.2 m. Use of a different size object requires approval.
7 In escarpment terrain design speeds can be lower (see Table 7-1) and/or hairpin stacks may be required (Section 6.6.5).

Table 7-4: Paved LVR 4 (1) geometric parameters (AADT 200-400)(2)

Design Element		Unit	Flat	Rolling	Mountain(7)
Design Speed		km/hr	70	60	50
Width of Carriageway (Table 5-1)		m	5.5 – 6.5		
Width of Shoulders (2) (High CE only) (Table 5-1)		m	1.0 – 2.0		
Minimum. Stopping Sight Distance	g = 0%	m	110	85	64
	g = 5%	m	120	95	68
	g = 10%	m	140	105	75
Minimum Passing Sight Distance		m	210	180	155
Minimum Horizontal Curve Radius(3)	SE = 4%	m	220	150	95
	SE = 6%	m	190	135	85
	SE = 8%	m	175	120	80
Maximum Gradient (desirable)		%	6	7	7
Maximum Gradient (absolute)		%	8	9	10(4)
Minimum Gradient(5)		%	0.5	0.5	0.5
Maximum Super-elevation (LVR4)		%	6	6	6
Minimum Crest Vertical Curve(6)		K	30	17	10
Minimum Sag Vertical Curve		K	12	9	7
Normal Camber/Cross-fall		%	3	3	3
Shoulder Cross-fall		%	3	3	3

Notes

1 If there are more than 30 Large Heavy Vehicles, then Table 7-5 for LVR 5 should be used.
2 In urban and peri-urban areas parking lanes and footpaths may be required.
3 On hairpin stacks, the minimum radius may be reduced to a minimum of 15 m.
4 If the number of Large Heavy Vehicles <10 this can be increased to 12%.
5 In some circumstances in very flat terrain, this can be reduced to 0.3%.
6 These values are based on an object height of 0.2 m. Use of a different sized object requires approval.
7 In escarpment terrain design speeds can be lower (see Table 7-1) and/or hairpin stacks may be required (Section 6.6.5).

Table 7-5: Paved LVR 3 (1) geometric parameters (AADT 100-200)(1)

Design Element		Unit	Flat	Rolling	Mountain(7)
Design Speed		km/hr	70	60	50
Width of Carriageway		m	4.5 – 5.5		
Width of Shoulders(2,3) (Table 5-1)		m	0.5/1.0 -2.0		
Minimum. Stopping Sight Distance	g = 0%	m	110	85	64
	g = 5%	m	120	95	68
	g = 10%	m	140	105	75
Minimum Passing Sight Distance		m	210	180	155
Minimum Horizontal Curve Radius(4)	SE = 4%	m	220	150	95
	SE = 6%	m	190	135	85
	SE = 8%	m	175	120	80
Maximum Gradient (desirable)		%	6	7	7
Maximum Gradient (absolute)		%	8	9	10
Minimum gradient (5)		%	0.5	0.5	0.5
Maximum Super-elevation (LVR4)		%	6	6	6
Minimum Crest Vertical Curve(6)		K	30	17	10
Minimum Sag Vertical Curve		K	12	9	7
Normal Camber/Cross-fall		%	3	3	3
Shoulder Cross-fall		%	3	3	3

Notes

1 If there are more than 20 Large Heavy Vehicles, then LVR 4 should be used.

2 On road class LVR3, when a 4.5 m carriageway width is adopted, 2 x 0.50 m paved shoulders should be considered on curves and at other appropriate locations to provide a roadway width of 5.5 m which will accommodate the occasional passing of large vehicles. In areas with heavy mixed traffic and CE > 300, paved shoulders 1.0 – 2-0 m wide should be considered.

3 In urban and peri-urban areas parking lanes and footpaths may be required.

4 On hairpin stacks, the minimum radius may be reduced to a minimum of 15 m.

5 In some circumstances in very flat terrain, this can be reduced to 0.3%.

6 These values are based on an object height of 0.2 m. Use of a different sized object requires approval.

7 In escarpment terrain design speeds can be lower ((see Table 7-1) and/or hairpin stacks may be required (Section 6.6.5).

Table 7-6: Paved LVR 2(1) geometric parameters (AADT 50-100)(1)

Design Element		Unit	Flat	Rolling	Mountain (7)
Design Speed		km/hr	70	60	50
Width of Carriageway (Table 5-1)		m	3.5 – 4.5		
Width of Shoulders (2,3)		m	0.5		
Minimum. Stopping Sight Distance	g = 0%	m	110	85	64
	g = 5%	m	120	95	68
	g = 10%	m	140	105	75
Minimum Passing Sight Distance		m	210	180	155
Minimum Horizontal Curve Radius(4)	SE = 4%	m	220	150	95
	SE = 6%	m	190	135	85
	SE = 8%	m	175	120	80
Maximum Gradient (desirable)		%	6	7	7
Maximum Gradient (absolute)		%	8	9	10
Minimum Gradient(5)		%	0.5	0.5	0.5
Minimum Crest Vertical Curve(6)		K	30	17	10
Minimum Sag Vertical Curve		K	12	9	7
Normal Camber/ Cross-fall		%	3	3	3
Shoulder Cross-fall		%	3	3	3

Notes

1 If there are more than 20 Large Heavy Vehicles, then LVR 4 should be used.
2 Where passing bays are not provided, the minimum width of the roadway will be 4.5 m comprising a carriageway of 3.5 m and 2 x 0.50 m unpaved shoulders.
3 In urban and peri-urban areas parking lanes and footpaths may be required.
4 On hairpin stacks, the minimum radius may be reduced to a minimum of 15 m.
5 In some circumstances in very flat terrain, this can be reduced to 0.3%.
6 These values are based on an object height of 0.2 m. Use of a different sized object requires approval.
7 In escarpment terrain design speeds can be lower (see Table 7-1) and hairpin stacks may be required (Section 6.6.5).

Table 7-7: Paved LVR 1(1) geometric parameters (AADT <50)(1)

Design Element		Unit	Flat	Rolling	Mountain(9)
Design Speed		km/hr	60	50	40
Width of Carriageway (Table 5-1)			3.5		
Width of Shoulders(2, 3)		m	0.5		
Minimum. Stopping Sight Distance	g = 0%	m	85	64	45
	g = 5%	m	95	68	47
	g = 10%	m	105	75	50
Minimum passing sight distance		m	180	155	135
Minimum Horizontal Curve Radius (4)	SE = 4%	m	150	95	55
	SE = 6%	m	135	85	50
	SE = 8%	m	120	80	50
Maximum Gradient (desirable)7,8		%	6	7	7
Maximum Gradient (absolute)		%	8	10	10
Minimum Gradient(5)		%	0.5	0.5	0.5
Maximum Super-elevation		%	6	6	6
Minimum Crest Vertical Curve(6)		K	17	10	5
Minimum Sag Vertical Curve		K	9	7	4
Normal Cross-fall/Camber		%	3	3	3
Shoulder Cross-fall		%	3	3	3

Notes

1 If there are more than 10 Large Heavy Vehicles, then LVR 2 should be used.
2 Where passing bays are not provided, the minimum width of the roadway will be 4.5 m comprising a carriageway of 3.5 m and 2 x 0.50 m unpaved shoulders.
3 In urban and peri-urban areas, parking lanes and footpaths may be required.
4 On hairpin stacks, the minimum radius may be reduced to a minimum of 13 m.
5 In some circumstances in very flat terrain, this can be reduced to 0.3%.
6 These values are based on an object height of 0.2 m. Use of a different sized object requires approval.
7 Maximum gradient also depends on road class.
8 In escarpment terrain design speeds can be lower and hairpin stacks may be required (Section 6.6.5).

Table 7-8: Unpaved(2) LVR5 geometric parameters (AADT > 400)(1)

Design Element		Unit	Flat	Rolling	Mountain
Design Speed		km/h	80	70	50
Width of Carriageway (Table 5-1)		m	6.5		
Min. Stopping Sight Distance	g = 0%	m	160	125	70
	g = 5%	m	190	145	80
	g = 10%	m	235	175	90
Min. Passing Sight Distance		m	240	210	155
Min. Horizontal Curve Radius	SE = 4%	m	355	255	115(2)
	SE = 6%	m	265	190	85
Max. Gradient (desirable)		%	6	6	6
Max. Gradient (absolute)		%	7	7	7
Min. Gradient(3)		%	0.5	0.5(3)	0.5
Min. Crest Vertical Curve (4)		K	58	35	11
Min. Sag Vertical Curve		K	16	12	7
Normal Camber/Cross-fall		%	5	5	5
Shoulder Cross-fall		%	5	5	5

Notes

1. If there are more than 80 Large Heavy Vehicles, then the specifications for the classification of next traffic level should be used.
2. On hairpin stacks, the minimum radius may be reduced to a minimum of 15 m.
3. In some circumstances in very flat terrain, this can be reduced to 0.3%.
4. These values are based on an object height of 0.2 m. Use of a different sized object requires approval.

Table 7-9: Unpaved LVR 4[(1)] geometric parameters (AADT 200-400)[(1)]

Design Element		Unit	Flat	Rolling	Mountain	Escarp't
Design Speed		km/hr	70	60	45[(2)]	25
Width of Carriageway (Table 5-1)		m	5.5 – 6.5			
Min. Stopping Sight Distance	g = 0%	m	125	95	65	23
	g = 5%	m	145	110	70	24
	g = 10%	m	175	130	75	25
Min. Passing Sight Distance		m	210	180	145	50
Min. Horizontal Radius		m	255	175	90	15[(3)]
Max. Gradient (desirable)		%	6	6	6	7
Max. Gradient (absolute)		%	7	7	7	7
Min. Gradient[(4)]		%	0.5	0.5	0.5	0.5
Max. Superelevation		%	6	6	6	6
Min. Crest Vertical Curve [(5)]		K	35	20	10	3
Min. Sag Vertical Curve		K	25	19	11	3
Normal Camber/Crossfall[(6)]		%	5	5	5	5
Shoulder Cross-fall		%	5	5	5	5

Notes

1 If there are more than 30 Large Heavy Vehicles then LVR 5 should be used.
2 The design speed has been adjusted to provide the same minimum radii of curvature as for the paved LVR4 standard.
3 On hairpin stacks, the minimum radius may be reduced to a minimum of 15 m.
4 In some circumstances in very flat terrain, this can be reduced to 0.3%.
5 These values are based on an object height of 0.2 m. Use of a different sized object requires approval.
6 Cross-fall can be reduced to 4% where warranted (e.g. poor gravel – for safety, low rainfall).

Table 7-10: Unpaved LVR 3(1, 2) geometric parameters (AADT 100-200)(1)

Design Element		Unit	Flat	Rolling	Mountain	Escarp't
Design Speed		km/hr	70	60	45(2)	25
Width of Carriageway (Table 5-1)		m	4.5 – 5.5			
Min. Stopping Sight Distance	g = 0%	m	125	95	60	25
	g = 5%	m	145	110	70	25
	g = 10%	m	175	130	75	30
Min. Horizontal Radius		m	255	175	90	25(3)
Max. Gradient (desirable)		%	6	6	6	6
Max. Gradient (absolute)		%	7	7	7	7
Min. Gradient(4)		%	0.5	0.5	0.5	0.5
Max. Super-elevation		%	6	6	6	6
Min. Crest Vertical Curve (5)		K	35	20	9	1
Min. Sag Vertical Curve		K	12	9	5	2
Normal Camber/Crossfall(6)		%	5	5	5	5
Shoulder cross-fall		%	5	5	5	5

Notes

1 If there are more than 20 Large Heavy Vehicles, then LVR 4 should be used.
2 Design speed adjusted to provide the same minimum radii of curvature as for the paved LVR3 standard.
3 On hairpin stacks, the minimum radius may be reduced to a minimum of 15 m.
4 In some circumstances in very flat terrain, this can be reduced to 0.3%.
5 These values are based on an object height of 0.2 m. Use of a different sized object requires approval.
6 Cross-fall can be reduced to 4% where warranted (e.g. poor gravel -for safety, low rainfall).

Table 7-11: Unpaved LVR2(1,2) geometric parameters (AADT 50-100)(1)

Design Element		Unit	Flat	Rolling	Mountain	Escarp't
Design Speed		km/hr	60	50	35(2)	20
Width of Carriageway (Table 5-1)		m	3.5 – 4.5			
Width of shoulders		m	0.5(3)			
Min. Stopping Sight Distance	g = 0%	m	95	70	45	20
	g = 5%	m	110	80	47	20
	g = 10%	m	130	90	50	20
Min. Horizontal Radius		m	175	115	55	15(4)
Max. Gradient (desirable)		%	6	6	6	6
Max. Gradient (absolute)		%	7	7	7	7
Min. Gradient(5)		%	0.5	0.5	0.5	0.5
Max. Super-elevation		%	6	6	6	6
Min. Crest Vertical Curve (6)		K	20	10	5	1
Min. Sag Vertical Curve		K	9	7	4	1
Normal Camber/Cross-fall (7)		%	5	5	5	5

Notes

1. If the number of Large Heavy Vehicles >20 then LVR 4 should be used.
2. Design speed adjusted to provide the same minimum radii of curvature as for paved standard.
3. On road class LVR2, where passing bays are not provided, the minimum width of the roadway will be 4.5 m comprising a carriageway of 3.5 m and 2 x 0.50 m unpaved shoulders.
4. On hairpin stacks, the minimum radius may be reduced to a minimum of 13 m.
5. In some circumstances in very flat terrain, this can be reduced to 0.3%.
6. These values are based on an object height of 0.2 m. Use of a different sized object requires approval.
7. Cross-fall can be reduced to 4% where warranted (e.g. poor gravel-for safety, low rainfall).

Table 7-12: Geometric parameters for design class LVR1 (AADT <50)(1)

Design Element		Unit	Flat	Rolling	Mountain	Escarp't
Design Speed		km/hr	60	40	30(2)	20
Width of Carriageway (Table 5-1)		m	3.5			
Width of shoulders		m	0.5(3)			
Min. Stopping Sight Distance	g = 0%	m	95	50	30	20
	g = 5%	m	110	55	35	20
	g = 10%	m	130	60	37	20
Min. Horizontal Radius		m	175	65	35	15(4)
Max. Gradient	Desirable	%	6	6	6	6
	Absolute	%	7	7	7	7
Min. Gradient(5)		%	0.5	0.5	0.5	0.5
Min. Crest Vertical Curve(6)		K	20	5	3	1
Min. Sag Vertical Curve		K	9	4	3	1
Normal Camber/Cross-fall		%	5	5	5	5

Notes

1 If there are more than 10 Large Heavy Vehicles, then LVR 2 should be used.
2 Design speed adjusted to provide the same minimum radii of curvature as for paved standard.
3 On road class LVR 1, where passing bays are not provided, the minimum width of the roadway will be 4.5 m comprising a carriageway of 3.5 m and 2 x 0.50 m unpaved shoulders.
4 On hairpin stacks, the minimum radius may be reduced to 13 m.
5 In some circumstances in very flat terrain, this can be reduced to 0.3%.
6 These values are based on an object height of 0.2 m. Use of a different sized object requires approval.

For the lowest category of road, it may sometimes be necessary to adopt a basic access only approach. For such roads it may be too expensive to provide a design speed but minimum absolute standards must be applied. These are summarised in Table 7-13.

Table 7-13: Minimum standards for basic access only

Characteristic	Minimum requirements	
Radius of horizontal curvature	12 m absolute but up to 20 m depending on expected vehicles	
Vertical curvature K value for crests K value for sags	 2.0 0.6	
Maximum gradients: Open to all vehicles Open only to cars and pick-ups	 14% 16%	
Minimum stopping sight distance	Flat and Rolling terrain Mountainous Escarpments	50 m 35 m 20 m

7.5 Cross Section

A summary of the recommended dimensions for the various cross-section elements for both paved and unpaved roads is shown in *Chapter 5 – Cross Section*, Figure 5-2 to Figure 5-6.

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Part B

Urban Roads

Contents

1 Overview

2 Approach to Design

3 Fundamental Design Considerations

4 Traffic

5 Stormwater Drainage

6 Cross Section

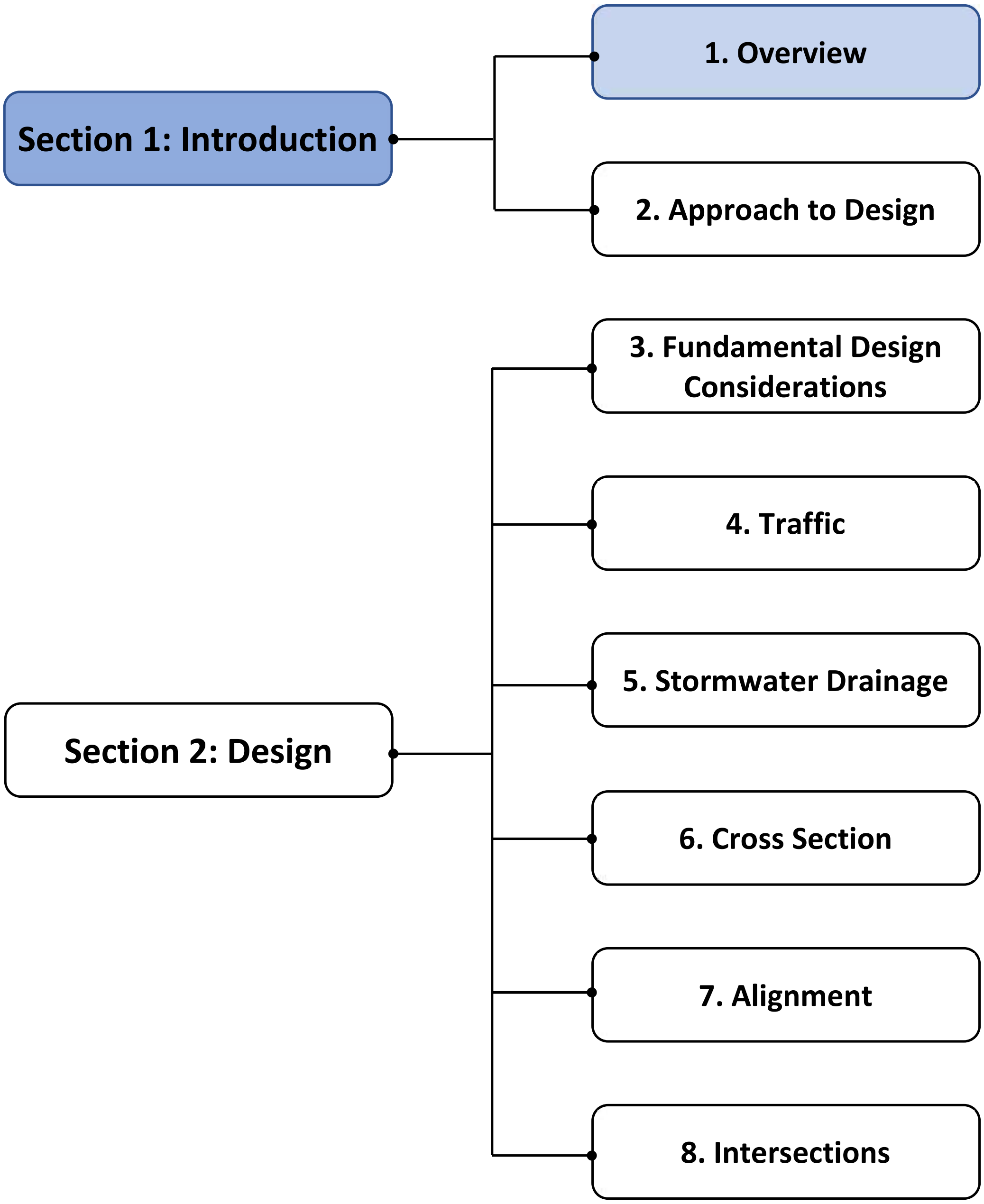
7 Alignment

8 Intersections

Section 1

Introduction

Low Volume Roads Manual
Part B – Geometric Design: Urban Roads



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1.1 Background

As Malawi follows the global trend towards increased urbanisation, it is important to ensure that the country's urban townships and settlements are pleasant, safe and vibrant places to live, work, study and play in. Such an environment will be to the benefit of everyone by generating and sustaining communities and neighbourhoods, with wide-ranging economic, social and environmental advantages.

Roads and streets in the urban environments in Malawi constitute an important component of the overall road network and transport system in the country and should provide for the safe and efficient movement of people and goods in an integrated, cost-effective and sustainable manner. Urban roads and streets serve all modes of transport, including pedestrians, cyclists, motorcyclists and even the occasional animal-drawn cart. Thus, in order to achieve operational efficiency, road safety and public amenity, a balanced approach is needed for road planning, design and stormwater management. This will require professionals of different disciplines to work together to achieve better urban road designs.

Regional and international guidelines have been developed for human settlement planning and design. Recent developments in this field have promoted a shift of emphasis from more conventional approaches that are concerned with the movement of traffic to more sustainable approaches concerned with multi-modal movement, and streets as places. This approach has been a guiding principle in the development of the Manual.

1.2 Purpose

The main purpose of this Manual is to provide a holistic and integrative approach to the design of roads and streets in urban environments in Malawi. It does so by presenting, in a structured format, a series of principles, approaches and standards that are necessary to achieve balanced, best-practice design outcomes with regard to street networks and individual streets ranging from macro to micro-level considerations. The Manual does not purport to account for every scenario that a designer will encounter, particularly when retrofitting existing streets, nor can it cover every technical detail, but should provide sufficient information to guide a designer through most situations that may be encountered.

1.3 Scope

The Manual applies to the design of roads and streets in both planned and existing urban residential settlements, whether formal or informal. It is likely to be used extensively in upgrading and retrofitting existing settlements, which can only be satisfactorily achieved if there is a prior appreciation of all the requirements for achieving a balanced approach to the development of such settlements. On this basis, the designer can then prioritise competing requirements on a rational basis.

The Manual first presents the philosophy behind the design of low volume urban roads and streets and provides a definition applicable to these facilities before addressing fundamental design considerations. The Manual then addresses the technical aspects relating to traffic volumes and safe vehicular operations, as well as stormwater drainage, before dealing with the physical aspects of street cross sections, horizontal and vertical alignment and intersections between streets. Road safety forms an integral aspect of the technical design, which is addressed in Part C – Road Safety of the Manual.

1.4 Structure

Part B is divided into two separate sections as presented in Table 1-1.

Table 1-1: Structure and content of Part B

Section	Chapter
A. Introduction	1. General Introduction
	2. Approach to Design
B. Design	3. Fundamental Design Considerations
	4. Traffic
	5. Stormwater Drainage
	6. Cross Sections
	7. Alignment
	8. Intersections

1.5 Terminology

The terminology used to describe various components of a low volume street is illustrated below for ease of reference in the use of this Manual.

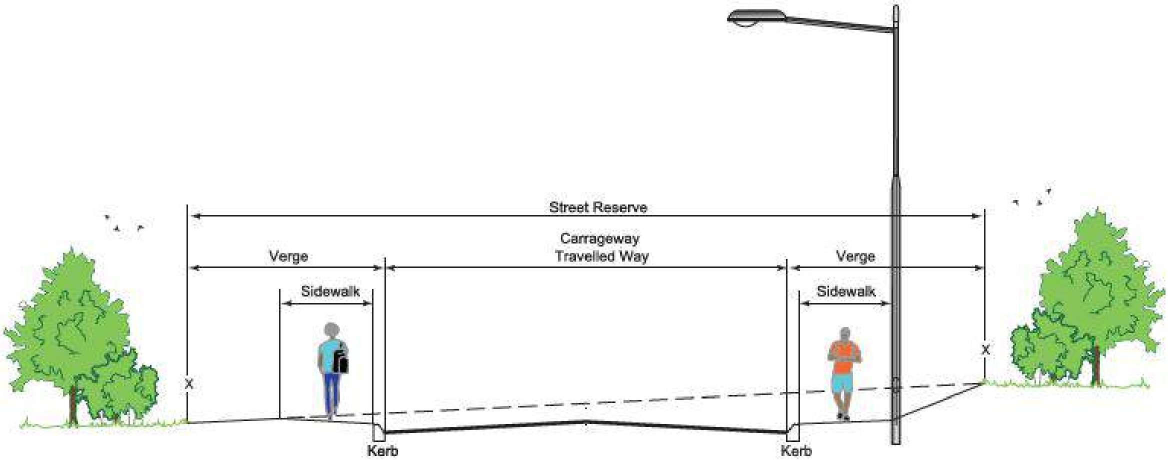

Figure 1-1: Street cross section

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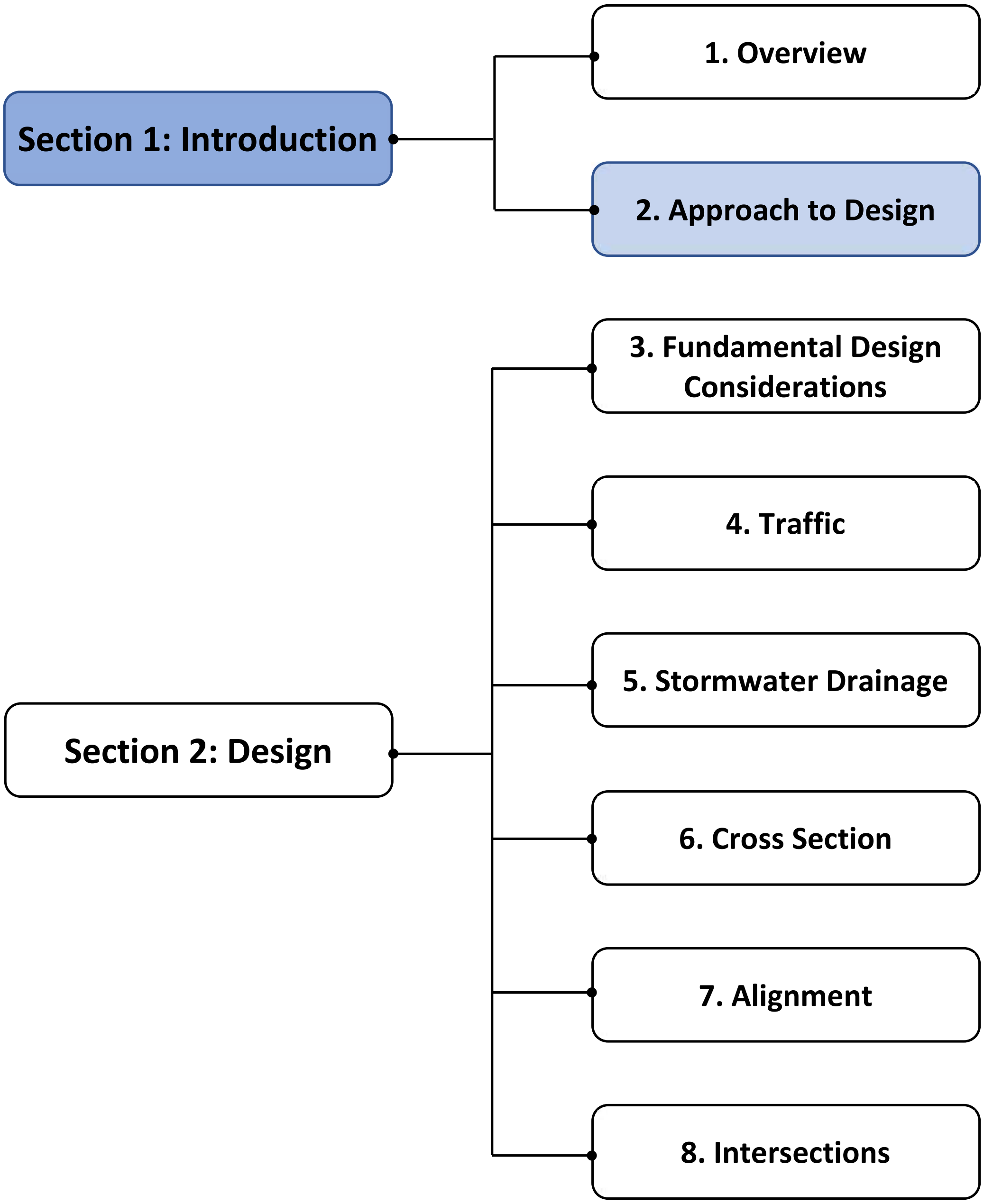

Chapter 2 – Approach to Design

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2.1 Introduction

2.1.1 Background

Urban areas attract people because of the opportunities offered not only for living but to work, trade, study, socialise and play. Creating an environment conducive to these activities requires suitably designed public amenities of which the urban roads and streets form a major component. Hence, the geometric design of urban roads and streets differs appreciably from that of roads in the rural environment, where the emphasis is on connectivity.

Because of the many differences between rural and urban geometric design as discussed in more detail in Section 2.2 below, the geometric design of urban roads and streets has been addressed in this separate, self-standing Part B of the Geometric Design Manual for Low Volume Roads.

2.1.2 Purpose and Scope

The purpose of this chapter is to position the geometric design of urban streets in the wider context of urban design and town planning and to define low volume streets. It also introduces the principles of Movement Networks, Context-Sensitive Design and Complete Streets as elements of urban geometric design.

The Manual highlights some of the differences between the approach to geometric design in urban versus rural environments. It then discusses the urban design process in broad terms and the expectations that the various users may have of a street facility, before dealing with fundamental design considerations and the details of the geometric design of such streets.

The Manual is aimed at the urban context and does not deal with rural low volume roads passing through villages. However, some of the principles and aspects covered would be equally applicable to the rural situation, particularly aspects such as traffic calming, the use of frontage streets to separate through and local movements, road safety and drainage measures.

2.2 Differences between Rural Road and Urban Street Design

The major differences between rural road and urban street design are summarised as follows:

- Street space has to serve a much broader activity demand than a rural road in terms of having to cater for a wide range of users including pedestrians, joggers, children playing, people socialising, cyclists, motorists, public transport, etc., all of whom have to be accommodated in an adequate and safe manner.
- Cognisance also has to be taken of vulnerable street users such as blind persons and wheelchair-bound people.
- Vehicle size and the difference between vehicle sizes are much more significant and there is much more inter-vehicular friction in urban areas.
- In the rural environment, vehicles are well spaced, moving at such speeds as the speed limit and the vehicle and road conditions would permit, whereas in the urban situation, traffic densities are higher and speeds are lower.
- Intersections, generally, are far apart in rural areas, whilst closely spaced in urban areas, with a significant influence on road capacity.
- Travel distances are also shorter in the urban context and there are few occasions to encounter animal-drawn vehicles, but pedestrians and cyclists abound.
- Incorporation of the street as an integral part of the urban stormwater drainage system. In rural areas, there is a need to get water away from the road as quickly as possible, while within the urban area, the street forms the first element of the drainage system. This requires that streets should be slightly depressed to facilitate drainage of the adjacent

properties, while roads are slightly elevated to facilitate cross drainage and to keep water/moisture away from the pavement structure.

- Utility services, in particular, have to be accommodated in the street space. Providing for sewers operating on gravity can have a significant impact on street layout and grades.
- Land acquisition costs are amongst the major factors determining street space. In low-income residential areas, street space tends to be more restricted than in high-income areas.

In an urban environment, the geometric street designer has far less freedom than the rural road designer and has to practice the art of design in a cooperative interdisciplinary effort with several other role-players.

2.3 Principles of Movement Networks

2.3.1 General

In defining low volume streets, it is necessary to focus initially on the various functions of a street. In meeting the broader needs of people concerning road and street space, the concept of movement networks evolved in recent times. Movement networks comprise public rights of way, incorporating roads and streets as well as footways and cycleways. The basic principle of movement networks is one of ensuring continuous pedestrian-friendly public rights of way. This principle also recognises the multi-faceted nature of local residential streets, morphing into public transport-orientated, more extensive area movement networks, linking to mobility orientated facilities for higher speed movement of people and goods. Where appropriate, movement networks will include railways.

Local movement networks are made up of (a) links and (b) junctions of public right-of-way or reserves. These links and junctions contain overlaid systems of “ways” for different movement modes– including footways, roadways, pathways, cycleways and sometimes railways (see Figure 2-1). Viewing a movement network as a network of public rights-of-way, as opposed to simply as a network of roads, is central to the planning approach presented in this chapter.

An understanding of the potential range of functions that each link within a movement network may be expected to perform enables the appropriate number of lanes, the pavement structure, the footway width, the on-street parking provisions, and the intersection configurations and spacings, etc., to be selected.

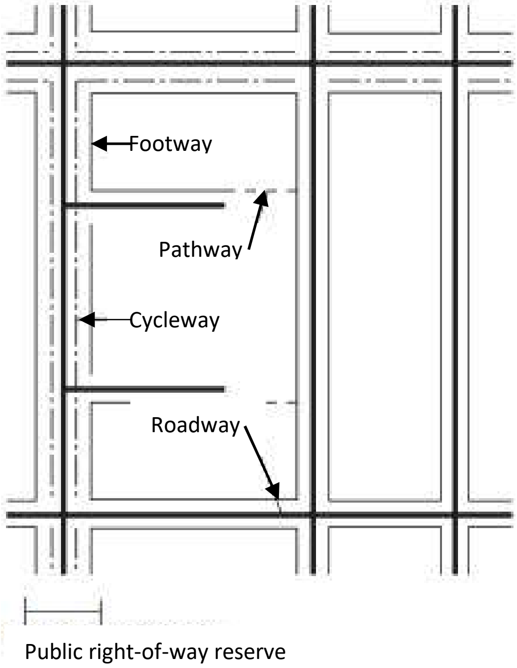

Figure 2-1: Illustration of a movement network as a series of overlaying "ways"

The scale of the movement networks varies from pedestrian-only through mixed-use to vehicle-only. Vehicle-only links correspond with major arterial roads and freeways, while pedestrian-only links are typically designed to preclude motorised modes. Middle-order links perform a mixed-mode function, at the one end tending to pedestrian domination with vehicle domination at the other end. Access to adjacent land varies with the function of the link, from unrestricted in the case of pathways and local streets to prohibition in the case of vehicle-only mobility routes.

Junctions also perform more than one function. With regard to movement functions, the carrying capacity of an urban street is determined by the intersection capacity, not the street capacity. Thus, it is the intersection performance that often determines the operational efficiency of the network of streets as a whole. Whilst intersection capacity on low volume streets should not present any problems, intersections with higher-order streets may well do so. With regard to non-movement functions, it is the exposure to two movement routes that attracts economic activity to a junction, immediately creating a conflict between a need for ready access to the adjacent land, and the need for unencumbered safe traffic flow.

2.3.2 Role and Function of Movement Networks

Movement networks also include the concepts of human factors, context-sensitive design and "Complete Streets". Human factors design is as much focused on the drivers and their wishes and capabilities as on what the vehicles can do. Context-sensitive design addresses safety and efficiency while being responsive to the road or street's natural and human environment. A Complete Street is a street that accommodates all street users, allows for safe movement giving priority to the most efficient mode while responding to the neighbourhood character and contributes to a healthy, vibrant public realm in a sustainable, harmonious, cost-effective way. Establishing movement networks is a major aspect of urban design and goes much wider than the field of geometric design, but one in which the input of the geometric design engineer forms a significant contribution.

2.3.3 Classes of Movement Networks

Table 2-1 identifies the six classes of movement network elements referred to in this Manual and offers in broad terms a comparison between movement network systems, the Five-tier Road Network System and other nomenclature in use for various road and street classes. In considering this table, it should be clearly understood that the comparison is in broad terms and that there is no direct relationship between the movement network and other classifications. As indicated above, movement networks encompass much more than the matter of accessibility versus mobility that lies at the heart of the other systems. References to "class" in this Manual are to the movement network classes as defined in this table under the heading "Urban Street Class".

It may also be noted that higher-order, mixed-use routes would carry higher volumes of traffic and or accommodate higher orders of roadside economic activity. Lower order routes would involve local and access-seeking traffic and/or accommodate higher levels of social and recreational activity.

Table 2-1: Movement Network Classification and Other Systems

Movement Network	Five -Tier System	Other Nomenclature	Urban Street Class
Vehicle-only Route	Class 1 Regional Distributor	Principal Arterial Freeways	1
Vehicle-only Route	Class 2 Primary Distributor	Major Arterial	2
Mixed Pedestrian and Vehicle Route: Higher-order	Class 3 District Distributor	Minor Arterial	3
Mixed Pedestrian and Vehicle Route: Middle-order	Class 4 Local Distributor	Collector	4
Mixed Pedestrian and Vehicle route: Lower-order	Class 5 Access Street (sub-classes)	Local Street	5
Pedestrian and Cycle-only Pathways		Pathways NMT Routes	6

On mixed-mode links that accommodate lower traffic volumes, the following should be noted (Figure 2-2):

- Intersection spacing should be influenced more by, inter alia, pedestrian circulation, block sub-division and internal utility service reticulation considerations than by traffic circulation considerations. By limiting straight, unbroken stretches of roadway in which vehicles are able to pick up speed, network configurations can be used as traffic-calming mechanisms, which enhance the ability of pedestrians to use streets for social and recreational purposes.
- Low traffic volumes do not usually justify investment in intersection control, in the form of traffic signalisation. T-junctions can, therefore, be used as a way of breaking long stretches of roadway.
- Intersections between two mixed-mode links that accommodate smaller volumes of traffic are less accessible and therefore provide opportunities for less intensive trade and collective servicing points. Activities should not therefore be prevented from locating close to the intersection.

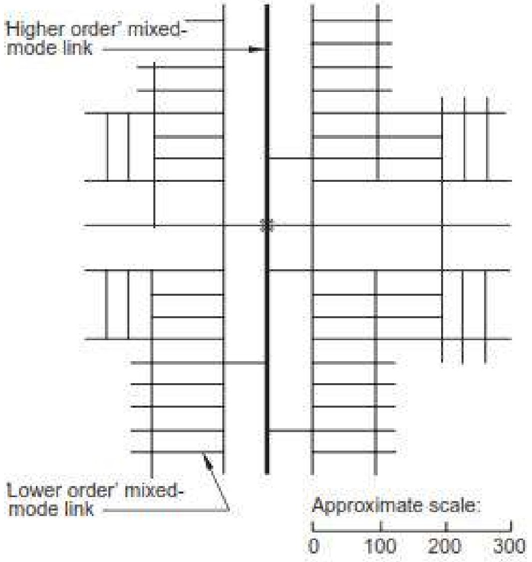

Figure 2-2: Relationship between higher and lower order mixed-mode links

2.3.4 Definition of Low Volume Urban Roads and Streets

Against the background discussed above, the question that arises is what constitutes low volume urban roads or streets. It is evident that the normal approach followed for rural roads, of a certain number of vehicles per day, or equivalent standard axles, will not suffice. It will also be very difficult to apply. Hence, a functional approach is followed with guidance taken from the principles embodied in movement networks.

For this part of the Manual, low volume urban streets are defined as those facilities in the movement network primarily concerned with the middle and lower order mixed pedestrian and vehicle routes, i.e. Classes 4 and 5, as well as the non-motorised transport (NMT) pathways, Class 6. The following township layout sketch serves to some degree as an illustration of this definition.

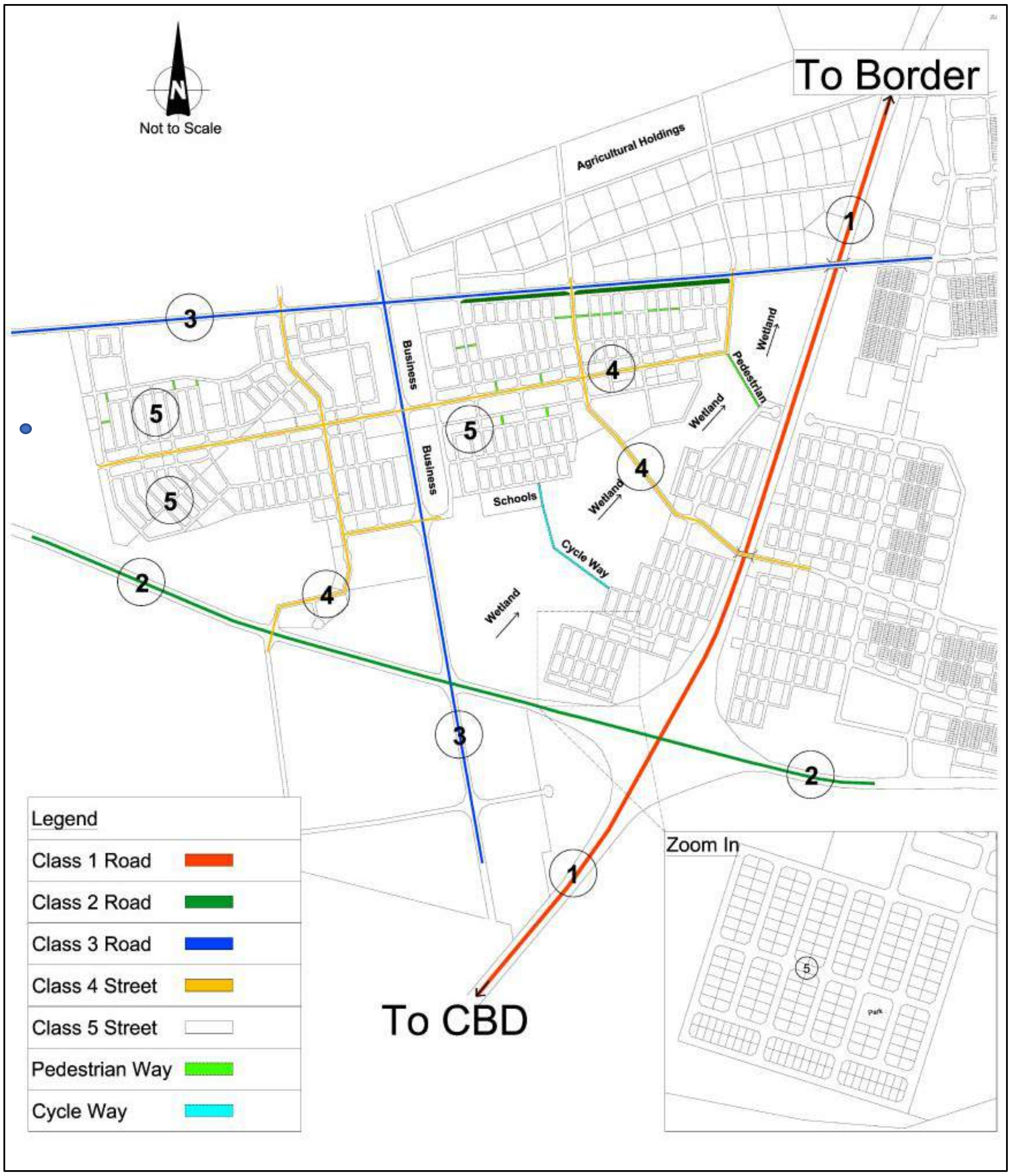

Figure 2-3: Illustration of different movement network functional road categories

2.4 Characteristics of Low Volume Streets

Low volume streets are characterised in the first instance by being primarily for people. This involves:

- People walking to school, to public transport, to work, to shop, to public amenities (clinics, hospitals, etc.) and to visit
- People socialising
- Children playing
- Hawking activities
- Recreational cycling

In the second place, it serves an access function requiring vehicle movements involving:

- Relatively slow speeds
- Left and right turns in and out of properties
- Parking

Low volume streets also provide access to municipal service vehicles such as waste removal trucks, emergency vehicles, other municipal services (e.g. water supply and electricity maintenance) and may also in some instances serve as bus routes and mini-bus other municipal services routes, and, excepting pathways, also have a drainage function to fulfil, as any other street.

2.5 Design Considerations

A first step in the geometric design process should be to consult the urban development plan of the area involved or to assist in establishing cardinal aspects of such a plan, in order to guide the detailed design. Ideally, the development plan should comprise a roads master plan which includes a public transport master plan and a drainage master plan amongst its outcomes. *Chapter 3 – Fundamental Design Considerations* discusses pertinent aspects of such a development plan in more detail. The development master plan would also incorporate information on other engineering services to be taken into account, like electricity, water supply and sewer mains, and other public services like internet cable, telephone, etc.

With a drainage and roads master plan in place, attention should then focus on the street or group of streets in the area under consideration within the context of movement networks and normal engineering geometric considerations.

The two classes of streets that would be primarily involved are:

- Lower-order mixed pedestrian and vehicle routes (Class 5 Access/Local/Residential) streets.
- Middle-order mixed pedestrian and vehicle routes (Class 4 Local Distributor/Collector) streets.

However, consideration should also be given to possible intersections with higher-order streets as well as cycle and pedestrian pathways. In the planning process, due cognisance should be given to space for stormwater drainage systems as well as utility services.

In situations where retrofitting is required a holistic approach should be adopted against the backdrop of a preconceived master plan. Piecemeal solutions should be avoided as they tend to provide short-term solutions that may address a particular symptom rather than the cause of the problem. For example, the installation of a traffic-calming hump may slow traffic locally, but it does not address the broader issue of the road design or street network where separate traffic-calming measures may be warranted.

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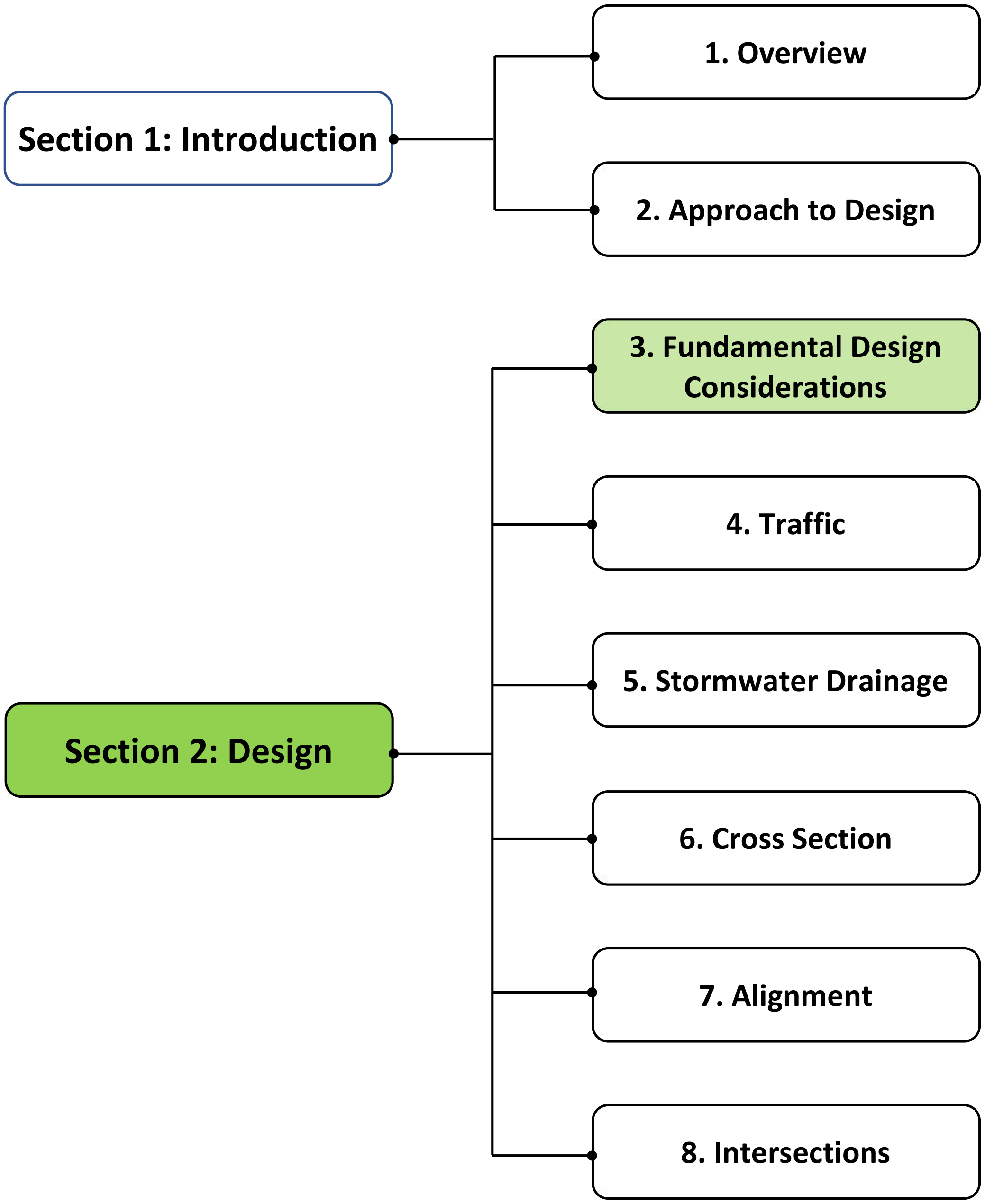
Section 2

Design

Low Volume Roads Manual
Part B – Geometric Design: Urban Roads



Chapter 3 – Fundamental Design Considerations

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3.1 Introduction

3.1.1 Background

Geometric design is the process of selecting and applying values to the various visible elements of the road or street. It is a complex task and goes beyond applying values extracted from tables and graphs in design manuals. Good design requires creative input based on a sound understanding of the principles involved. Design tables and graphs, as well as typical drawings, are provided to guide the designer, but the information has to be applied in the context of the particular road or street being designed.

Road design is traditionally approached from the perspective of the horizontal alignment, modified as necessary by vertical alignment considerations and the constraints of the "typical" cross section. In recent times, aspects such as human factors, context-sensitive design and consistency of design have become more prominent in road design.

In street design, these factors remain important but, to a large extent, have to be considered and decided on upfront during the urban design and town planning phases of an urban development project. The input of the geometric designer remains crucial but has to be exercised working in a multi-disciplinary team.

3.1.2 Purpose and Scope

There are certain fundamental considerations that influence the setting of detail design requirements pertinent to the geometric design of low volume, low-order street systems. A good grasp of these underlying considerations is of great value to designers. The purpose of this chapter is to sensitise designers to these fundamentals and to ensure that the various design tasks are undertaken in an informed way.

The chapter highlights the various planning considerations which influence the approach to urban design. It then presents the basic design parameters that affect the design of low volume streets and provides guidance on how such designs can be implemented in the case of new developments and the retrofitting of existing developments.

3.2 Planning Considerations

3.2.1 Urban Environment

Geometric design normally tends to focus on the movement of motor vehicles, hence the need to stress that the design of streets must take cognisance of the urban environment and the wider aspects incorporated in the concept of movement networks.

In creating an attractive environment, stormwater management stands paramount. A characteristic of an attractive urban environment is one of good stormwater drainage.

3.2.2 Urban Design

The urban design process encompasses the establishment of an urban development framework, incorporating a movement network system. It also takes into account the geophysical as well as the biophysical and social environments. Major elements of the development framework include a movement master plan, a drainage master plan and the requirements of the developer or authority concerned regarding the land use budget, e.g. the number of stands of various sizes per hectare, target selling prices, other land use needs to be met, developmental costs, etc.

Movement master plan

The movement master plan will focus predominantly on the mobility elements of the envisaged movement network and the necessary linkages to the wider area network. The design standards for the alignment and linkages of these roads and streets must meet the design criteria of the relevant authority. Typically, spacing standards will apply to these routes, with particular emphasis on spacing of intersections. Other requirements will concern design speed, limiting criteria on radii of curves and gradients, as well as cross-sectional requirements.

Internationally, nominal road reserve widths for these roads are of the order of:

- 25 m to 30 m for higher-order mixed pedestrian and vehicle roads (Class 3);
- 36 m to 40 m for the vehicle only routes in the class of major arterials (Class 2); and
- 50 m to 60 m for the vehicle only routes in the class of highways and freeways (Class 1).

Actual cross-sectional and road reserve requirements will be set by the Roads Authority or the local authority involved, as the case may be.

The movement master plan will also strive to identify the envisaged bus routes to serve the area. Generally, bus routes will follow Class 2 and Class 3 routes, but bus routes may also occur on some Class 4 routes. The ideal in identifying bus routes is to provide as efficient a route service as possible, without having people to walk more than 1.5 km to reach a bus stop. Apart from the street network, the movement master plan should also make allowance for pedestrian and bicycle pathways.

Drainage master plan

The drainage master plan will strive to establish pre-development stormwater flow patterns and identify measures needed to ensure that post-development runoff does not exceed those flows, inter alia by attenuation and other suitable means. The drainage master plan will also strive to ensure that drainage of stormwater by gravity is possible and that urban development does not take place in very flat areas that will become inundated by stormwater. It will also try to avoid urban development on very steep slopes with high erosion and other risk potential. Should it not be possible to avoid such areas, appropriate building and construction standards, for example, raising floor levels at least 250 mm to 500 mm above the expected major storm inundation level, should be instituted. *Chapter 5* deals with drainage aspects.

Other considerations

In addition, the geology, topography, social, e.g. heritage, and the biophysical aspects, e.g. wetlands, fauna and flora to be protected, all have to be taken into account before the more detailed town planning can proceed.

Illustrative example

Figure 3-1 serves as an illustrative example of an urban design framework.

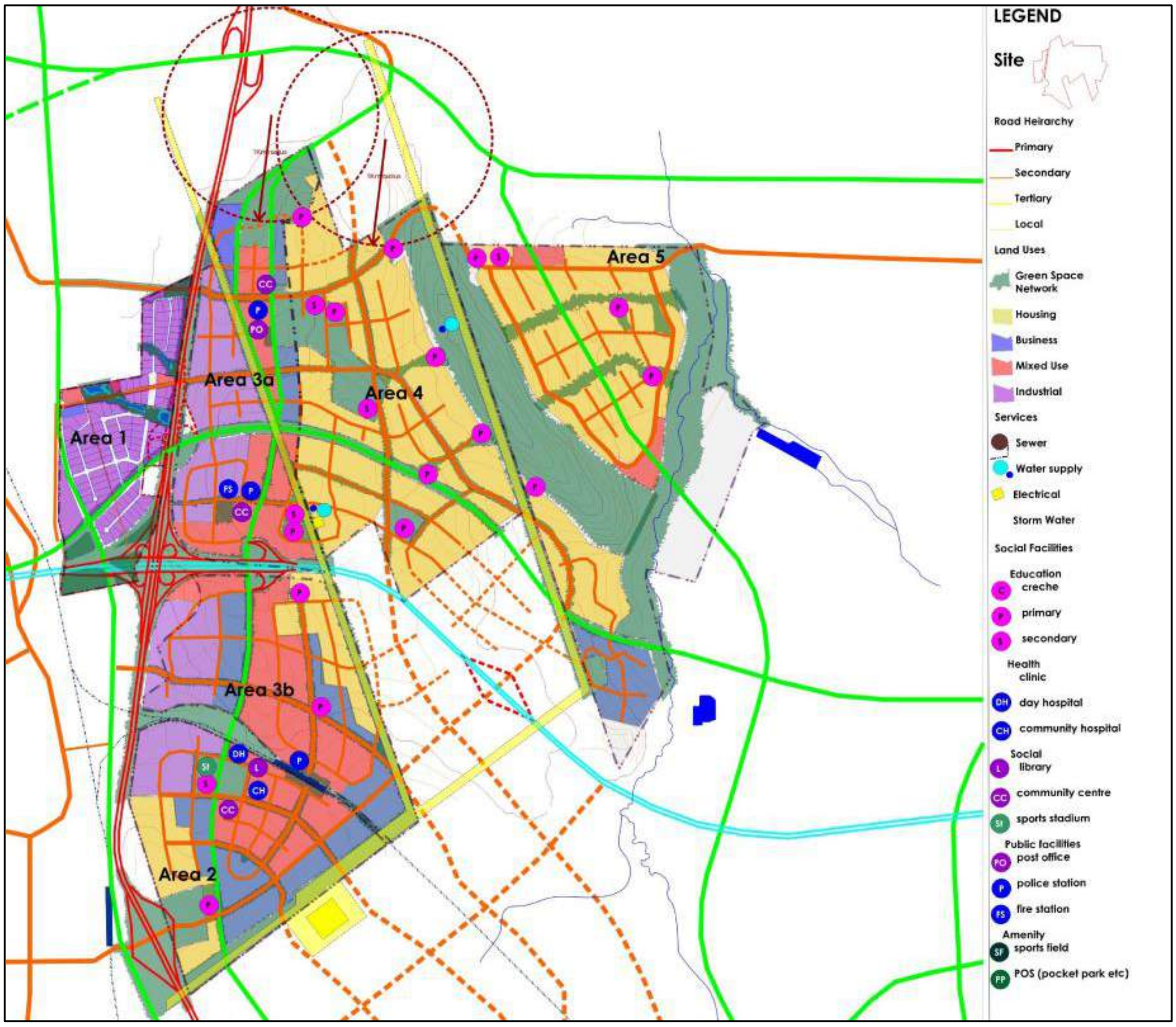


Figure 3-1: Illustrative urban design framework

3.2.3 Town Planning

Town planning takes the urban design further and determines the placing of urban amenities, street block and stand layout as well as street reserve widths, whilst considering the various street space demands as well as normal geometric and other engineering requirements. In this process, appropriate guidelines such as contained in this Manual with regard to streets will provide input to the planners and geometric designers. Thus, this Manual is aimed as much at the town planner as the geometric design engineer.

The town planner also has to consider the other needs, such as those of internal utility services. Another important consideration when deciding on street block lengths and street reserve widths is the fire-fighting equipment available to the relevant urban authority.

Typical town planning norms for street widths are of the order of:

- 25 m to 36 m for higher-order mixed pedestrian and vehicle streets (minor arterials);
- 20 m to 22 m for collectors also acting as bus routes;
- 16 m to 18 m for collectors;
- 13 m to 16 m for residential streets;
- 8 m to 10 m for cul-de-sac or short streets;
- 4 m to 5 m for pedestrian and cycle pathways.

Once the township layout has been confirmed, the geometric designer can proceed with the design of the street system. This comprises determining the vertical and horizontal alignment, final street cross section, any other elements to be provided, such as bus bays, as well as the drainage requirements. In the process, due cognisance must be taken of, and provision made for, utility services like power, water, sewer, telecoms and gas, planned and designed by others.

3.2.4 Upgrading and Retrofitting

The process described thus far is aimed at greenfield developments, but many projects will be concerned with upgrading or retrofitting of facilities into existing developments, so-called brownfield development. Upgrading generally refers to smaller-scale improvements to existing facilities, while retrofitting borders on redevelopment. Figure 3-2 illustrates a situation where retrofitting would be required, while Figure 3-3 reflects a typical upgrading situation.

Figure 3-2: Candidate site for retrofitting

Figure 3-3: Candidate site for upgrading

In both instances, the process remains the same, except that in the case of upgrading the geometric engineer may not have the benefit of a team and have to do the work alone in conjunction with the authority involved. The essential first steps would be to identify the drainage system and movement network and then attend to the functional classification and other related matters. Once the overall plan is in place, consideration can be given to rectifying the shortcoming of the existing situation by applying, as closely as possible, the principles of a functional movement network and street layout.

Undertaking upgrading projects without a master plan is not recommended as the full benefit of funds expended may not be obtained. The priority should be on resolving the drainage issues, followed by pedestrian facilities and then the travelled way and parking space.

3.3 Basic Design Parameters

3.3.1 Functional Classification

The primary design parameter will be the functional classification of the street in question, as determined during town planning or in a retrofitting process, as shown in Table 2-1. The movement master plan, and particularly the public transport element of that plan, will play a major role in this process.

3.3.2 Traffic Volume and Composition

Traffic volume and composition will play a minor role in the geometric design of residential streets because the function of the street will be the determining factor. This holds true for collector streets as well, but in case of evidence of congestion at intersections, mainly with higher-order streets, traffic data will have to be acquired whether by means of traffic counts, impact studies or modelling, as discussed in more detail in *Chapter 4*: *Traffic*.

3.3.3 Design Speed and Sight Distance

Design speed

Design speed is a yardstick selected for the purposes of design to ensure the correlation of the various design elements and consistency in design. Conventionally, the design speed is the maximum safe speed that can be maintained by 85% of drivers over a specific section of road when conditions are so favourable that the design features of the road govern.

Design speeds for urban low volume street facilities, by the very nature of the situation, will be relatively low. The following is recommended:

- Lower-order mixed-use routes (Residential streets – Class 5): 40 km/h
- Middle-order mixed-use routes (Collector streets – Class 4): 60 km/h

Design speed is not to be confused with, and is independent of, speed limits or speed restrictions that may be imposed on a road or street under design. Should situations arise that make it desirable to reduce the operating speed of vehicles, for instance, passing a school or a modal transfer point, it would be extremely unwise to reduce the design speed, as it would also reduce the sight distance requirements in a situation where sight distance is critical.

A section of a collector street also acting as an activity street, with shops and trading, is another instance where the design speed should be maintained, although a ceiling speed may be imposed.

Sight distance

Sight distance requirements are directly linked to design speed. A driver must be able to note hazards on the road or street with sufficient time to initiate and execute any required safety action. This time determines the sight distance required. On a two-lane road or a street of some length, it may also be necessary for a driver to pass or overtake a stationary or slow-moving vehicle by entering the opposing lane. For an overtaking manoeuvre a minimum clear space in the face of oncoming traffic is required. Sight distance is also a fundamental aspect in the design of intersections, albeit applied slightly differently.

Sight distance requirements are dealt with in *Chapter 7 - Alignment* and *Chapter 8 - Intersections*.

3.3.4 The Design Vehicle

The design vehicle is a theoretical composite rather than a real vehicle. It represents a combination of the critical features of those vehicles that would have an influence on geometric design. The following is recommended:

- For residential streets (Class 5):
    - The passenger car for horizontal and vertical alignment and other sight distance-related aspects, i.e. all speed-related aspects.
    - The single unit (SU) truck for intersection and other manoeuvrability design aspects.
- For collector streets (Class 4) whether serving as bus routes or not:
    - The passenger car for horizontal and vertical alignment and other sight distance-related aspects.
    - The single unit bus for intersection layout and other manoeuvrability design aspects. The bus also determines the maximum gradient that can be accepted.

In the case of residential streets (Class 5), the single unit truck is used as representing waste removal vehicles. In the case of collectors (Class 4), the single unit bus is used, as representing buses and emergency vehicles such as fire engines. Table 3-1 below shows typical dimensions of such vehicles and Table 3-2 minimum turning circle radii.

Table 3-1: Dimensions of design vehicles (m)

Vehicle	Wheel Base	Front Overhang	Rear Overhang	Width
Passenger car (P)	3.1	0.7	1.0	1.8
Single unit truck (SU)	6.1	1.2	1.8	2.5
Single unit bus (BUS)	7.6	2.1	2.6	2.6

Source: SATCC Code of Practice for Geometric Design of Trunk Roads

Turning templates are essential in ensuring that the kerb lines at intersections accommodate the path that the design vehicle will follow in negotiating left turns and, in the presence of median islands, the right turn. They also have applications in designing the layouts of parking areas and modal transfer stations.

Turning templates for various design vehicles, including specialised vehicles, can be plotted using commercially available computer-aided draughting programs, or can be constructed from the information contained in Table 3-2 if required.

Table 3-2: Minimum turning circle radii at crawl speed (m)

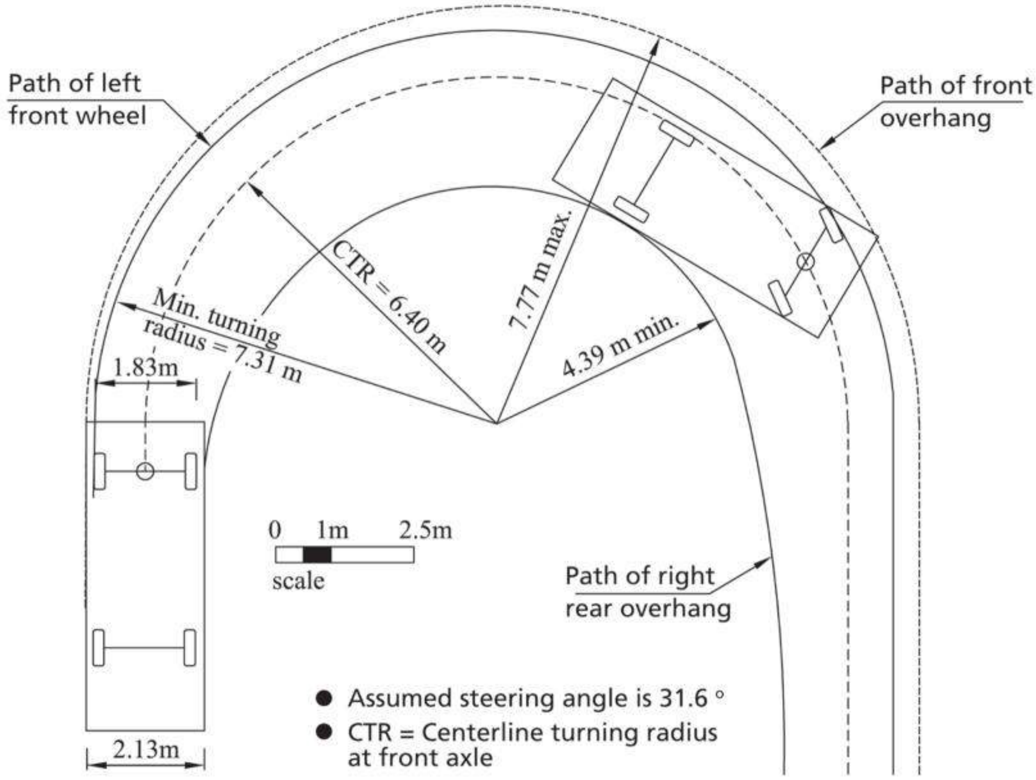
Vehicle	Minimum Turning Radius Outer Wheel Path	Minimum Turning Radius Inner Wheel Path
Passenger car (P)	6.2 m	4.4 m
Single unit truck (SU)	12.8 m	8.64 m
Single unit bus (BUS)	13.1 m	7.8 m
Note: Allow an additional 0.5 m front overhang for P and SU vehicles and 1.0 m for BUS over the outer wheel path when determining clear space required for turning. Refer to Figure 3-4 below for an illustration of such a turning template.		

Source: SATCC Code of Practice for Geometric Design of Trunk Roads

Should larger vehicles comprise more than 10 % of the traffic mix, which is unlikely in the case of residential and collector streets, it will become necessary to use them as design vehicles for manoeuvrability, in which case reference will have to be made to other appropriate design manuals.

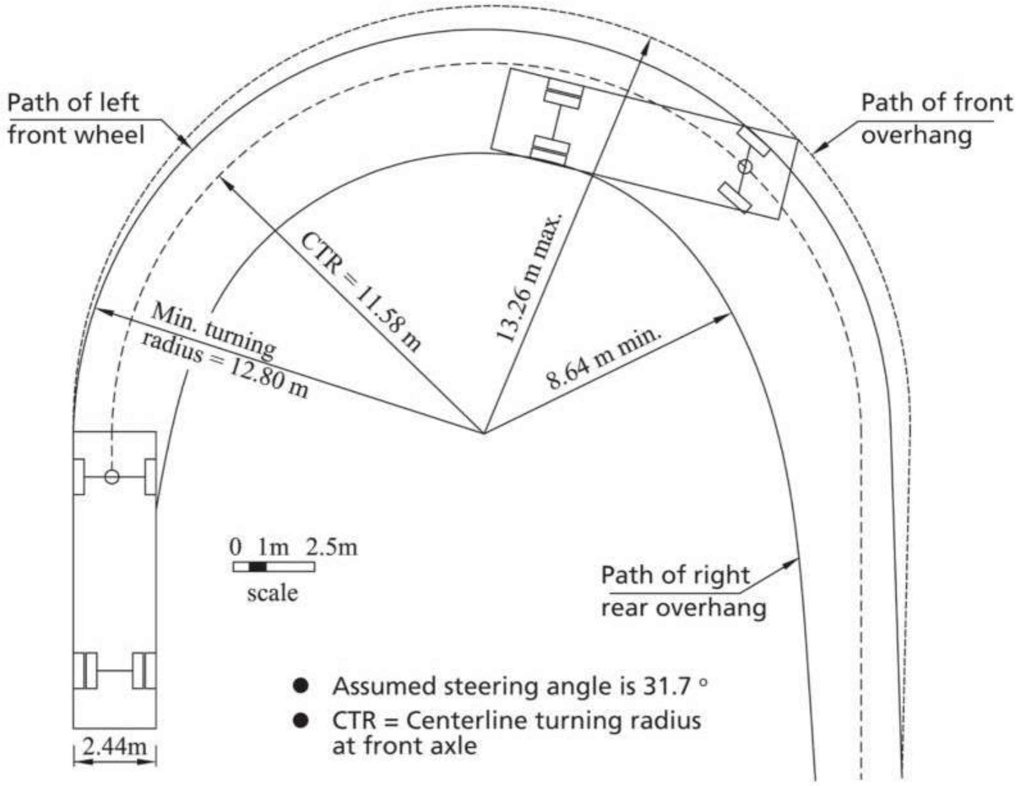
Some typical turning templates are illustrated in Figures 3-4 and Figure 3-5.

The maximum height of vehicles is controlled by legislation and has no direct bearing on the design of low volume streets. For sight distance purposes, the height of the passenger car is taken as 1.3 m, whilst a height of 2.6 m is ascribed to the Bus and the SU-truck.



- Assumed steering angle is 31.6 °
- CTR = Centerline turning radius at front axle

Figure 3-4: Turning template for Passenger Car



- Assumed steering angle is 31.7 °
- CTR = Centerline turning radius at front axle

Figure 3-5: Turning template for Single Unit Truck (SU)

3.3.5 The Design Driver

Two aspects, pertaining to the design driver, influence the design, namely, the eye height of the driver above the road or street surface and the driver's reaction time to events in the traffic stream or in the immediate surroundings.

The majority of passenger car drivers have been found to have an eye height of 1.05 m or higher and hence this value has been adopted for use in this Manual. The value for truck and bus drivers is 1.8 m.

A time period of 2.5 seconds is generally accepted as the reaction time for driver response to a single stimulus. It is deemed unlikely that drivers will be required to react to multiple stimuli in the residential or collector street environment and, hence, this value is adopted for the purposes of this Manual.

3.3.6 The Road Surface

The primary aspect of the road surface to be considered in geometric design is the skid resistance or the friction between the vehicle tyres and the road surface. This affects both the stopping as well as the turning capabilities of vehicles and, hence, the stopping distance required is as given in *Chapter 7 - Alignment*.

3.3.7 Design Life

The design life of residential streets and collectors is determined by the pavement design because the geometry would not easily change unless major redevelopment takes place. Should redevelopment take place, the functional classification has to be revisited, and the geometry adjusted to suit any changes.

3.3.8 Miscellaneous Design Aspects

Apart from the geometric design, other aspects that should be considered include:

- Designing requirements for vulnerable road users in mind. Principally, such users are accommodated by appropriate sidewalk design, including suitable kerb line breaks and the selection of appropriate street and sidewalk surfacing.
- Environmental requirements, particularly in respect of drainage.
- Choice of surfacing. For intersections, sidewalks and cycle lanes, concrete paving blocks and/or cobblestones may be the preferred option, either for improved skid resistance or aesthetic reasons. These surfacings would also create more employment during the construction process than the use of a bituminous surfacing.
- Landscaping to create a pleasing environment.

3.4 Implementation

3.4.1 Need for a Strategic Approach

The implementation of integrated design solutions, whether for new developments or existing developments through appropriate retrofitting and upgrading, requires a strategic approach where design professionals work collaboratively with urban planners and the affected communities.

Upgrading or retrofitting of existing urban areas is particularly challenging as the existing resident population will be inconvenienced to some degree. Effective public participation will be required during the planning and design phases and must be maintained for the duration of the construction work.

3.4.2 Choice of Construction Method and Phasing

The choice of construction method has very little influence on the geometric design of streets. However, it should be noted that urban development projects, be they new developments or upgrading and retrofitting projects, offer excellent opportunities for labour-based construction since workers are normally available in sufficient numbers within the communities. With the required training and good management, virtually all components of an urban street can be constructed by labour supported by appropriate plant and equipment without any relaxation of standards.

Phased construction, i.e. constructing lower layers of the street pavement structure and allowing its use as running surface for all developmental traffic until work on house building has been completed, saves not only possible overstressing of the upper pavement layers, but also damage to kerbing and sidewalks.

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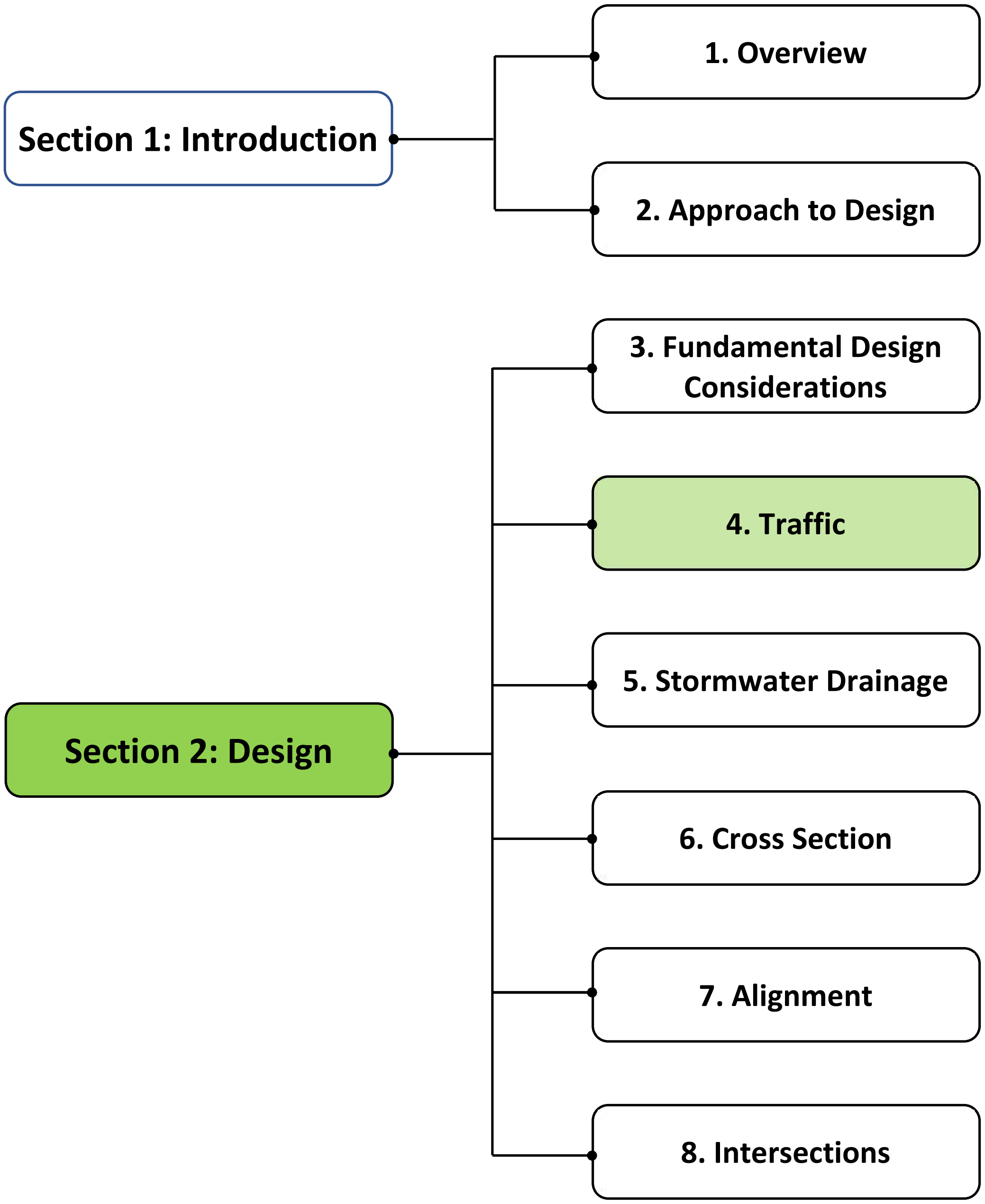

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4.1 Introduction

4.1.1 Background

Traffic volume and composition normally have a direct impact on the dimensional aspects of a road or street being designed, influencing mainly the number and width of lanes to be provided. In some cases, traffic volume and composition may also influence the road alignment. For instance, traffic with a high proportion of heavy vehicles would require the selection of easier grades in rolling terrain instead of following the shortest route with commensurate steeper gradients. Traffic numbers are also essential information for the design of intersections. Volumes of both through and turning traffic have to be known to determine the need to provide auxiliary and turning lanes.

In the case of low volume streets, traffic volume and composition, by the very nature of the situation, will play but a modest role in the design, except in so far as Class 4 collector streets are concerned, where traffic information may be needed for intersection design with higher-order routes. Hence, methods of determining design traffic volumes are incorporated in this Manual. The design of such intersections themselves is to be undertaken in terms of the design manual for high volume roads.

4.1.2 Purpose and Scope

The purpose of this chapter is to outline the procedures required for determining the future design year peak hour traffic as a basis for the geometric design.

In scope, this chapter:

- Introduces the concepts of design hour and design hour traffic.
- Deals with traffic surveys of existing facilities to determine design hour traffic volumes.
- Discusses traffic or transportation modelling as a means of determining design volumes for major urban developments or redevelopments. This information is provided as background knowledge should the geometric designer become involved in such work and finds the need to establish a movement master plan first, before starting on the lower-order street design.
- Covers traffic impact assessments for the reasons given above. Manuals dealing with the subject matter are included in the Bibliography.

4.2 Design Hour and Design Hour Traffic

As in the case of design speed, the design hour is also an indicator of conditions being designed for and is not an hour, as such. These conditions include:

- Traffic volume in equivalent vehicles per hour.
- Traffic composition, that is the proportion of various classes of traffic such as cars, buses, trucks, etc., in order to determine the equivalent volume.
- Directional split, which in urban peak hours could be as high as 80:20, with the afternoon peak often mirroring the morning one.

Traffic volumes are normally expressed in terms of average daily traffic (ADT) or annual average daily traffic (AADT) if counted for a full calendar year or converted to average full-year traffic. As weekends and holidays are excluded, ADT is greater than AADT. ADT should be used in preference to AADT in an urban area.

In urban conditions, the average highest peak hour count is used. Peak periods on different routes may have different peak characteristics. The peak period may also be longer or shorter than an hour and can contain short periods with very intense flows. The 15-minute period with the highest flow is often used for intersection design but may result in over-design if it is an isolated occurrence.

4.3 Obtaining Traffic Information

4.3.1 Traffic Counts

A classified traffic count is an important source of data for the geometric design of roads and streets. On vehicle-only roads, permanent and regular intermittent counts by automatic counters supported by manual counts are features of road traffic management. In the urban context, the focus is on intersections, and traffic data on all the legs of an intersection is required. As such, it is not feasible nor necessary to undertake long term counts. Urban traffic patterns are also fairly stable and reliable information can be obtained from short term counts.

Procedures

Intersection counts are normally done manually, with or without the assistance of hand-held counting devices, as illustrated in Figure 4-1. Automatic counters are sometimes employed at very busy intersections for short periods of time. In low volume situations, the count can be done by a single person, noting the different movements by the various vehicle classes on pre-printed forms, per hour or quarter-hour. Denser traffic will require a person counting for each leg of the intersection. Personnel doing traffic counts must be equipped with personal safety wear and take all due precautions to ensure their safety.

Figure 4-1: Manual counting with and without hand-held counters

Urban traffic remains fairly constant over the seasons but is affected by holiday periods and also weekends.

Thus, the timing, frequency and duration of traffic surveys should be given very careful consideration in terms of striking a balance between cost and accuracy. Generally, it is not advisable to count on Mondays or Fridays or days before or after public holidays. Counts should not be taken in school holiday periods, nor over the Christmas/New Year period. Pre-observation of traffic patterns should be undertaken to ensure that both the morning as well as the afternoon peak periods are covered. It could be necessary to start counts as early as 04:00 in the morning and to continue until about 22:00 in the evening, depending on the findings of a reconnaissance survey done beforehand. Peak period counts for intersection design purposes should be done recording data in 15-minute intervals. A single midweek day count would normally suffice for most intersections, with two- or three-day counts reserved for very busy ones. Research has found that urban traffic patterns are very stable, and thus, there is little need for extensive counting. Figure 4-2 and Figure 4-3 illustrate the counting operation.

When information on pedestrians and/or cyclists is also required, a separate count should be held and not combined with vehicle counts.

Axle load surveys are not necessary for geometric design. Modelling and origin-destination surveys are generally carried out for planning purposes.

Figure 4-2: Counting in progress

Figure 4-3: Roadside O-D survey

Vehicle classifications and equivalencies

Table 4-1 shows the vehicle classification system recommended for compiling the results of the traffic surveys undertaken for geometric design purposes, as well as the equivalency factors involved for geometric design.

It will be noted that the classification is fairly straight forward, distinguishing mainly between heavy and light vehicles. Heavy vehicles are taken as equivalent to 3 light ones. Motorcycles are classed as 0.5 of a light vehicle (car).

Cyclists are normally not considered in determining lane capacity. Where policy, traffic studies or counts indicate a need to accommodate cyclists, separate cycle lanes are to be provided. However, where cyclists constitute more than>10 % of the traffic mix, it is recommended that a car equivalency factor (CEF) of 0.1 is ascribed to them to account in some way for their influence on intersection capacity.

Animal-drawn vehicles are seldom found in urban areas and hence need not be considered. Should there be a significant number (>5 %), they should be treated as a heavy vehicle with a CEF of 3 owing to their slow speed.

Vexing questions concern mopeds, scooters, motor-assisted cycles and the like that do not fit in the category of bicycles or motorcycles. Until research points otherwise, a CEF of 0.25 is ascribed to them.

Equally, vexing is the CEF for tricycles, human-drawn conveyances and the like, and research is required in this regard. In the interim, should the numbers be significant (>5 %), a CEF of the order of between 0.1 and 0.25 could be used at the discretion of the design engineer.

Table 4-1: Vehicle classification system for urban geometric design

Type	Vehicle Type	Description	Car Equivalency Factor (CEF)
Car	Passenger car, Minibus (<16 seats); LDV (Pick-up)	2 axles	1
Heavy vehicles	Small bus 16 to 25 seats; Large bus (more than 25 seats); Light goods vehicle, up to 3 ton; Heavy goods vehicle, more than 3 ton; Tipper trucks, Multi-axle trucks.	2 or 3 or more axles	3
Motorcycles		> 250 cc	0.5
Small motor-cycles, scooters, etc.		250 cc and less	0.25
Bicycles		< 10 % > 10 %	N/A 0.1
Animal carts		< 5 % > 5 %	N/A 3

Pedestrians

Pedestrians are dealt with separately and hence not ascribed a CEF. Information on pedestrians should be gathered in separate surveys should such information be required for safety and pedestrian facility capacity purposes.

4.3.2 Modelling

Transportation modelling is a process that represents the movement needs that are generated by development in an urban area and provides data for the drafting of transport plans and transport infrastructure development programmes. It is a powerful tool and considered indispensable for any large-scale development initiative.

In the first phase of modelling, land use data is collected and the trip making characteristics determined. In the second phase, technical analysis is undertaken in what is known as the four-step process. Computer-based programs have been developed to assist in this process, ranging from models specifically developed for modelling large networks, through models aimed at local networks or individual routes and their intersections, to simulation models for studying local intersections and making visual presentations of the findings. The four steps in the process are:

- Trip generation
- Trip distribution
- Modal choice
- Route assignment

The main outcomes of the analysis are traffic flows and speeds on each link of the modelled network of all the modes of transport envisaged on the network, including walking, cycling, private car, public transport or rail.

Trip generation

Trips generated are person trips and are separated into categories in terms of their origin and purpose, viz. home-to-work or home-to-school. All trips also have a destination and can have a length and route ascribed to them. The home-to-work trip normally predominates, takes place in the peak hours and has a longer distance and travel time than the home-to-school trip. Trip generation is known to differ between socio-economic groups and factors could differ for different areas.

Data on trip making is acquired by dividing the study area into traffic zones, identifying the land uses and sizes, undertaking household surveys and gleaning information from census data. Roadside origin-destination surveys are also used. The traffic zones should be chosen so as to contain homogeneous land-use types and take natural boundaries such as rivers and highways into account.

Trip attraction

Trip attractors are partly identified from surveys, but mainly from the size and nature of the development. Typical trip attractors are places of work, shopping centres, educational facilities, etc.

Matching generation and attraction

As every trip has an origin and a destination, it follows that the sum of trips attracted to and generated by the various traffic zones should match. Invariably, this is not the case and leads to mathematical balancing to come to as close a match as possible. Fortunately, an excessive effort is not required as the degree of accuracy required is modest. Adding a passing lane to an intersection, for instance, will provide an additional capacity of 600 vehicles per hour.

Modal split

Modal split involves assigning the person trips to travelling modes, for example, walking, cycling, private car, bus, minibus etc. on the basis of the survey information, thereby creating vehicle trips. In the process, due cognisance is taken of normal average occupancy rates of the vehicles involved.

Route assignment

Route assignment is the process whereby the different vehicle trips are assigned to the road links in the road network. Various assignment techniques have been used in the past, e.g. “All or Nothing”, but with the advent of powerful computers, equilibrium assignment has become the norm. This implies that all vehicle trips follow the most cost-effective route, not necessarily the shortest as the cost of congestion delays on shorter links exceeds the cost of the extra distance travelled on alternative links.

Model calibration

Once the route of the base year traffic on the base year (actual) road network has been assigned, the model is checked against actual traffic counts and adjusted as necessary in a reiterative process. On larger models, this calibration activity is undertaken over screen lines as it is impractical to do so over individual routes.

Model use

The model is now ready for use and modelling can be undertaken of future land use and network scenarios. The future land use projections are required in order to forecast the number of trips in the future year, which are then assigned to the existing and any future network using the constructed model, to establish capacity restraints and the effect of envisaged new road links in relieving expected congestion.

4.3.3 Traffic Impact Assessments

Overview

Traffic impact assessments (TIAs) are, in essence, mini transportation studies, looking at the effect(s) of envisaged new developments on the road network. A TIA sets out to:

- Project the changes to traffic flow resulting from the development.
- Establish which network improvements are required to accommodate the changes in flow.
- Evaluate the number and location of access points to the development and make recommendations as to their design.
- Provide a basis to determine a commercial developer's responsibilities for specific network improvements required as a result of the development.

A TIA does not normally require the sophisticated software needed for modelling studies and is usually reliant on hand calculations. The assessment should include an analysis of:

- Capacity.
- Intersection improvements within a radius of 1.2 km to 1.5 km.
- Need for street lighting and intersection signalisation.
- Pedestrian movements and numbers to ensure road safety.

Estimation of trip generation

Trip generation can be estimated by:

- Modelling as discussed above (seldom required for TIAs)
- Use of trip generation tables such as those published by the Institute of Transportation Engineers (ITE), or in TMH 17.
- Basic analysis involving:
    - Estimating the number of persons involved.
    - Their departure and arrival times at the development in case of residential developments or arrival and departure times in case of non-residential development.
    - Modal split.
    - Vehicle occupancy rates.

In considering trips attracted by commercial development, allowance has to be made for trips calling in at the development whilst on a primary trip such as work-home, in this case, a non-primary trip as far as the development is concerned. In assessing access to the development, all trips have to be allowed for, but in respect of network implications, only those trips that qualify as primary trips to the development should be considered.

Threshold level for TIAs

Not all new developments require TIAs, as the additional traffic generated may be minimal. Normally the threshold level for requiring a TIA is set at 50 vehicles per hour. Any development generating more than 150 vehicles per hour should always be subject to a TIA, whilst the state of the actual traffic situation on the street(s) affected should guide the need for a TIA where the traffic generated lies in between.

4.4 Traffic Projections

4.4.1 Approach

Traffic for geometric design has to be projected to the design year chosen. In modelling, the land use is normally projected and the four-step process repeated for the new land use and economic situation. In other instances, traffic data has to be escalated exponentially on the basis of growth expectations. However, there is no need to project the different classes of vehicles separately. The current or historic number of equivalent vehicles can simply be escalated together, from the base year to the target year. To arrive at the number of equivalent vehicles, the various numbers in the different vehicle classes are multiplied by the appropriate equivalency factor and added to the number of light vehicles (passenger cars).

4.4.2 Selection of Target Year

As indicated in the introduction, there is little need for traffic numbers in the design of residential streets (Class 5) and residential collectors (Class 4) and hence no need to project such numbers. However, should higher-order roads be involved during the design of low volume urban streets, for instance in the design of an intersection with the higher-order road, guidance should be sought from the controlling authority of such road about the target design year for traffic using the intersection. Generally, using a target year 10 to 15 years into the future for such designs should suffice.

4.4.3 Estimating Traffic Growth

Traffic growth is very sensitive to economic conditions and prone to error. It may, therefore, be prudent, should the implementation costs be high, to assume low, medium and high traffic growth rates as an input to a traffic sensitivity analysis. Calculating future traffic numbers follows the rules of compound interest, with traffic growth expressed as a percentage. Thus, if the total basic traffic is denoted by $AADT_o$ and the general growth rate is i %, per annum, then the traffic in any subsequent n years into the future, is given by the equation:

$$AADT_n = AADT_o\,(1 + i/100)^n$$

There are several approaches for estimating the traffic growth percentage i. The two most common ones are:

- **Local historical precedent:** In this instance, growth trends are established from past traffic counts and projected into the future. Information on growth on other roads in the same area may also be a good guide as to what to expect on the project in question.

- **Government expectations of economic growth:** Growth in traffic is closely related to the economic growth of a country or region, hence expected economic growth rates obtained from government plans and growth forecasts could also be used in traffic projections. In this instance, it is preferable to use regional economic growth estimates, as there are often large regional differences.

4.4.4 Turning and Through Lane Traffic Distribution at Intersections

Unless there are clear indications of new developments that may lead to changes in traffic patterns, it is reasonable to assume that future turning traffic at intersections will replicate current trends. Projected through traffic at intersections can be taken as equally divided between the through lanes available.

4.4.5 Pedestrian activity at trading/commercial venues

To account for pedestrian movements and also trading activity levels, pedestrian counts need to be undertaken. This would require counting people movements over a cordon around the area of interest and would require a large staff complement.

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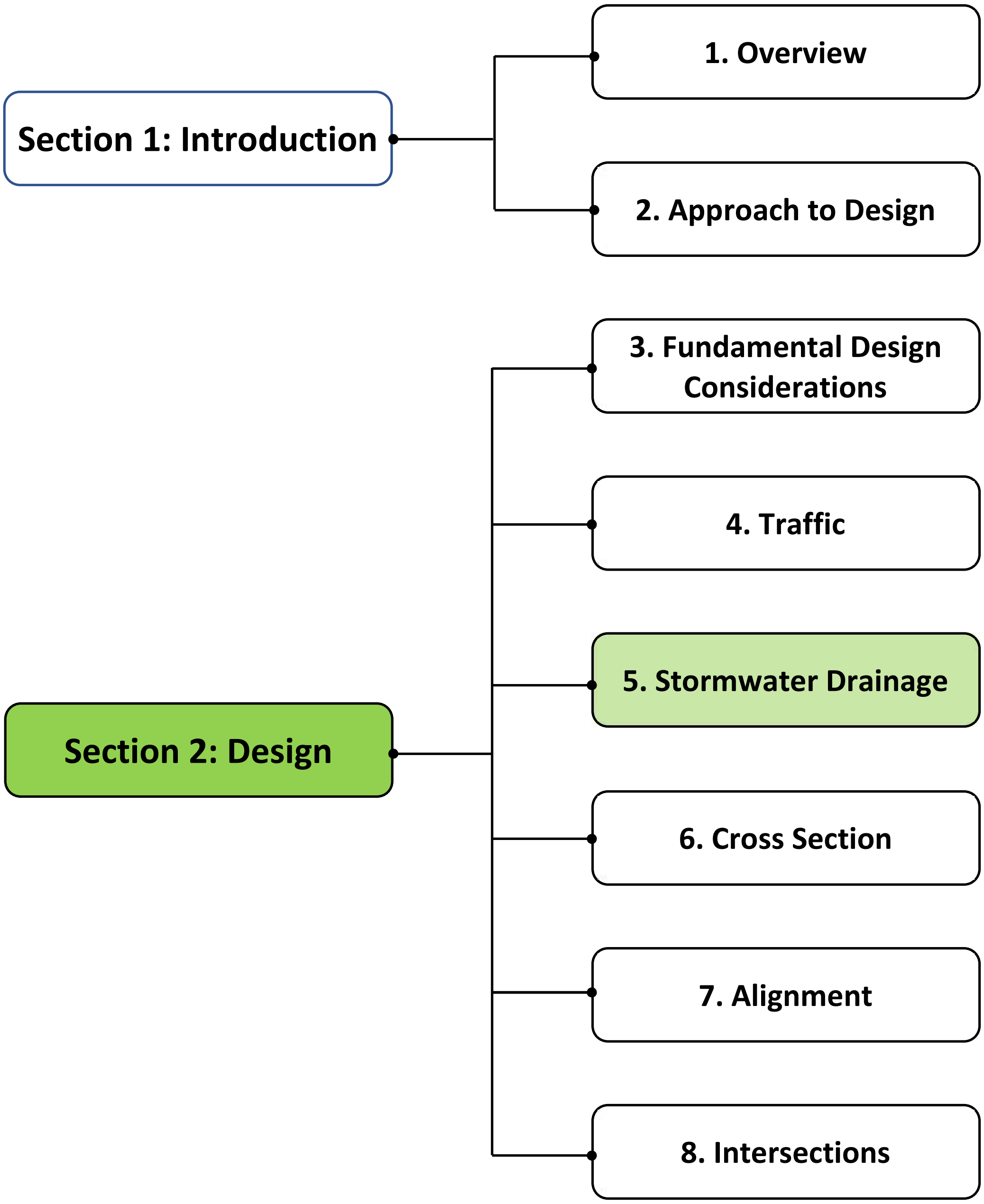

Chapter 5 – Stormwater Drainage

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5.1 Introduction

5.1.1 Background

Stormwater management is based on the need to protect the health, welfare and safety of residents as well as properties from flood damage, in a sustainable manner and with a responsibility to the natural environment. In this regard, streets play a major role.

Broadly speaking, urban stormwater drainage is by means of the street itself, with appropriate connections to an underground system of pipe culverts, or adjacent open drains, which in turn discharge into natural streams.

The design of a stormwater system involves the assessment of the characteristics of the catchment area, the selection of the design flood frequency, determination of the quantity of stormwater to be accommodated and the sizing and design of the drainage system required for its management, all within the ambit of legislation and the principles of sustainable development.

5.1.2 Purpose and Scope

The purpose of this chapter is to introduce urban hydrology and the hydraulic design of the drainage system, including the tools that are available for the drainage design.

The chapter addresses design flood frequencies as an input to the planning and design of urban stormwater systems and illustrates typical stormwater management structures.

The chapter is not intended to be a drainage manual but is primarily focused on providing the designer with an approach to urban stormwater drainage and the data that would be required for the design. Nevertheless, a worked example is provided to aid the users of the manual in coming to a better understanding of the various issues involved. Detailed information on urban drainage design may be found in self-standing guidelines and manuals such as those listed in the bibliography,

5.2 Design Flood Frequencies (Return Periods)

The determination of the design flood frequency concerns the acceptance of risk of damage by natural precipitation, from both severe but infrequent storms (termed major events) to frequent common storms (called minor events). In urban stormwater management, both events must be contended with, and a distinction is drawn between the accommodation of minor and major hydrologic events or storms.

Economics dictate that it is not possible to provide for major storms in the design of all road and street infrastructure. Yet, major storms can cause significant damage. To handle this dichotomy a dual approach is used. In the first instance, the drainage system is aimed at preventing damage and nuisance from frequent storms by means of the minor system. The major system is supported by the minor system but will accommodate the higher runoff from less frequent storms while accepting some degree of inconvenience and nuisance.

The stormwater master planning will be predominantly concerned with the major system.

The following design flood frequencies are recommended:

- Major systems: 1:50 years for all master drainage planning for urban development;
- Major systems: 1:50 years for stream crossings;
- Major systems: 1:20 years for Class 4 streets (collectors) also acting as bus routes;
- Minor systems: 1:2 years for Class 4 and Class 5 streets, in residential developments.

As discussed in Volume 1: *Chapter 3 – Physical Environment,* in the long term, the changes in rainfall due to climate change are predicted to be marginal. Thus, the above flood frequencies would not need to be changed.

5.3 Planning Aspects

5.3.1 Legal Aspects

Stormwater drainage is largely governed by legislation following common law rules but slightly modified to give certain rights to public authorities. Of particular interest to the drainage designer is the natural-flow rule and the reasonable-use rule.

The natural-flow rule places an onus on lower land to accept stormwater from higher ground flowing along its natural course. The implication of this rule is that stormwater may not be dammed by road and street construction to the detriment of higher-lying property.

The reasonable-use rule permits property owners (and authorities) to make reasonable use of their land even though it may alter the flow of surface water, e.g. affect stormwater drainage through the street system, but not to the detriment of others without incurring liability. As the intensity and volume of runoff from developed land invariably exceeds the runoff prior to development, this, in turn, has led to the need to manage stormwater from developed land and release it in keeping with natural flow regimes from before development, except if downstream conditions would allow otherwise.

5.3.2 Master Drainage Plan

The objective of the drainage master plan is sustainable development. In order to meet the requirements of the reasonable-use rule, and in many cases also environmental requirements, it behoves the party responsible for the development, whether government or private, to draw up a drainage master plan identifying the following:

- The catchment area.
- Routes for stormwater flow.
- Volume of pre-development flows affected by the development.
- Measures to ensure that post-development discharges do not cause damage to the environment or any property.
- The master plan should also determine the 1:50-year flood lines.

No residential development should be undertaken below the 1:50-year flood lines and the flood lines should be shown on township development plans for general information.

The drainage master plan shall consider all relevant topographical, geological, biophysical and social aspects and adhere to all relevant Malawian legislation. No drainage master planning should be done without a site visit by the personnel involved to ascertain conditions prevailing, particularly in respect of natural watercourses.

The drainage master plan informs the urban framework referred to earlier and guides the town planning and the design of the detailed street drainage system. In the town planning, suitable sites must be identified for detention or retention purposes, whether ponds in parks, sports fields or private land and be so identified in title deeds. The drainage master plan must also identify areas that are too flat or too steep for development, if such areas would occur in the overall area.

If development has taken place or cannot be avoided, it is imperative to establish the probable level of major storm inundation and ensure that all floor levels are raised at least 150 mm to 200 mm above that level.

5.3.3 Detention and Retention

Detention and retention measures are intended to attenuate runoff, specifically the peak flows. Generally, these measures comprise strategically placed dams that will discharge retained flows at a rate not exceeding predevelopment flows, or alternatively, store the stormwater future use. Thus, the sizing of the dams requires estimation of the outflow. Proprietary computer programs are available to assist in this task. Design of retention dams being a dam must also meet all safety and related legal requirements.

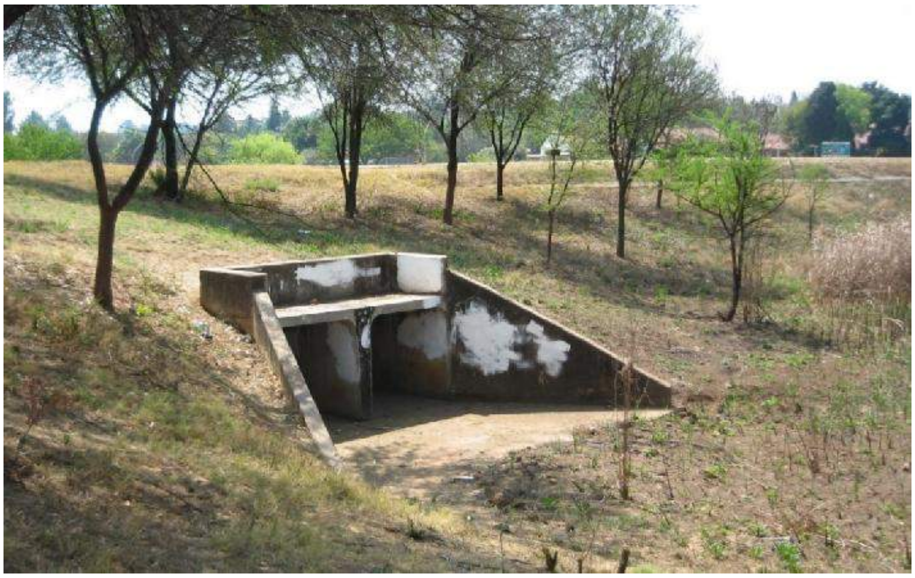


Figure 5-1: Attenuation dam and inlet to outlet structure

Outlets to detention facilities often comprise a short pipe culvert section. The volume of flow through culverts is dealt with in a number of readily available nomographs and textbooks. Outlets must be designed with care, not to create erosion problems and energy dissipaters must be provided. This can take the form of widening the outlet channel, increasing the roughness of the channel, constructing small protrusions or providing rip rap. Also, bear in mind that the structure must be aesthetically pleasing. Whatever forms the outlet structures take, it must be provided with a cut-off footwall to prevent scour of material from below the structure, causing it to collapse.

All dam structures, whether for detention or retention, must have spillways. The design of the spillway forms part of the design of the dam wall.

5.4 Design Aspects

5.4.1 Calculation of Runoff

For street drainage design, the so-called rational method is widely used to calculate runoff from areas of 15 km² and smaller. It can also be used for larger areas, but then with circumspection. The formula for runoff is:

$$Q = C\, i\, A / 360$$

where Q = Peak runoff rate in m^3/s due to rainfall of intensity i over a catchment area A;

C = catchment runoff coefficient, a dimensionless number, less than 1;

i = Rainfall intensity(mm/h)

A = Area (ha) of the land draining to the point where the peak runoff rate is required.

The three aspects C, *i* and A are discussed in more detail below.

The catchment runoff coefficient

The runoff coefficient is the fraction of the rainfall that becomes surface runoff and thus has a value of between 0 and 1. It is influenced by the slope of the land, the soil type, the degree and type of vegetation and the extent to which the land has been covered by development. In the last-mentioned regard, the size of stands plays a significant role. Runoff coefficients for rural/predevelopment conditions appear in Table 5-1, while coefficients for urban areas appear in Table 5-3.

Table 5-1: Runoff coefficient for rural/predevelopment areas (600-900 mm annual rainfall)

Cs Slope		Cp Soils/Permeability		Cv Vegetation	
Flat (Less than 1 %)	0.03	Sandy to gravelly	0.04	Dense	0.04
Undulating (1 % -5%)	0.08	Sandy clays	0.08	Farmland	0.11
Hilly (5 % - 8 %)	0.16	Clay and loam	0.16	Grassland	0.21
Steep (More than 8 %)	0.26	Shallow rock	0.26	No vegetation	0.28
Runoff coefficient Ct = Cs + Cp + Cv					

The return period also has an important effect on the runoff percentage, as the degree of ground saturation tends to vary with it. Hence it is necessary to adjust the Ct coefficient by multiplying with a reduction factor Ft, obtained from Table 5-2.

Table 5-2: Reduction factors (Ft) for Ct

Return period (years)	2	5	10	20	50	100
Ft for steep and impermeable catchments	0.75	O.80	0.85	0.90	0.95	1.00
Ft for flat and permeable catchments	0.50	0.55	0.60	0.67	0.83	1.00

The reduction factors should be adjusted at the discretion of the designer to suit the topography and permeability of the area under design.

Because of the fairly large coverages found in urban areas, it is normally not necessary to reduce the value of Cu in terms of the return period. However, adjustment can be made if considered necessary on the terms indicated in Table 5-2.

Where the catchment area comprises more than one type of land use, a weighted Cu value should be used.

Table 5-3: Runoff coefficient for urban areas

Land use	Slope	Soil/Permeability	Residential Stand Sizes (m²)	Cu
Residential	Flat	Sandy	10 000	0.30
			2 000	0.50
			500	0.75
		Heavy	10 000	0.35
			2 000	0.60
			500	0.80
	Steep	Sandy/gravelly	10 000	0.35
			2 000	0.55
			500	0.80
		Heavy	10 000	0.40
			2 000	0.65
			500	0.85
Recreational	Flat	Sandy	Lawns, sports fields, parks	0.10
		Heavy	Lawns, sports fields, parks	0.15
	Steep	Sandy, gravelly	Parks	0.20
		Heavy	Parks	0.30
Industry	Flat	Sandy or heavy	Light industry	0.65
			Heavy industry	0.80
Business	Flat or steep	Sandy or heavy	Central Business District	0.90
			Suburban	O.70
Streets	Flat or steep	Sandy or heavy	General	0.90

The rainfall intensity (i)

The rainfall intensity (*i*) is a function of the return period and the duration of the design rainstorm.

With regard to the return period, the intensity of a design storm varies with the return period, that is, increases as the return period becomes longer.

Regarding the duration of design rainstorm, this is set to equal the time it would require for the whole catchment area to contribute to the runoff at the point of measurement. In other words, the time it takes for water from the furthest point in the catchment area to reach the point where the peak runoff rate is to be determined. This is termed the time of concentration (Tc). Tc is discussed in more detail below.

The intensity of rainfall (*i*) is obtained from Intensity-Duration-Frequency charts provided by the Meteorological Department. Such charts vary across the country and are also not always available for the site in question. In such cases, interpolated values derived from charts for areas closest to the design area may be used, amended based on judgement and discussions with local residents.

It may also be noted that it is difficult to determine the rainfall intensity of storms of less than 15 minutes. In road and street drainage, the volume of runoff resulting from a storm of less than 15 minutes is normally not large and much of this volume gets absorbed in filling of the watercourses. Hence, the intensity assumes a minimum storm duration of 15 minutes.

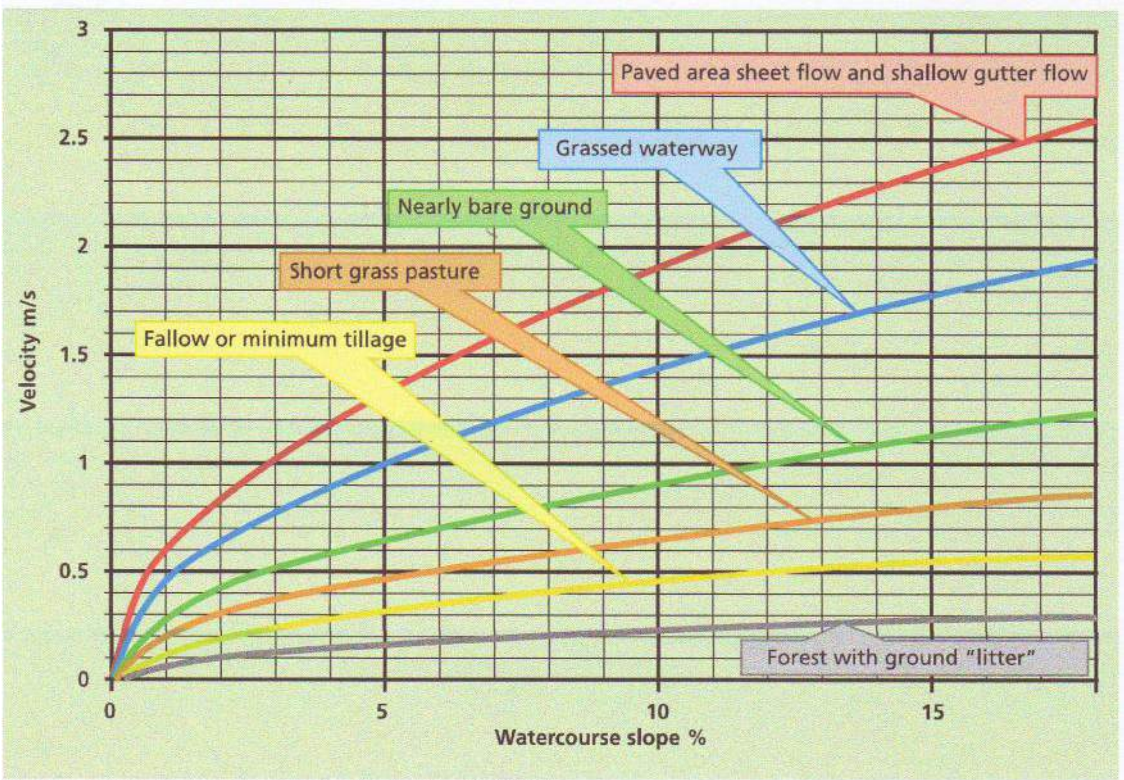
The time of concentration (Tc)

The rainfall intensity (*i*), is a function of the duration of a storm and the duration of the storm is arrived at based on the time of concentration (Tc). The time of concentration is the length of time it takes for a drop of water to move from the point of the catchment area furthest away from the inlet or culvert being designed. This means that the entire catchment area is contributing to the flood. Setting the time of concentration and the duration of the storm equal will give the maximum flow rate.

Time of concentration, Tc (in seconds), is calculated by dividing the distance from the furthest extremity of the catchment area (m) by the velocity of the flow (m/s).

Tc = Length of longest flow path (m)/Velocity of flow (m/s).

The velocity of flow is influenced by the slope of the catchment and the vegetation and can be estimated from graphs such as Figure 5-2.



Source. FHWA. Hydraulic Engineering Circular No. 19. (1984).

Figure 5-2: Velocity of flow for various surfaces

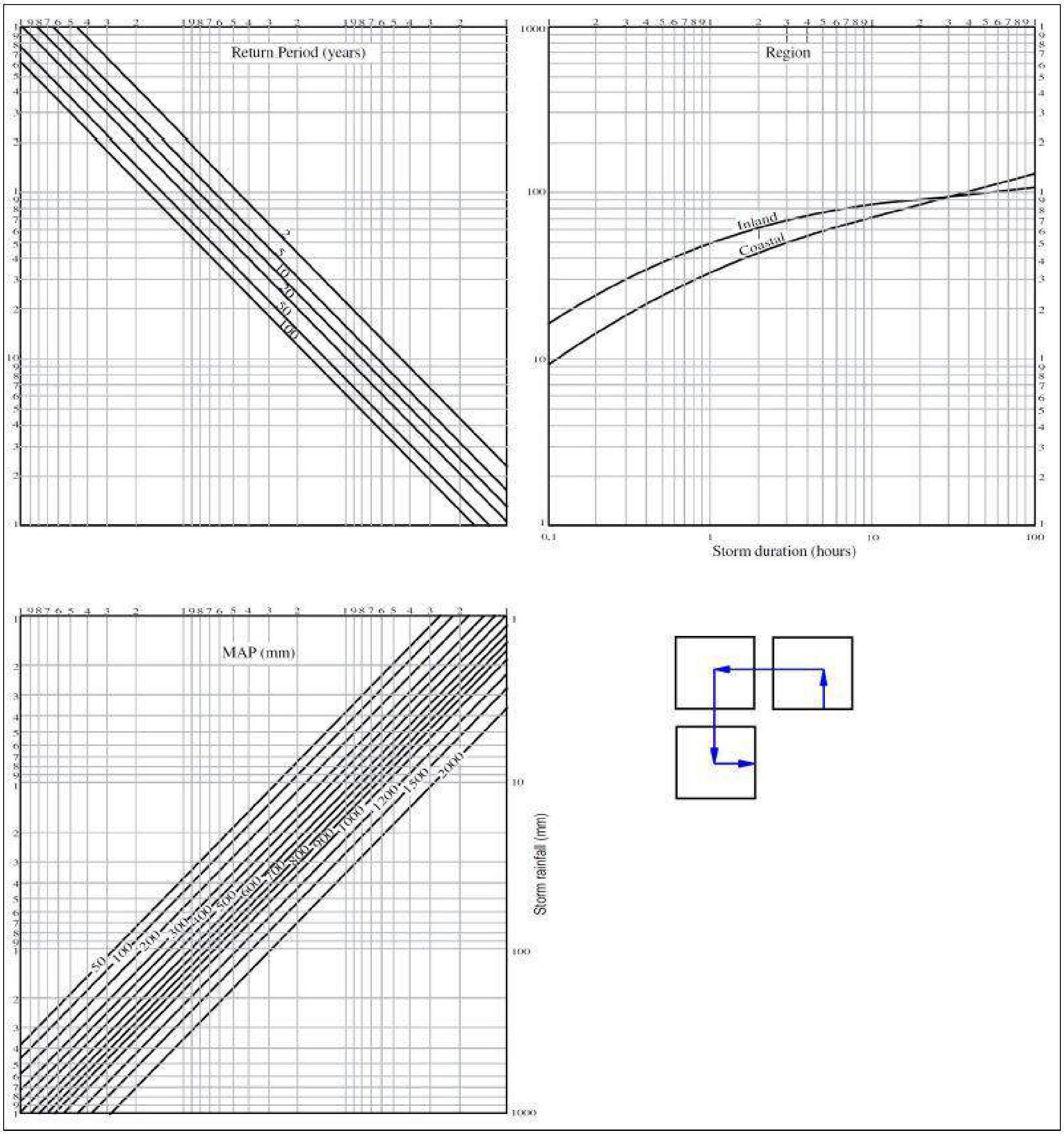
In urban areas, the effect of flow in streets or street-side channels and in pipe culverts must also be considered in determining Tc. Generally, taking obstacles into account, overland flow will be at right angles to contours down to the nearest street and then along the street to the catch pit or structure involved. Thus, Tc will be the sum of the times of concentration for overland flow and for side-channel flow.

Where new intake points occur along a stormwater line, whether such new intake points are kerb inlets or other pipes joining the system, the time of concentration at such points are different. Thus, thus peak flows from different areas in the catchment will not pass through points simultaneously. The design flow at such a point is therefore determined by summing the areas contributing to flow at the point in question and then using the longest time of concentration from the various areas to calculate the intensity and hence the total runoff. However, as mentioned, for times of concentration of less than 15 minutes, it is recommended that Tc be set at a minimum of 15 minutes for street drainage design purposes.

With Tc determined, the next step is to determine the associated point rainfall with the help of Depth-Duration-Frequency diagrams such as in Figure 5-3. The point rainfall is then converted to intensity by dividing the point rainfall by the time of concentration Tc with Tc expressed as a decimal fraction of an hour, i.e. for a Tc of 15 minutes use 0.25 h.

For inland conditions; a 2-year return period and mean annual rainfall of 600 mm,

Figure 5-3 yields a point rainfall of 12 mm, which when divided by Tc (0.25) gives an intensity of 48 mm per hour.



Source: The South African National Roads Agency SOC Limited Drainage Manual

Figure 5-3: Depth – Duration – Frequency diagram

5.4.2 Flow in Streets

A dichotomy

When considering flow in streets, two opposing requirements must be considered. In the first instance, from an economic point of view, the street serves as the first element of the drainage system and should accommodate as much flow as possible to save on pipe culverts and drains. On the other hand, water accumulating on the road creates safety risks with spray from passing vehicles obscuring drivers' vision, whilst water on the road can lead to skidding when braking. Crossing a stream of water flowing through an intersection can be very unnerving and dangerous. Splashing will also cause a massive nuisance to pedestrians, particularly at intersections. For these reasons, stormwater inlets are normally positioned on the upstream side of intersections. Aquaplaning is not normally a problem on low volume streets, as this phenomenon only becomes an issue at speeds higher than 80 km/h.

The approach adopted requires that during minor storm events, the two main functions of a street, namely serving movement and managing stormwater should not be in conflict. It is further accepted that during major storms, the movement function will be interrupted and that, within limits, the streets will act as stormwater channels.

Permissible encroachment on streets by stormwater runoff

The permissible encroachment of runoff on streets for minor and major storms is shown respectively in Table 5-4 and Table 5-5.

In practice, the designer should do the design for the minor storm and then check whether the drainage provided would be sufficient to accommodate the major storm, augmenting the design by providing such additional drainage capacity as may be required for the major storm.

Table 5-4: Permissible encroachment of the major flood on roads

Street Classification	Maximum encroachment
Class 4 streets also acting as bus routes	Flow should not exceed a depth of 150 mm at the crown

Table 5-5: Permissible encroachment of the minor flood on roads

Street Classification	Maximum encroachment
Class 4	No kerb overtopping. Flow spread must leave at least 30 % of width of roadway free of runoff
Class 5	No kerb overtopping. Depth of flow not to exceed 10 mm at crown/centre line

Meeting encroachment requirements

Inlets are normally positioned adjacent, upstream, of intersection bellmouths, to prevent water rushing across an intersection, as well as further upstream as may be required. The number and spacing of any additional inlets further upstream will be determined mainly by the encroachment requirements and speed of flow, but other factors such as the draining of vertical sag curves and local low spots would also play a role. Meeting the encroachment requirements can be eased by requiring a minimum longitudinal gradient of 0.67 % (1:150).

It is immaterial from a drainage point of view, whether the cross slope of streets with cross fall is with or against the slope of the land in view of the requirement of no overtopping of the kerbing. From an earthworks and economic point of view, and to ease vehicular access to properties, it is preferable for the cross fall to follow the natural slope.

Velocity of flow at the street edge

The maximum road gradient should be such that the velocity of flow in the street edge does not exceed 3 m/s. High velocity flows carry the risk of damaging the road surfacing and bypassing inlets. Should the velocity exceed this value, inlet spacing should be increased or other measures incorporated in the design to dissipate energy.

The velocity of flow can be estimated with the help of Figure 5-2 and by using the Manning formula:

$$V = (R^{0.67} \times S^{0.5})/n.$$

Where: V = cross sectional average flow speed in m/s;

n = Manning coefficient of roughness (of the order of 0.017 for kerbside flow);

R = hydraulic radius (m) computed by dividing the channel cross section by the length of the wetted perimeter;

S = slope of the channel expressed as a number, i.e. 0.03 for 3 %;

The volume of flow follows from:

$$Q = V \times A.$$

Where: Q = volume in m^3/s;

A = cross section of flow channel in m^2.

Unsurfaced roads

It is particularly important in the case of gravelled or unsurfaced roads that the volume and velocity of flow do not lead to scouring. This is an instance where the geometric and pavement design engineers must work closely together and adapt the drainage design to suit the road-building materials available. Runoff from unsurfaced roads will contain grit and grit settling down in culverts can eventually block the system. Such blockages are difficult to clear, rendering the system ineffective.

5.4.3 Components of the Urban Drainage System

Stormwater is drained by kerbs and channels, discharging into inlets, connected to underground pipe culverts and ultimately discharging into natural streams or other flow paths. Alternatively, stormwater can also be drained into a system of open drains fulfilling the function of underground pipe culverts.

Kerb inlets

The predominant inlet type is the kerb inlet, also known as a side or lateral inlet. Many different typical designs of kerb inlets are in use by municipalities or could be drawn up from first principles. Aspects to consider are:

- Hydraulic performance
- Accessibility for cleaning
- Safety for pedestrians and vehicle users
- Cost

The capacity of kerb inlets is substantially increased by the inclusion of a transition section and opening the side of the inlet on the upstream side.

A further logistical consideration regarding kerb inlets concerns a limit on their length. The maximum length of a kerb inlet should not exceed half the street front dimension of the stand opposite it.

For a normal 2.0 % to 3.0 % camber/cross fall, the length of kerb inlets can be determined by the formula:

$$L = 2.0797 \times \sqrt{(Q/Cf)} / 1.25.$$

Where L = length of kerb inlet in metres;

Q = runoff in m^3/s;

Cf is a factor equal to $= 0.012362 - 0.001498 \times G + 0.00006 \times G^2$;

G = gradient of street expressed as a percentage.

The kerb inlet should be designed with an open upstream face in addition to the normal road edge opening and should be preceded by an inlet taper of 2 m in length, as shown in Figure 5-4.

Kerb inlets are to have the same gradient as the street and must be positioned upstream of intersections, such that the downstream side of the inlet coincides with the start of the intersection bell mouth. Irrespective of the volume of flow involved, kerb inlets must be positioned at all low points in streets. The channel can be depressed to facilitate ingress of water into the inlet, but the height of the inlet opening shall not permit access by a child.

Figure 5-4: Kerb inlet

Inlets could be sited directly over the main stormwater culvert or linked to the main culvert by short sections of the discharge pipe, connecting to the main culvert at a manhole.

Grid inlets

Grid inlets are drop-down inlets positioned in the flow channel, with street users protected by an iron grid over the opening. They are generally easier to construct but suffer from inefficiencies during high velocity flows and particularly when partly or fully clogged, and they do clog easily.

For subcritical flow the capacity of grid inlets is given by the formula:

$$Q = C \times F \times A\sqrt{2 \times g \times H} \text{ (m}^3\text{/s)}$$

where:

C = inlet coefficient (0.6 for sharp and 0.8 for rounded edges)

F = blockage factor (normally 0.5)

A = effective cross-sectional plan area of the opening (m^2)

H = Total energy head above grid (m)

Grid inlets should not be considered where supercritical flow conditions occur, i.e. Froude numbers above 1. (See note on Froude numbers at end of the section.)

Manholes

In addition to positioning manholes at the intercepts of inlet discharge pipes with the main culvert, intermediate manholes should be spaced to facilitate cleaning. On culverts with a diameter of less than 900 mm, the spacing between manholes should be of the order of 80 m to 100 m. On larger diameter pipes, the spacing can increase to 120 m to 150 m. Manholes should also be provided at:

- Changes in direction of 15° or more
- Changes in the size of pipes
- All junctions between pipes
- Slope reductions.

Rendering, i.e. shaping of the floors of manholes to match the lower half cross sections of adjacent pipework in order to achieve laminar flow, is not required, but is preferred by some authorities.

Pipe culverts

Manufacturers' recommendations should be followed when ordering pipes for culverts. A distinction is normally drawn between pipes for culverts running under sidewalks and pipes for culverts running under or crossing the roadway.

From a maintenance perspective, the minimum pipe diameter to be considered is 600 mm for piped systems. In the case of open drain systems, the minimum diameter at street crossings is 900 mm.

Routing of pipe culverts through stands should only be allowed in exceptional circumstances.

Open drains

Open drains could be lined or unlined, depending on the nature of the in-situ soils and the neighbourhood they are passing through.

The decision between pipe culverts or open drains is one to be taken at the level of urban design, as the provision of open drains will generally require wider street reserves. In this decision, the value of the land of stands lost to wider streets, the cost of culverts at crossing streets, minor bridges to facilitate access to stands and other related aspects such as maintenance should be weighed against the additional costs of pipe culverts and their maintenance.

A common problem with open drains is blockage by waste. Aesthetically, open drains are also not pleasing, particularly if they are filled with garbage, which unfortunately often happens in urban areas and which blocks the system with the first rains.

Open drains can take the form of a large (wide) open roadside channel, as illustrated in *Chapter 6 – Cross Sections*, Figure 6-14, or a separate channel behind the sidewalk as illustrated in Figure 6-15. In the latter case, an unlined channel could be a first implementation phase of a pipe culvert system to be constructed later.

Froude numbers

In open channel flow a Froude number of 1, is termed "critical". Slower flow is recognised as subcritical and faster flow as supercritical. The Froude number (Fr) is found from the formula:

$$Fr^2 = Q^2 B/gA^3$$

where:

Q = flow rate (m^3/s)

A = cross-sectional area of the flow (m^2)

B = width of the water surface (m)

5.4.4 Cross Culverts and Pipe Culvert Drains

Where streets drain into parallel running open drains, cross culverts are required at every cross street encountered. The design of such culverts is akin to that of culverts crossing rural roads and, hence, is not dealt with herein. Reference can be made to the drainage manual listed in the biography as well as to the section on drainage in the Pavement Design volume, Volume 1, of this set of manuals.

With regard to pipe culvert drains, precast concrete pipe manufacturers have undertaken in-depth studies of the characteristics of their products and have developed design charts that can be used with confidence. Hence, the design of pipe culverts is also not dealt with herein.

5.4.5 Illustrations of Typical Drainage Structures

Drainage structures take various shapes, depending on the purpose and function of the structure. A few photographs follow below, together with some notes, illustrating various drainage functions other than the kerb inlets discussed earlier.

It may be noted that the side drain as illustrated in Figure 5-5 is appropriate to rural and vehicle only roads, but not suitable for mixed-used roads and streets, as being very pedestrian-unfriendly. However, with suitable adaptations, the principle of a stone-pitched side drain can be put to use in street design.

Figure 5-5: Undesirable drain design

Figure 5-6 shows a lined open drain adjacent to a higher-order mixed-use road. A pedestrian sidewalk has been created at the same level as the road. Pedestrians are protected against traffic and traffic from running into the drain, by the kerb-like protrusions, but there is no protection for pedestrians against falling into the drain. With stormwater from the road flowing unimpeded across the sidewalk, the sidewalk will be difficult to negotiate during rainy weather and virtually loses its function.

Figure 5-6: Lined open channel and sidewalk

Figure 5-7 shows a cycle pathway crossing of a local stream constructed with minimum disruption of the natural environment.

Figure 5-7: Cycle pathway crossing of local stream

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Appendix A: Worked Example

Objective

The worked example sets out to determine the length of a kerb inlet required to drain a residential street block and adjacent downstream street.

Scenario

The street has a cambered cross section. The site comprises sandy soils. The development is taking place at an inland situation with a mean annual precipitation (MAP) of 600 mm. Stand sizes are of the order of 500 m^2.

Considerations and situation assessment

Being a residential development the return period to be designed for is 1:2 years

Input parameters obtained from a topographical layout plan of the town area, shows a catchment area of 2 ha, determined by planimetry, or triangular mathematical computation and summation. This includes the half width of the street.

Inspection of the topographical map indicates that the longest flow path to the provisional position of the kerb inlet will comprise 50 m of sheet flow over the block and 100 m of channel flow along the v-drain formed by a semi mountable kerb and the road surface. No obstacles are envisaged along the flow path.

The difference in height between the start of the flow path and the point where it intersects the kerb line is 2.0 m. Hence, the slope over the ground section is 4 % (slope = 2.0 x 100/50). The slope along the street, determined in a similar manner is 3.0 %.

Computation

Time of concentration (Tc)

Inspecting Figure 5.2, the following velocities are determined for this situation:

- Sheet flow along the open ground for a slope of 4 % = 0.6 m/s (nearly bare ground)
- Channel flow along the v-drain or gutter for a slope of 3 % = 1.0 m/s (shallow gutter flow)
- Time of concentration, Tc, for this situation = 50 m/0.6 m/s + 100 m/1.0 m/s = 180 seconds or 3.0 minutes.

This is far shorter than the recommended minimum time of concentration to be used of 15 minutes, hence use a Tc of 15 minutes i.e. 0.25 hour.

Rainfall intensity (i)

With the help of Depth-Duration-Frequency diagrams such as illustrated in Figure 5-3 for point rainfall, determine the point rainfall, following the arrows as shown in the figure. In this instance the point rainfall (Pt) is 12 mm.

The rainfall intensity is then found by dividing the point rainfall by the time of concentration, i.e.

- Intensity (i) = Pt/Tc = 12/0.25 = 48 mm/h.

Runoff coefficient (C)

Visiting Table 5.3, bearing in mind stand sizes, sandy soils and slopes of the order of 4 %, indicating the site is relatively flat, the resultant C-value is found as 0.75.

Peak flow

The peak flow can now be found applying the basic formula Q = CiA/360 m^3/s:

Q = 0.75 x 48 x 2/360
= 0.2 m^3/s or 200 ℓ/s.

Kerb inlet length

Determining the kerb inlet length follows from using the formula given earlier in Section 5.4.3:

$$L = 2.0797 \times \sqrt{(Q/Cf)} / 1.25 \text{ m}$$

where L = length of kerb inlet in metres;

Q = runoff in m^3/s;

$Cf = 0.012362 - 0.001498 \times G + 0.00006 \times G^2$;

G = gradient of street expressed as a percentage.

Calculating Cf first, it is found as

$$Cf = 0.012362 - 0.001498 \times 3 + 0.00006 \times 3^2$$

$$Cf = 0.00841$$

Hence $L = 2.0797 \times \sqrt{(0.2/0.00841} / 1.25$

$L = 8.11$ m to which must be added the 2.0 m length of upstream transitional length.

This is evidently too large a structure and hence it should be considered to provide an intermediary inlet higher up the street, halving the flow to be accommodated and thus the length of the structure.

Checking depth of flow

Checking for depth of flow in the street is by a simple first approximation:

- Divide the volume of runoff (Q), by the velocity (v) obtained from Figure 5-1, to determine the cross-sectional area of flow (Ar)

  In this instance the flow area required (Ar) would be: $Q/v = 0.2/1.0 = 0.2 \text{ m}^2$

- Determined the flow depth using the particulars of the street geometry.

  A 6 m wide street with a 2 % camber will yield an available near side triangular area (Aa) between crown and kerb of approximately:

  $Aa = 3.0 \times 0.06 / 2 = 0.09 \text{ m}^2$

  This indicates that the street crown will be overtopped in this instance.

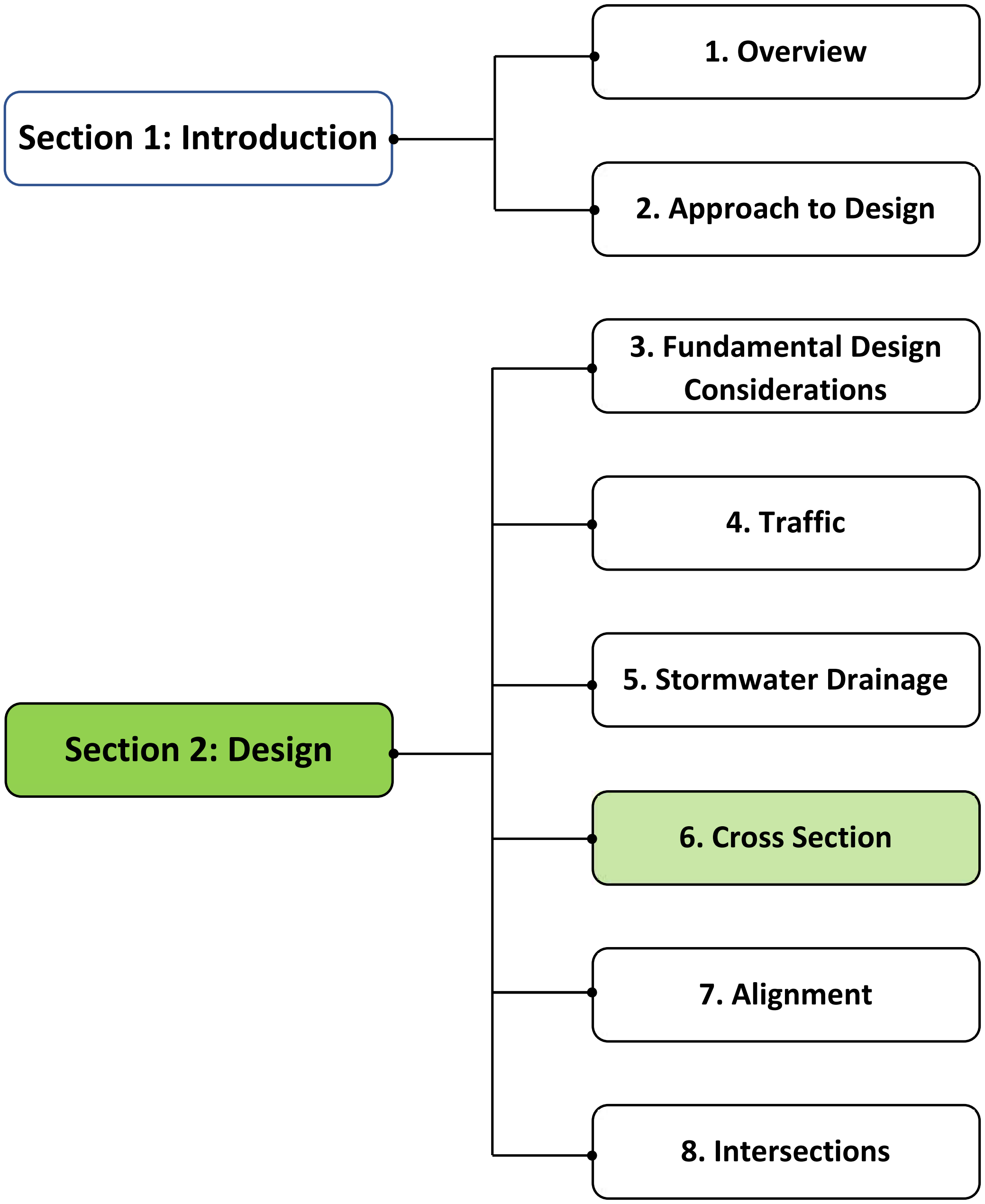
  The far side triangle yields a further 0.09 m^2 and the total area available is now 0.18 m^2, nearly meeting the required 0.2 m^2

- Further geometric calculation shows that this means the overtopping of the crown would be only by approximately 3 mm and that no overtopping of kerbing would take place.

Further refinement can be undertaken following the Manning equation given in Section 5.4.2, should there be a need.

In conclusion of this worked example, it must be emphasised that the sample calculation is aimed at assisting designers to understand the basic aspects of drainage design. The situation sketched is hypothetical and bears no relation to any actual design. This chapter, including the worked example, provides an approach to and information on the data that would be needed for street drainage design and does not purport to be a manual in drainage design. Appropriate manuals are available and should be consulted and used by the designer.

Low Volume Roads Manual
Part B – Geometric Design: Urban Roads



Chapter 6 – Cross Section

Contents

List of Figures

6.1 Introduction

6.1.1 Background

The multiple functions of a street find expression in the cross-sectional design. In the first instance, the cross section of a street should accommodate all the movement needs of all its users. These include the movement needs of the various classes of vehicles that can be expected on the street in the context of its functional classification, as well as the parking needs of these vehicles. It also includes the movement needs of pedestrians, those of cyclists as well as disabled and vulnerable people.

In addition to the above, there are the social needs of residents to meet informally. Streets also act as playgrounds for children where the stands are too small for this purpose. Vendors, abutting traders, light industrial activity and window shoppers also make use of street space.

The street cross section should also provide space for utility services, streetlights, drainage, roadside furniture and landscaping.

There is little calculation involved in the development or choice of the cross section and reliance is generally based on policy decisions supported by engineering judgement during the urban design and town planning aspects of the development planning and design. Careful consideration of functional classification and context-sensitive design in terms of the complete street principles will dictate the selection of the elements required in the cross section.

6.1.2 Purpose and Scope

The purpose of this chapter is to consider the diverging spectrum of needs mentioned above and to discuss and put forward proposals related to the various cross-sectional elements in order to ensure that these needs are met.

These elements include:

- Basic traffic lanes
- Bus bays
- Cycle lanes
- Parking
- Sidewalks and verges for the classes of streets in question
- Kerbing and channels
- Cut and fill slopes

Drainage remains an important consideration and receives particular attention.

The issue of utility services and their role in the street cross section is also covered, including street lighting as well as roadside amenities, details of which are provided in *Part C – Road Safety.*

This chapter concludes with a series of sketches of typical cross sections and some discussion on each.

6.2 Main Components of a Street

The two main components of a street are the visual elements and underground services. The visual elements comprise in main terms the travelled way, normally two lanes, one in each direction, with or without formal parking strips, and the verges, including the sidewalks, one on each side of the street. Figure 6-1 illustrates the nomenclature used to describe road and street cross sections.

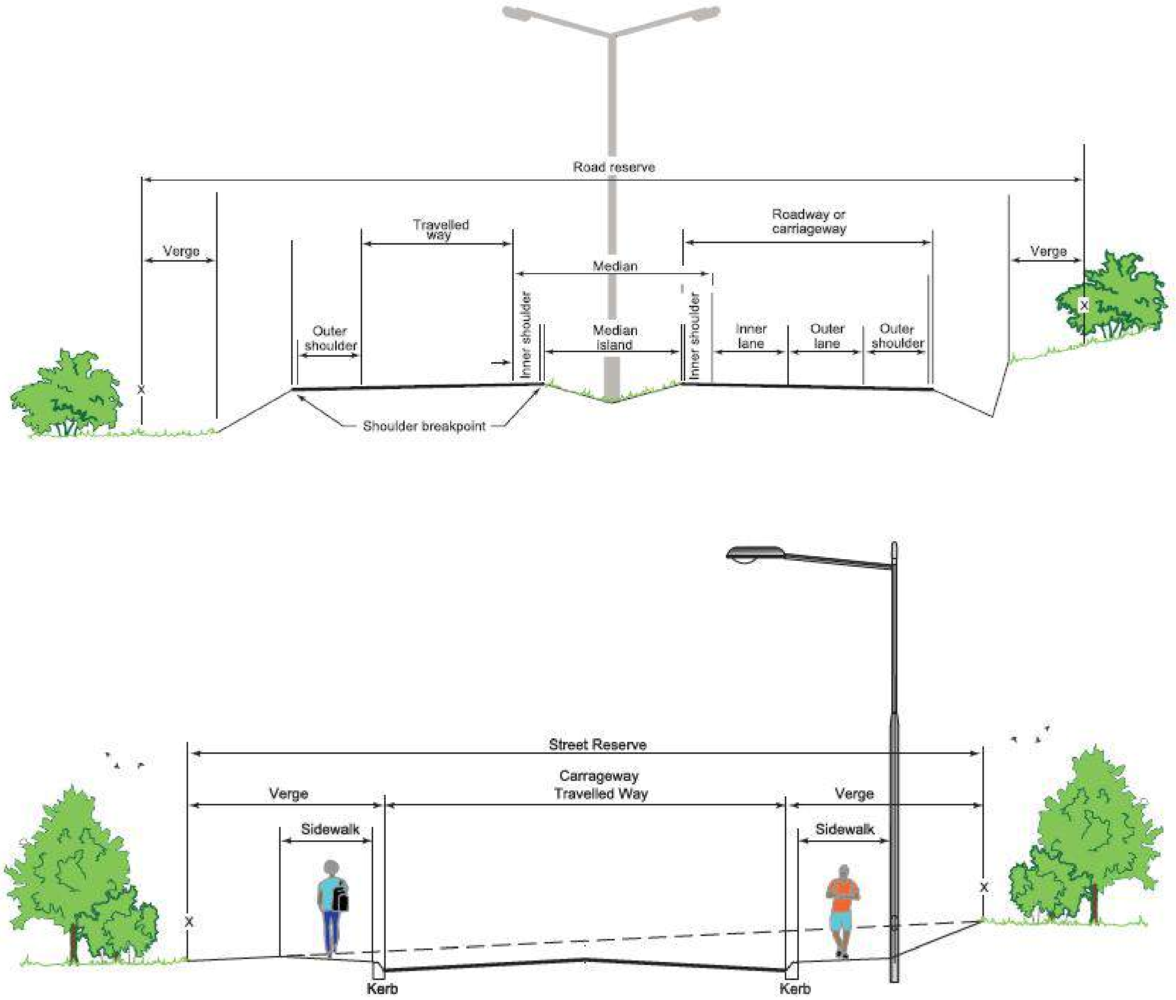


Figure 6-1: Nomenclature used for road (above) and street (below) cross section

The underground services comprise the utilities and the stormwater drainage, should pipe culvert drains be elected as the drainage system. Utilities refer to water and sewer reticulation, as well as any underground cabling for gas, telephone and electricity reticulation.

A third component, above ground, the road or street furniture comprising road signs, barriers, bus stops, street lighting, etc., completes the picture. Bus laybys are not normally provided on Class 4 streets in view of the light traffic volumes on this street class, with the bus stopping in the traffic lane for embarking and disembarking passengers, as illustrated in Figure 6-2. However, in some instances the volume of passengers may warrant provision of a bus layby.

Figure 6-2: Typical bus stop on a Class 4 street

To prevent traffic build-up behind buses, bus bays should be provided with a layout and design as shown in *Part C – Chapter 4: Roadside Furniture.*

The various components of a street system are briefly discussed in the following sections, which should be read with reference to the typical cross-sectional sketches that appear in *Section 6.10*.

6.3 Nominal Street Reserve Widths

Typically, nominal street reserve widths for the lower order of streets, Class 4 and Class 5, incorporating underground stormwater drainage systems, vary between 10 m and 16 m, with the latter used for Class 4 collector streets. However, should the collector street also serve as a bus route, a slightly wider reserve is preferred to provide for larger turning radii, roadside furniture, etc. A width of 20 m is thus indicated for collector streets, also serving as bus routes. The optimal width for lower-order mixed-use streets (Class 5), appears to be of the order of 13 m. These dimensions relate to relatively flat and lightly rolling terrain. On terrain with steeper slopes, the widths may have to be increased to accommodate side-cut and side-fill slopes.

For open-drain stormwater systems, an extra 4 m to 5 m should be added to these dimensions.

Generally, street reserve widths are based on two-way traffic. One-way streets are not favoured for lower-order streets as they are irksome for residents and tend to lead to speeding. However, they may offer a solution in retrofitting situations. In the case of very narrow 9 m to 11 m reserves, a more suitable option may be a single trafficked lane for two-way operations but coupled to regular laybys in order to allow for passing opportunities. Short crescents also lend themselves to one-way operations without the need for passing bays, if very clearly signposted.

6.4 Camber, Crossfall and Superelevation

Camber and crossfall are provided to facilitate drainage. Normally the camber lies in the range of 2.0 % to 3.0 % with 2.0 % the most common for surfaced streets. Unsurfaced streets should have a minimum camber of 2.5 %. Where the longitudinal gradient is at or close to the minimum of 0.67 %, a camber of 3.0 % is indicated for both surfaced as well as unsurfaced streets.

Crossfall comprises a single slope from kerb to kerb, the one kerb being higher than the other. The use of crossfall is indicated for the narrower roadways, to facilitate construction and drainage.

Superelevation is intended to offset the centrifugal forces operating on a vehicle negotiating a curve at speed. At the relatively low design speeds indicated for the lower order mixed-use streets, there is little need for superelevation along curves, except for collectors also serving as bus routes. In the latter case reverse camber should suffice, with superelevation developed and ran out over a distance of 40 m, half before and half inside the curve

On very narrow street reserves, e.g. 9 m or 10 m wide, a cambered street cross section is not indicated. Generally, a 2 % crossfall approach may be considered. In these circumstances, spatial restrictions will preclude the provision of drainage outside the width of the travelled way and pipe culverts will have to be installed below the street pavement structure.

In such cases, as an alternative to kerb inlet drainage, a cross section sloping inwards towards a central low line could also be considered. This would create a flat V-configuration with the entire surfaced area serving as a drainage area. This approach is applicable to short narrow streets that would not require stormwater inlets. On longer streets, grid inlets may be necessary to accommodate the larger stormwater flows. However, as grid inlets are very prone to blockage, this approach should be adopted with great caution.

6.5 Traffic Lanes

6.5.1 General

The selection of lane width is primarily based on vehicle type and traffic speed. The widest lane width normally used in road design is 3.7 m as no operational or safety benefits accrue from wider lanes. However, lanes of such width are commensurate with vehicle only streets and not applicable to the lower class of urban streets.

The narrowest lane widths normally considered is 3.0 m, which provides for a bus at 2.6 m or a truck at 2.5 m width and a nominal 200/250 mm clearance on either side. However, on residential streets, trucks would generally be restricted to waste removal vehicles, operating in one direction and hence in such instances, lane widths could be reduced to 2.8 m, but this is not recommended as a norm.

Intermediate conditions of vehicle type and speed can be adequately catered for by a lane width of between 3.1 m and 3.5 m.

On streets where there is a low demand for vehicular access (less than 10 cars per 100 m of street per day), a single traffic lane of 3.0 m to 3.3 m could be employed, with passing opportunities created at regular intervals. The spacing of such passing bays should not exceed 50 m and each bay should be visible from the next one.

High occupancy bus lanes are not compatible with the lower order of movement facilities and hence not considered.

6.5.2 Parking Lanes or Strips

On-street parking in parking lanes is normally not provided on Class 4 and Class 5 streets as parking can be accommodated on the verges. However, in very narrow reserves and in the vicinity of certain land uses, such as local shops and clinics, it may be necessary to provide for such facilities. The need for parking space may also be met by the provision in the town planning of small parking lots dispersed through the area, reducing the need for kerbside or verge parking. Sufficient parking space is needed to avoid illegal parking and blockage of traffic.

Parking lanes are normally 2.5 m wide, with a minimum width of 2.0 m. Individual parking bays are 6.0 m long and an additional clear space of 1.5 m is normally provided between pairs of parking bays to facilitate parking manoeuvres. In narrow street reserves, this 1.5 m space could be utilised for the planting of single trees or small shrubs.

Should heavy peak hour tidal traffic flow be expected in one direction on middle-order mixed pedestrian and vehicle streets (Class 4 also acting as bus route), the parking lane can be used as an additional traffic lane during peak hours, coupled with time-related parking restrictions. In such a case, the parking lane width should be increased to a minimum of 2.8 m.

6.5.3 Cycle Lanes

Should there be significant cycle traffic, of the order of 100 cyclists per peak hour, or if it is desired to promote cycling as a mode of transport, a cycle lane can be added outside the lanes intended for motorised vehicles. Such lanes should be 1.5 m wide and clearly demarcated for cycle use only. The use of wider cycle lanes should not be considered as motorists will tend to use them as an additional traffic lane. Cycle lanes should be contiguous with the travelled way with no distinction in surfacing for ease of construction and to prevent difficulties with maintenance, drainage and scour.

Figure 6-3: Cycle Lane on high-order road

6.5.4 Auxiliary Lanes

Auxiliary lanes do not normally form part of Class 4 and Class 5 street cross sections as they are lanes added to the roadway to assist in traffic flow and, as such, are mainly applicable to higher-order street and road facilities. However, auxiliary lanes may be required at intersections where lower-order streets join higher-order streets, as discussed in more detail in *Chapter 8 - Intersections*.

6.6 Shoulders

Shoulders are the trafficable areas adjacent and on either side of the roadway. Shoulders are normally provided on high order rural and urban roads to provide space for broken down vehicles, for recovery action by drivers of run off the road vehicles and for access by emergency vehicles. On Class 4 and Class 5 middle and lower order mixed-use urban streets, shoulders give way to sidewalks and are not provided.

6.7 Verges and Sidewalks

6.7.1 Purpose and Nomenclature

The street verge is defined as the area between the roadway edge and the street reserve boundary. This includes the sidewalk.

From a Complete Street point of view, the verges, also sometimes referred to as street sidewalks, provide an opportunity for meeting the needs of the various activities encountered in the urban public environment other than traffic movement. In this Manual, the term sidewalk refers to the made or constructed section of the verge dedicated to pedestrian use. This leaves the remainder of the verge for use for other purposes and is referred to simply as the verge, remainder verge, or ancillary width.

6.7.2 Sidewalks

Sidewalks are constructed strips parallel to the roadway, dedicated for use by pedestrians. Although preferable, sidewalks need not be paved but should be purpose-made, weatherproof and free of all obstructions. Cobblestones are not suitable as paving for sidewalks, being uncomfortable, especially for wheelchair users and other disabled persons.

Where bus stops are provided, the sidewalk should continue behind the bus stop structure. The minimum width of sidewalks should be 1.5 m. Wider sidewalks may be required at activity areas, such as shops or other centres. The width required can be obtained by taking a pedestrian count and dividing the volume (in pedestrians per minute) so obtained by a factor of 3.0 (pedestrians per minute per metre) for comfortable movements or by 4.6 (pedestrians per minute per metre) for rather cramped sidewalk conditions.

Sidewalks should be separated from the roadway by a kerb, with or without an accompanying channel and sloped at a cross slope of 2.0 % towards the roadway. Longitudinally the sidewalk should follow the grade line of the street itself. As a cost-saving measure, sidewalks are often only paved on one side of the street.

Figure 6-4 shows a block paved sidewalk on one side of a street where high volumes of pedestrian activity is experienced during peak hours.

6.7.3 Kerbing

It is envisaged that all streets will be kerbed, whether surfaced or not. This is to facilitate drainage, but also to demarcate the people space, control traffic and ensure a neat, amiable environment.

Figure 6-4: Wider than normal sidewalk

Kerbing may be cast in situ, be precast concrete elements, or be hewn from natural rock quarries. Kerbing along lower-order mixed-use streets should preferably be of the mountable type, with semi-mountable kerbing at intersection bellmouths and barrier kerbing at bus stops to ease embarking and disembarking. Precast or cast-in-situ kerbing should preferably conform to the dimensional standards of *SABS 927-1969 Figures 7 to 9,* as illustrated in Figure 6-5.

Where any kerbing other than mountable kerbing is provided, ramps should also be provided for wheelchairs, other disabled persons and prams. Barrier and semi-mountable kerbing are sometimes offset by a concrete channel of 150 mm width from the lane edge to ease construction, but a concrete channel is seldom provided with mountable kerbing.

Mountable kerbing normally comprises 300 mm wide concrete strips rising 100 mm over its width. If cast in situ, suitable expansion joints must be provided at intervals not exceeding 1.5 m and the sections cast alternately. Suitably shaped in-situ constructed transition sections are required between mountable and barrier or semi-mountable kerbing.

Kerbing hewn from natural rock should approach semi-mountable kerbing in shape and could be used to replace mountable kerbing.

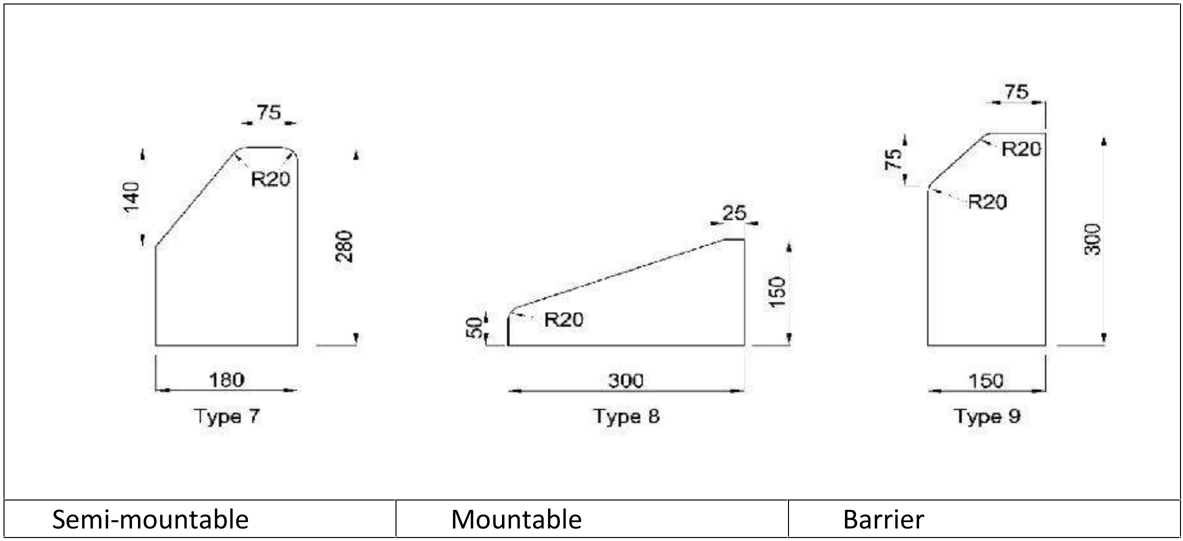


Figure 6-5: Dimensional standards of kerbing

Kerb types 7 and 9 should be provided with an in-situ concrete backing at every joint. Type 8 kerbing should be provided with an in-situ concrete bedding of 125 mm thickness.

6.7.4 Cut and Fill Batters (Side Slopes)

The intention with mixed-usage streets is that the grade line should be at or preferably slightly below the natural ground level. This is necessary to ensure drainage of the surrounding area and for ease of access to adjacent properties. To overcome difficulties created by steep natural cross slopes a cross section comprising crossfall instead of camber could be employed. Some cut and fill earthworks may also be required. In such cases, shallow slopes are required for safety and 1:4 (V:H) should be the steepest used on the fill side, with 1:6 preferred. On the cut side, the cross slopes can be steeper, but in both cut and fill cases vehicular access into properties would generally be the deciding factor on the slopes to be used.

In steep areas, shallow retaining walls erected at the 1.5 m mark, measured from the back of the kerb, could be used to ease the volume of earthworks. Alternatively, one of the sidewalks could be foregone and the street centre line offset in the street reserve. However, this should be a measure of last resort. The shallow retaining walls could comprise hand-packed stones, purpose manufactured precast blocks or in-situ concrete, but should not exceed 600 mm in height without a design. Obviously, wider street reserves could also be allowed for in the town planning to provide more space for embankment construction.

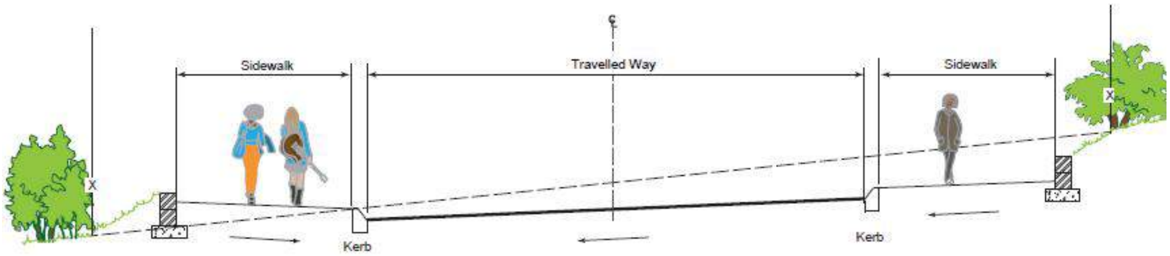


Figure 6-6: Easing steep side slopes

6.7.5 Open Drainage

Should open drains be elected as the drainage system, these should preferably be placed on the far side of the sidewalk, viewed from the road edge. The side of the drain closest to the sidewalk should preferably be provided with a near-slope of 1:3 – from a pedestrian safety point of view – and with a back-slope of 1:1.5. Drain depth would generally be of the order of 500 mm, with a bottom width determined by the volume of flow to be accommodated. Paving the drain would obviously be more expensive but will accommodate a larger flow within the same drain cross section.

Should it not be possible to adhere to the mentioned near-slope requirements, pedestrian safety barriers should be provided.

Open drains will have to be culverted at every cross street as discussed in *Chapter 5 – Stormwater Drainage*.

6.8 Medians, Outer Separators and Frontage roads

6.8.1 Medians

The purpose of medians is to separate opposing streams of traffic and provide refuge for crossing or right-turning traffic at intersections. They also provide refuge for pedestrians and provide space for the erection of signage and lighting. As such, medians are more applicable to higher-order streets but may also find their way to Class 4 and Class 5 streets in terms of certain town planning objectives as discussed below.

Medians should preferably be kerbed to enhance the protection of pedestrians but should be provided with suitable kerb breaks to accommodate people with disabilities, as well as wheelchairs and prams. The minimum width of a kerbed median should be 1.5 m. A median that is 5 m wide would be able to accommodate a right turn lane, with provision for a pedestrian refuge.

Medians are inappropriate in residential streets as they would inhibit right turning movements into properties and hence detract from the access function of such streets. However, medians may sometimes be used on lower-order streets to create a boulevard ambience, in which case two lanes per direction are required, and appropriately spaced median openings must be provided for traffic turning actions. The minimum width of such medians should be of the order of 9 m to accommodate a U-turn by a passenger car, turning from an inner lane to an outer lane.

Medians are generally designed to a shallow V-shape and drained by drop inlets and pipe culverts. In the case of very narrow medians (1.5 m), drainage could be foregone if the median is paved and shaped to drain towards the travelled ways.

6.8.2 Outer Separators

The purpose of an outer separator is to separate streams of traffic flowing in the same direction, but at appreciably different speeds and may be encountered where a local residential, access or service street abuts a higher-order road. The outer separator allows the splitting of the two functions.

6.8.3 Frontage Roads

Frontage roads are roads or streets immediately adjacent to a vehicle-only road, permitting two-way traffic. As such a low volume street could operate as a frontage road.

Frontage roads carry the risk of oncoming headlights on either of the two facilities at night, either blinding or misdirecting traffic on the other facility and must be used with circumspection in town planning layouts. The streets should be well lit at night, or sufficiently far enough apart for this not to happen. The streets could also be graded vertically at different levels.

Figure 6-7: Low volume frontage street to a Class 2 road

6.9 Utilities and Drainage

All utilities not directly connected to the road or street, are normally accommodated under the verge and sidewalk. Drainage pipe culverts are best located under or directly adjacent to the kerb inlets for the inlets also to act as access opportunities for maintenance. The typical cross sections shown below illustrate the manner of separating the location of utilities to minimise the risk of damage during maintenance. Guidance in this regard should be sought from the local authority concerned.

In the case of very narrow streets, there is no choice but to accommodate utilities under the roadway. This increases the cost of access for maintenance as well as the nuisance of interrupted access during maintenance. These factors should be considered when deciding on street widths.

6.10 Typical Cross Sections

6.10.1 General

Typical street cross sections for the various widths of Class 4 and Class 5 streets are illustrated below in a series of figures. Provision for public transport facilities is not shown in the figures but should be made where required according to *Part C – Roadside Furniture.*
The illustrations include street lighting. It is preferred that the lamp post be located on the far side of the sidewalk and the street lighting designed accordingly. Lamp posts at the back of the kerb, as sometimes encountered, are at risk of being easily hit by an out of control vehicle and are often a nuisance to pedestrians.

Preference is also given to the sidewalk being constructed contiguous with the roadway as a narrow strip of land between the two elements does not easily lend itself to landscaping and often become unsightly waste land.

Some figures also show formal parking strips in order to illustrate the principles involved, but they are seldom provided on lower-order residential streets, resulting in each verge becoming wider by the same dimension as the parking strip. In order to provide for parking, a suitable width of the verge on the far side of the sidewalk should be levelled. Parking should not be permitted on constructed sidewalks.

The following typical sections are illustrated:

- 20 m reserve with formal parking and cycle lanes
- 16 m reserve with formal parking
- 13 m reserve with formal paring on one side
- 10 m reserve with central drainage
- 10 m reserve with crossfall
- Alternative 16 m reserve with side drains
- Alternative 13 m reserve with side drains
- 16 m cross section with open drains.

6.10.2 Class 4 Street in 20 m Reserve with Parking

Figure 6-8 illustrates a typical Class 4 street cross section with allowance for cycle lanes and formal parking.

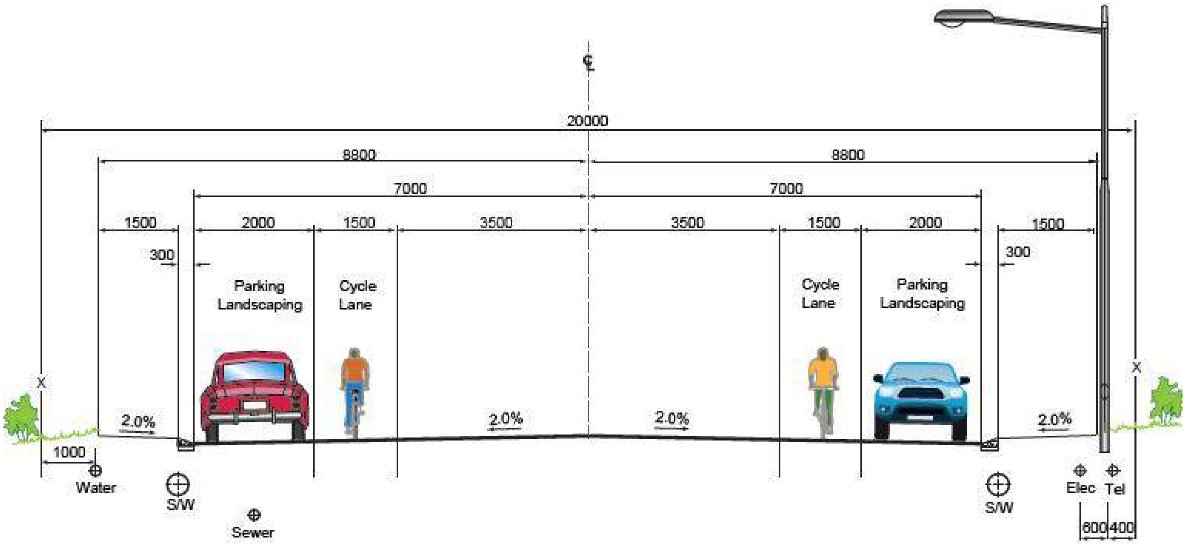


Figure 6-8: 20 m reserve

The parking strip widths are set at 2.0 m slightly narrower than the ideal in order to fit the nominal reserve with. Planting is possible within the 1.5 m gaps between every set of two parking bays, but not shown in the figure. The remainder verge is rather narrow at 1.2 m, signifying that following this rather busy cross section would only be possible in reasonably flat terrain. In steeper terrain, one or both parking strips would have to be foregone, or the street reserve widened.

Should formal parking strips not be required, their widths could be added to the verges, and informal parking resorted to as shown in Figure 6-13.

A 20 m street reserve is normally accepted as sufficient width for a Class 4 street serving as bus route. Although bus bays are not normally provided on Class 4 routes, it may be desirable in some instances to provide for a bus layby and bus shelter occupying approximately 5.0 m in width. From a consideration of Figure 6-8, it would not be possible to fit in a bus layby and bus shelter, should a parking strip and cycle lane also be required. In such cases, a wider street reserve should be adopted. Interrupting the parking strip opposite the bus stop would assist in minimising the extra reserve width needed.

6.10.3 Class 4 Street in 16 m Reserve with Parking

Figure 6-9 is a composite figure showing in the first instance an option with cycle lanes, and in the second instance, formal parking, in a 16 m reserve.

Again, as in the previous cross section, the available verge widths point to a reasonably flat terrain and that the parking strips or cycle lanes would have to be foregone in steeper terrain, or the reserve widened for instance to 18 m.

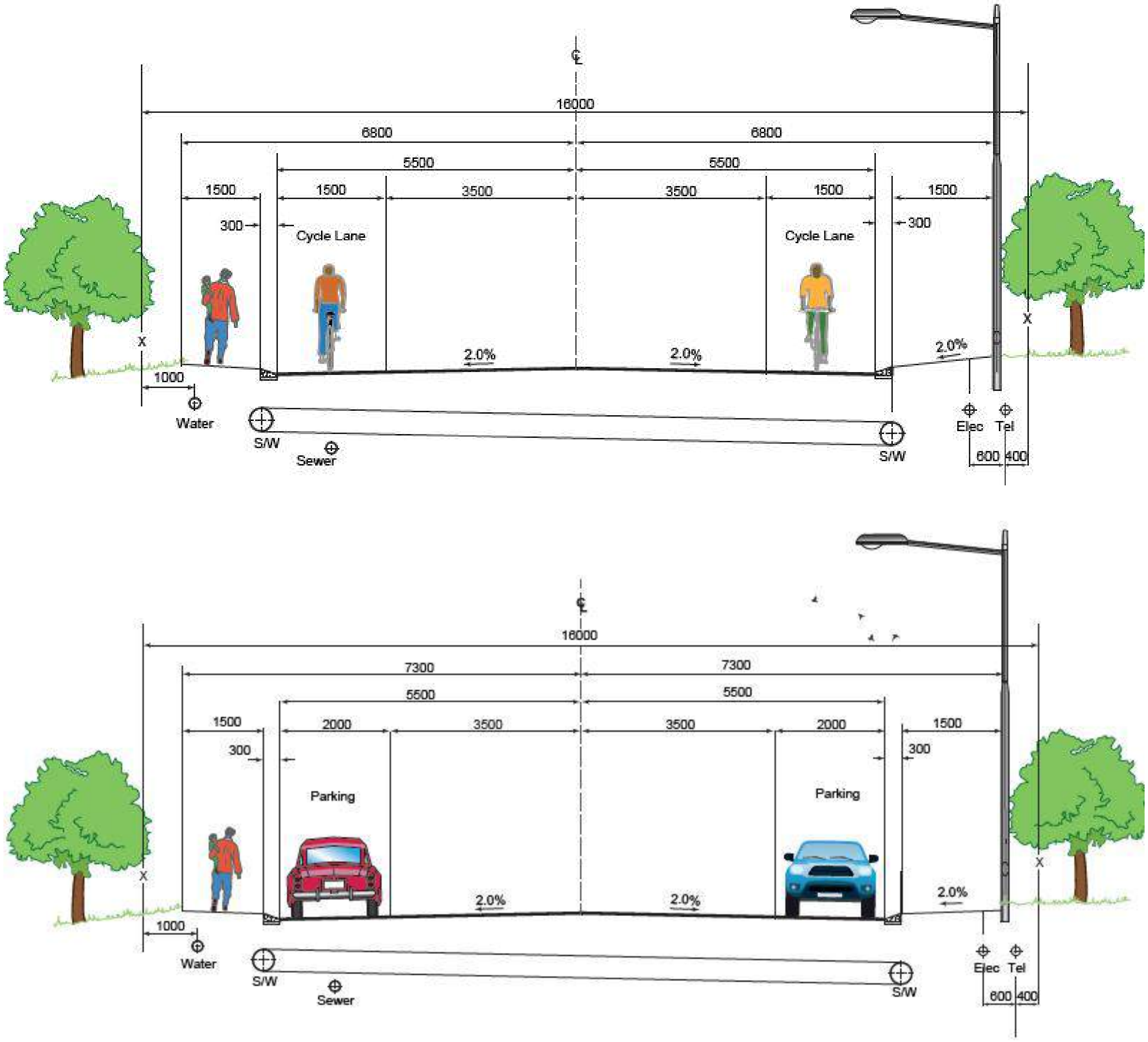


Figure 6-9: Alternative cross-section layouts on a 16 m reserve

As in the previous instance, it was elected, for the sake of clarity, not to show planting in the figure in the 1.5 m gaps between sets of parking bays for the parking option, but this is possible and should be encouraged.

6.10.4 Class 5 Street in 13 m Reserve with Parking on One Side

Figure 6-10 shows a typical residential Class 5 street in a 13 m street reserve with formal parking on one side of the street. This requires the street centre line to be positioned off-centre in the reserve. Should formal parking not be provided, as is normally the case, informal parking can take place on the verge behind the sidewalk on one side of the street. The 13 m reserve is too narrow to permit verge parking on both sides, except if one sidewalk is forgone.

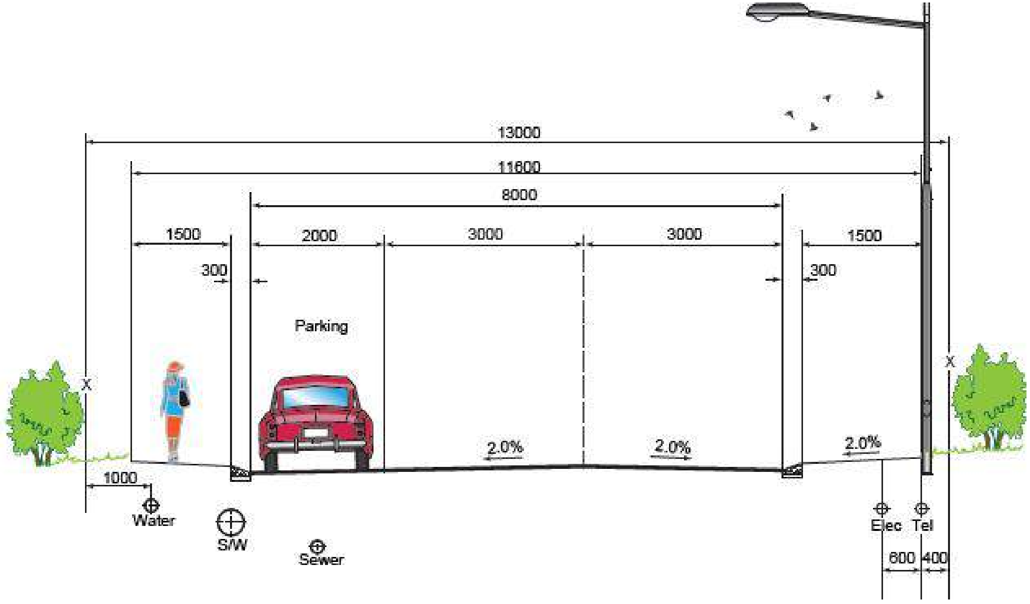


Figure 6-10: 13 m reserve (cross drain not shown)

6.10.5 Class 5 Street in 10 m Reserve with Parking and Dished Drainage

Figure 6-11 illustrates a very narrow 10 m wide reserve with a single two-way lane and parking on one side of the street. This layout requires intermittent laybys to create passing opportunities. The spacing of laybys is recommended at approximately 50 m intervals. Laybys should be 6 m long measured at the kerb side with tapers of 1:3 on either side. The layout requires the street centre line to be positioned off-centre in the reserve. Drainage is to a central low line.

Parking could be formal, as shown, or informal behind the sidewalk, with the space for formal parking reallocated to the verge. Alternatively, a system of one-way streets could be contemplated, retaining some laybys for overtaking purposes, but increasing the spacing to approximately 100 m. As previously, forgoing one sidewalk is another option for creating more parking spaces.

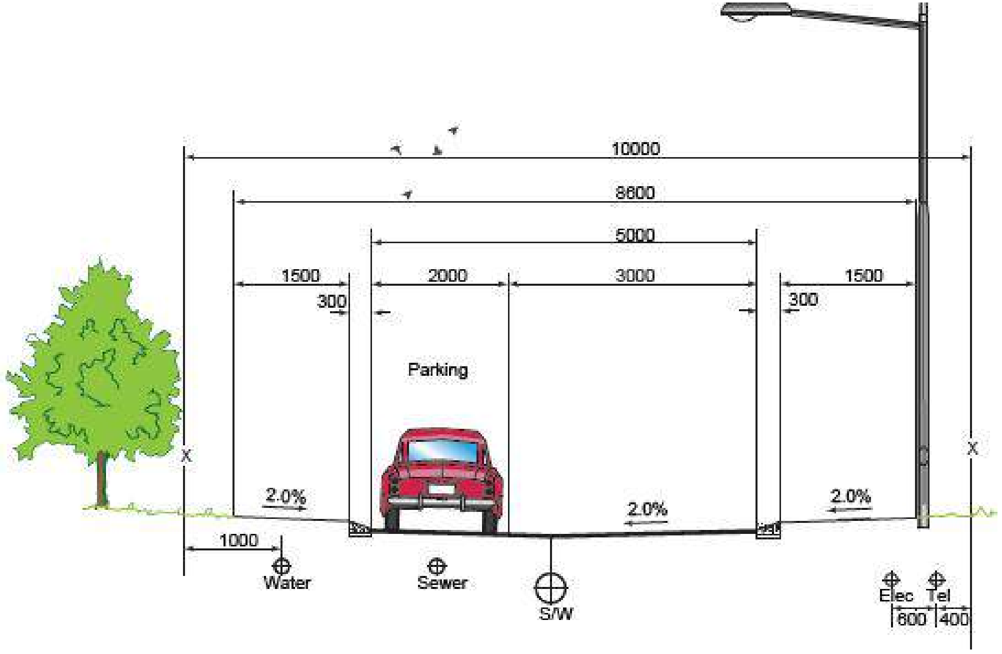


Figure 6-11: 10 m reserve with central drainage

6.10.6 Class 5 Street in 10 m Reserve with Parking and Crossfall

Figure 6-12 shows a similar cross section to the one shown in Figure 6-11, except for a more conventional crossfall and kerb inlet drainage approach.

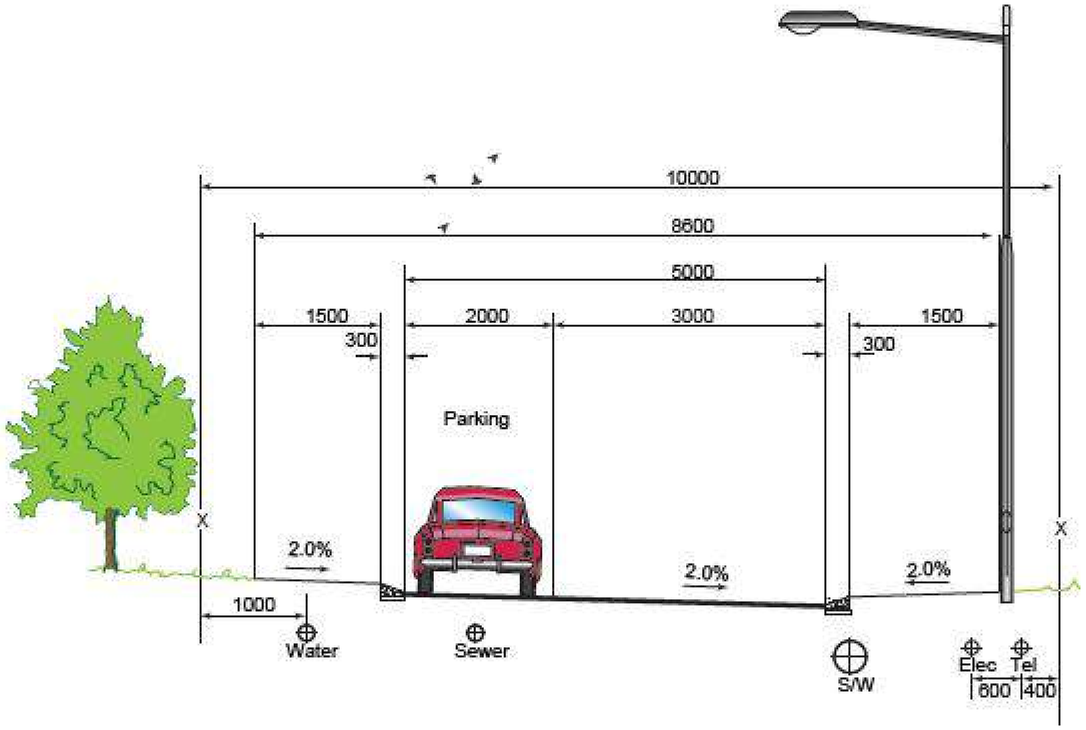


Figure 6-12: 10 m reserve with crossfall

6.10.7 Class 4 Street in 16 m Reserve with Side Drains

Figure 6-12 illustrates a possible alternative approach to the more conventional kerbing as street delineator, comprising a shallow side drain. The side drains could be in concrete or with grouted stone-pitching. Drainage could comprise grid drop inlets to a pipe culvert system. Parking could be informal as shown, or formal.

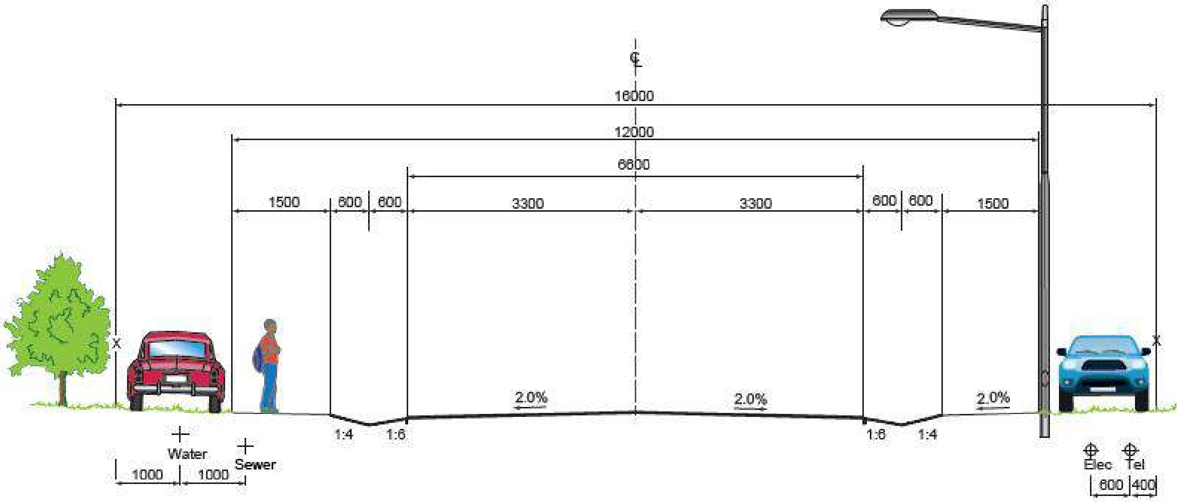


Figure 6-13: 16 m reserve with side drains in lieu of kerbing

6.10.8 Class 5 Street in 13 m Reserve with Side Drains

The illustration in Figure 6-14 is similar to the one in Figure 6-13, except for a 13 m reserve. A street with its centre line aligned with the centre of the reserve, as illustrated, results in very narrow verge widths, not lending themselves to informal parking. Positioning the street off-centre as in

Figure 6-10 would permit parking on one side of the street. Providing formal parking would also be possible in the latter case.

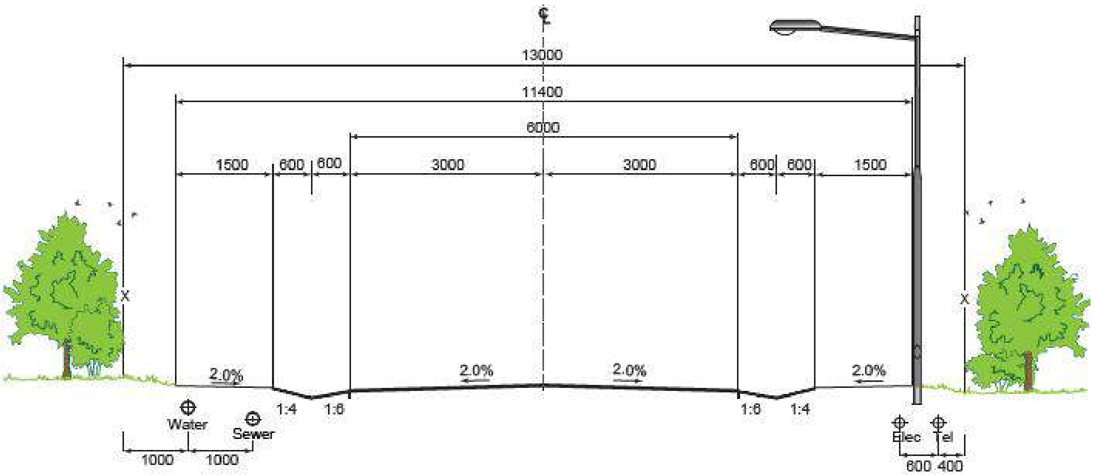


Figure 6-14: 13 m reserve with side drains in lieu of kerbing

6.10.9 Open Drainage

Pedestrian and vehicle-safe open drainage systems, in lieu of underground piped systems, require appreciably wider street reserves, as illustrated in Figure 6-15. This is equally true irrespective of using kerbing or side drains as street delineators.

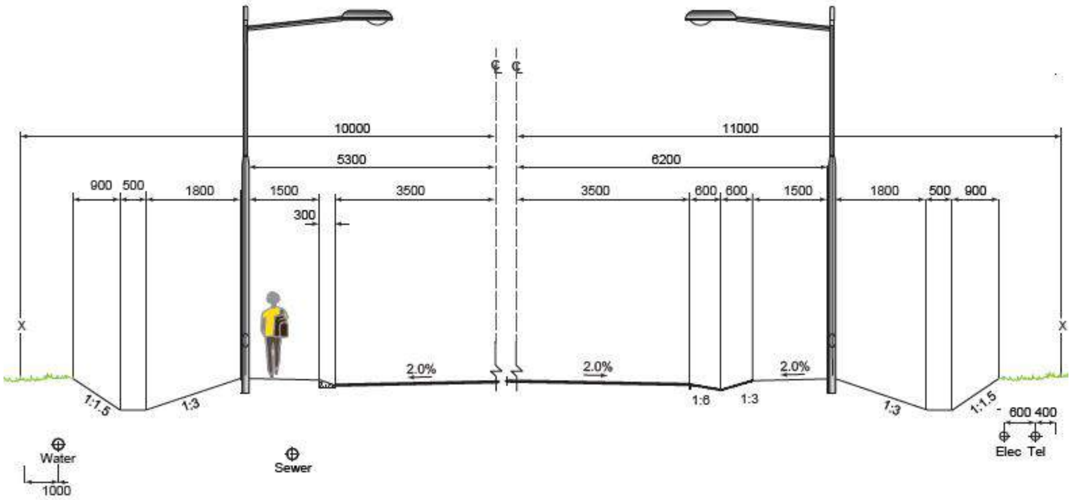


Figure 6-15: Effect of open drainage on street reserve requirements

Using an open drainage instead of a pipe drainage system would also require constructing small mitred causeways in the sidewalks in the positions where kerb inlets would normally be constructed to drain water from the roadway into the open drains.

6.10.10 Summary

The few typical cross sections illustrated and discussed above, clearly indicate that there is no single right answer to cross section selection and that there are various options and alternatives available to the town planner and geometric designer, to create varying streetscapes while still meeting the demands of functionality and economy. As indicated in the introduction to this part of the Manual, careful consideration of functional classification and context-sensitive design in terms of the complete street approach, will determine the selection of the elements required in a cross section.

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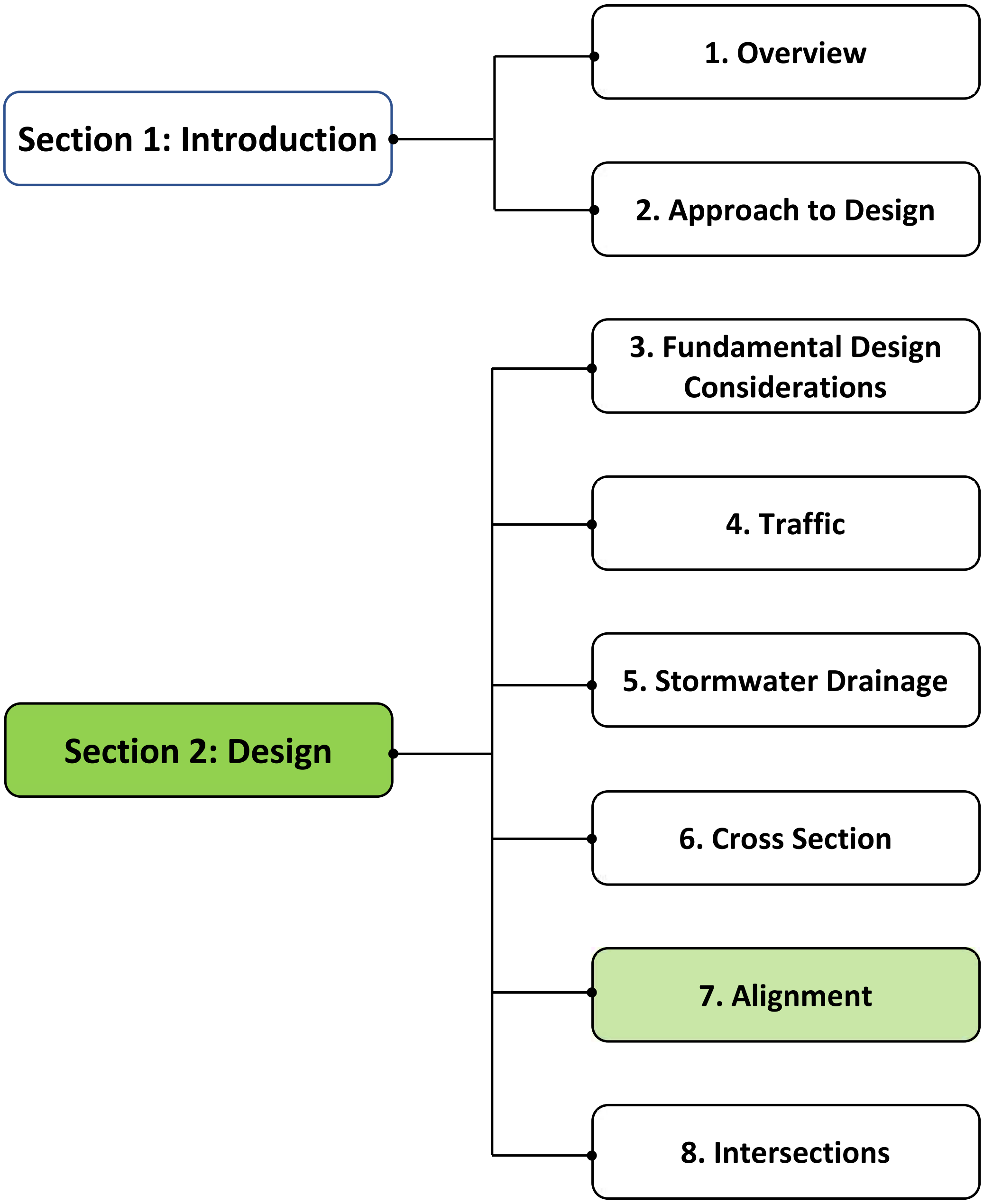
Low Volume Roads Manual
Part B – Geometric Design: Urban Roads



Chapter 7 – Alignment

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7.1 Introduction

7.1.1 Background

The basic elements of geometric design are the horizontal alignment, the vertical alignment and the cross section. The standards to be chosen for these design elements are dependent on the criteria for the design controls such as design speed, sight distance, traffic volume and level of service.

The horizontal alignment is the combination of straights (tangents) and curves, presented in plan view. Curves are usually circular, but spiral transitional curves are sometimes employed to enhance passenger comfort and geometric aesthetics. The vertical alignment is the combination of vertical curves, generally parabolic, and the straight (tangent) sections joining them.

Alignment design refers to the integration of horizontal layout and the vertical profile of the road or street, bringing together in three dimensions the plan and profile views of a roadway in a manner that is familiar to a driver of a vehicle.

The design of the road alignment is concerned with selecting the parameters of the geometric features of the road or street so that they provide a safe, comfortable and efficient means for transporting people and goods. However, for low volume streets, designed for access rather than mobility, speed is not the main concern.

A good design avoids catching a driver unaware by integrating all design controls, while being mindful of the road or street function, all the requirements of a movement network, as well as good drainage.

7.1.2 Purpose and Scope

The purpose of this chapter is to discuss the horizontal and vertical alignment elements which, together with cross-sectional elements, form the layout of low volume streets that should be designed in a safe and correctly functioning manner that is in harmony with the urban landscape.

The chapter covers the criteria that apply to the horizontal and vertical alignment and how they should be applied. Particular emphasis is placed on sight distance as the cornerstone of safe design.

The various classes of road and streets are defined in *Chapter 2 – Approach to Design* and Table 2-1. It will be apparent that in an urban environment, daily travel will usually involve several classes of roads or streets from the residential areas (Class 5) through Class 4 and probably Class 3 and higher. In the urban context, the links from Class 4 to higher-order classes are important, and therefore, such links are included where necessary, irrespective of volumes on the higher-order streets and roads.

The chapter concludes with some worked examples.

7.2 Sight distance

7.2.1 General

Sight distance is the most fundamental criterion of safe design and hence discussed in some detail before dealing with the alignments as such. The key element of alignment design is to ensure that drivers can stop safely or avoid the situation if a potentially hazardous event occurs ahead of them. Sight distance thus comes into play when considering stopping, manoeuvring, passing and decision making, with sub-aspects to each.

In determining the sight distance required, two criteria must be satisfied:

- Drivers must be able to see the potential hazard; and
- They must be able to react to it and stop or take avoidance action before they reach the hazard.

The first requirement is, therefore, clear lines of sight between the driver and the hazard, and the second is concerned with the reaction time of drivers and braking ability. These aspects are crucial to many aspects of alignment design and are therefore introduced before other aspects are dealt with.

It may also be noted that the information on sight distance requirements given in the tables below is commensurate with operational speeds normally encountered in an urban context and hence limited to design speeds of 80 km/h or less.

7.2.2 Stopping Sight Distance

The distance a vehicle requires to stop safely is called the stopping sight distance (SSD). It mainly affects the shape of the road on the crest of a hill (vertical alignment), but if there are objects near the edge of the road that restrict a driver's vision on approaching a bend, then it also affects the horizontal curvature.

The driver must be able to see any obstacle in the road, hence the stopping sight distance depends on the height of the object and the height of the driver's eye above the road surface. These heights are normally set at 0.15 m and 1.05 m, respectively. However, in the case of mixed-use local streets, the object height can be increased to 0.6 m, thus giving an expression of the safety and protection of children and pets, without incurring excessive earthworks and costs.

The driver needs time to react and then the brakes of the vehicle need time to slow the vehicle down, hence stopping sight distance is extremely dependant on the speed of the vehicle. The surface characteristics of the road also affect the braking time or distance, so the values for unpaved roads differ from those of paved roads, although the differences are small for design speeds below 60km/h.

The stopping distance also depends on the gradient of the road. It is harder to stop on a downhill gradient than on a flat road because a component of the weight of the vehicle acts down the gradient in the opposite direction to the frictional forces that are attempting to stop the vehicle. This is illustrated in Figure 7-1.

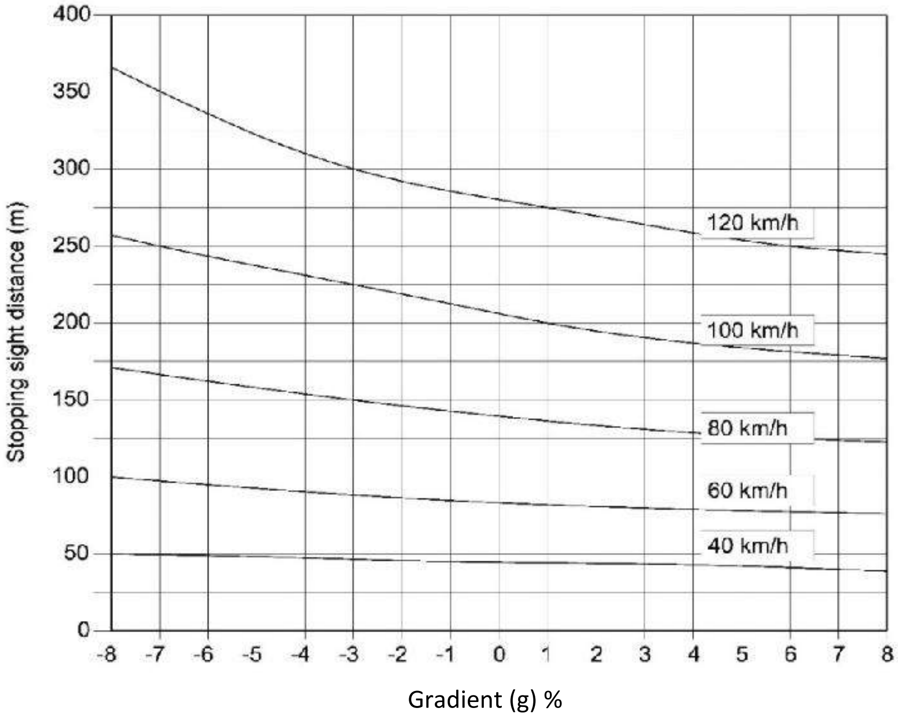

Figure 7-1: Effect of gradient on stopping sight distance

Full adherence to the required sight distances is essential for safety reasons. On the inside of horizontal curves, it may be necessary to remove trees, buildings or other obstacles to obtain the necessary sight distances. If this cannot be done, the alignment must be changed. In rare cases where it is not possible and a change in design speed is necessary, adequate and permanent signage must be provided.

Recommended stopping sight distances for paved and unpaved roads and streets at different design speeds are shown in Table 7-1 and Table 7-2.

Table 7-1: Minimum stopping sight distances for paved roads for various grades (g)

Design Speed (km/h)	Coefficient of Friction (f)	Stopping Sight Distance (m)		
		g = 0	g = -5 %	g = -10 %
20	0.42	18	18	18
25	0.41	23	24	25
30	0.40	30	31	33
40	0.37	45	47	50
50	0.35	65	70	75
60	0.33	85	95	105
70	0.32	110	120	140
80	0.30	140	155	180

Table 7-2: Minimum stopping sight distances for unpaved roads for various grades (g)

Design Speed (km/h)	Coefficient of Friction (f)	Stopping Sight Distance (m)		
		g = 0	g = -5 %	g = -10 %
20	0.34	19	19	20
25	0.33	23	24	25
30	0.32	32	34	37
40	0.30	49	55	60
50	0.28	70	80	90
60	0.26	95	110	130
70	0.25	125	145	175
80	0.24	160	190	235

Lateral obstructions

Stopping sight distance can also be affected by an obstruction such as a wall, bus shelter or landscaping elements, for example, shrubbery. It is therefore considered good practice to ensure that the line of sight remains within the width of the travelled way, plus shoulder or sidewalk, as the case may be. This requirement determines the minimum radius that can be adopted in horizontal design.

The clear offset provided by the width of the travelled way and sidewalk is measured from the street centre line and will normally be of the order of 4 m to 6 m. From plane geometry, the minimum curve radius for a design speed of 60 km/h and commensurate stopping sight distance of 80 m, would be 200 m for a 4 m offset. For an offset of 6 m the minimum radius for the same design speed would be 150 m. Figure 7-2 gives radii for various offsets and design speeds.

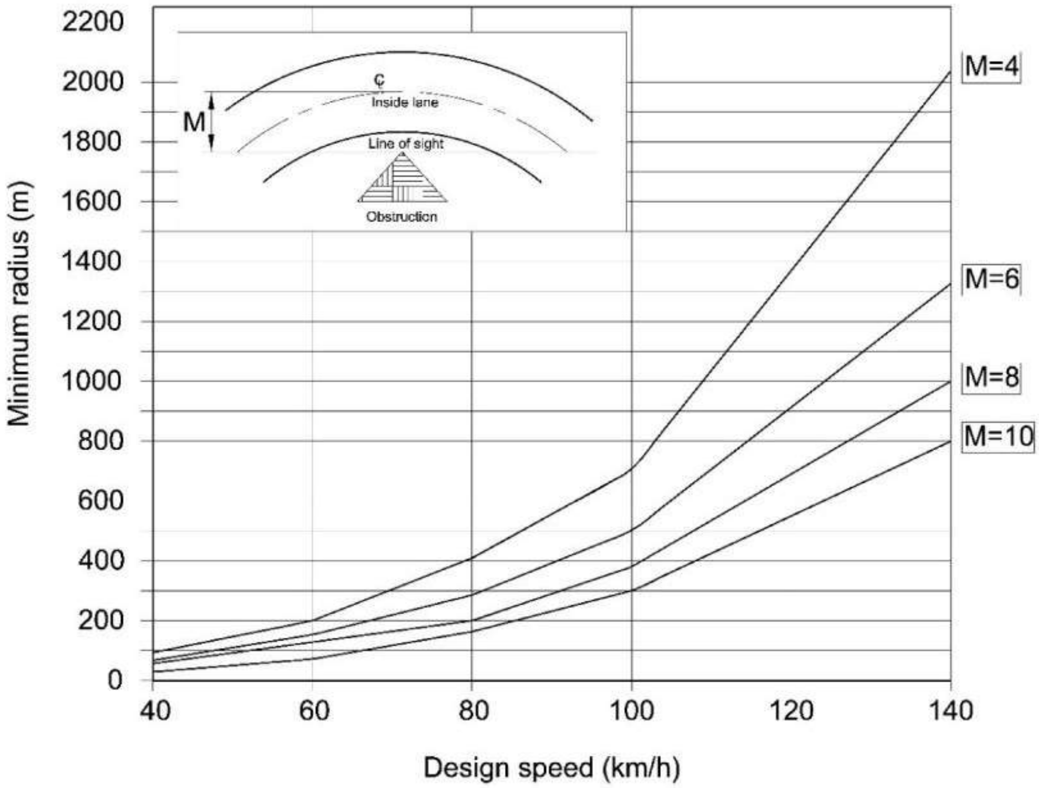

Figure 7-2: Minimum horizontal radius for stopping sight distance on curves

7.2.3 Decision Sight Distance

Decision sight distance, sometimes termed 'anticipatory sight distance', is the distance required for a driver to:

- detect an unexpected or otherwise 'difficult-to-perceive' information source or hazard in a roadway environment that may be visually cluttered;
- recognize the hazard or its potential threat;
- select an appropriate speed and path; and
- complete the required safety manoeuvre safely and efficiently.

Critical locations where errors are likely to occur and where it is desirable to provide decision sight distance include:

- areas of concentrated demand where sources of information such as roadway elements, opposing traffic, traffic control devices, advertising signs and construction zones, compete for attention (i.e. visual noise);
- approaches to interchanges and intersections;
- railway crossings, bus stops, bicycle paths, entrances of villages and towns;
- newly upgraded road sections or the change of road hierarchy;
- changes in cross-section such as at toll plazas and lane drops; and
- locations of design speed reductions.

Decision sight distance is measured from an eye height of 1.05 m to an object height of 0 m, i.e. the road surface. The road surface as object height is set in order to include road markings, for example, lane markings and road surface defects like potholes, as elements to be considered by the driver. The reaction time selected for this purpose is 7.5 seconds as compared to 2.5 seconds used in calculating stopping sight distance for an emergency stop. Table 7-3 gives values for decision sight distances required for various design speeds.

Table 7-3: Decision sight distance

Design speed (km/h)	Decision sight distance (m)
40	130
60	200
80	250

7.2.4 Barrier Sight Distance

Barrier sight distance (sometimes called meeting sight distance) is the limiting distance below which overtaking is prohibited. Barrier sight distance is intended to provide enough time for two vehicles approaching each other in the same lane at the design speed to come to a stop with a small safety margin. The barrier sight distance is therefore equated to twice the stopping sight distance plus a margin of 10 m to 20 m. Table 7-4 provides information on the barrier sight distances required for various design speeds.

Table 7-4: Barrier sight distance

Design speed (km/h)	Barrier sight distance (m)
40	110
60	190
80	300

Barrier sight distance is measured from an eye height of 1.05 m to an object height of 1.3 m.

In considering barrier sight distance, and also passing sight distance (see below), the risks associated with hidden dips in the vertical alignment of the road should be assessed. Hidden dips create a false impression that adequate sight distance is available. However, because of the relatively short lengths of streets in the urban environment, as well as the lower speeds involved, barrier sight distance is seldom a problem, but should always be borne in mind. It is, for instance, recommended that the barrier sight distance should be catered for, rather than only stopping sight distance at traffic control elements such as stop signs or traffic signals.

7.2.5 Passing Sight Distance

Passing site distance is seldom an aspect of concern in the design of lower-order mixed-use streets as it concerns the safe execution of overtaking manoeuvres as happens on higher-order and vehicle only roads. In the urban context, overtaking is mostly not possible or prohibited. Table 7-5, nevertheless, provides information on the sight distances required for the successful execution of such actions.

Table 7-5: Passing sight distance for successful manoeuvres

Design Speed (km/h)	Passing Sight Distance (m)
40	290
60	410
80	540

7.3 Vertical alignment

7.3.1 General

The vertical alignment of a street or road should be consistent with the topography. The main difference between a street and a road is that the street should be slightly depressed to facilitate drainage of the adjacent properties, while a road is slightly elevated to facilitate cross drainage and to keep water/moisture away from the pavement structure.

The street alignment should be designed to be aesthetically pleasing and due recognition should be given to the interrelationship between vertical and horizontal alignment. For example, a vertical curve that coincides with a horizontal curve should be contained within the horizontal curve and, ideally, have approximately the same length.

The grade line should be smooth, with gradual changes in keeping with the topography. Numerous short lengths of vertical curves and straights should be avoided for safety and drainage reasons.

In sags where the street user has a full view of the vertical alignment of the street, broken back vertical curves should be avoided. On crests, the broken back profile adversely affects passing opportunities.

7.3.2 Vertical Curvature

The parabola provides a constant rate of change of gradient and hence has become the normal curve for a vertical design. However, there is little difference in the results obtained between the parabola and a circular curve, and hence this manual is not prescriptive.

The basic formula of a parabola is:

$$y = a x^2 + b x + c$$

The gradient is provided by the first differential:

$$dy/dx = 2 a x + b$$

and the rate of change by $d^2y/dx^2 = 2 a$

The reciprocal of 2a, 1/2a, is identified as the factor K. K is thus the distance required to effect a 1 % change of gradient, where the gradient is expressed as a percentage.

Vertical curves are specified in terms of this factor K, and their lengths, L, as:

$$L = A K$$

where A is the change in gradient, i.e. the algebraic difference in grades.

The minimum rate of curvature is determined by sight distance requirements, as well as the comfort of operation and aesthetics. Generally, though, the last mentioned two factors will be met if sight distance requirements are met on vertical crest curves. The minimum sight distance is the stopping sight distance.

In the case of vertical sag curves, the sight distance is replaced by the headlight illumination distance of the same length. This is measured by assuming a headlight height of 0.6 m and a divergence angle of 1 degree above the longitudinal axis of the vehicle through the headlights. Where adequate street lighting is available, applying the headlight criterion may not be necessary, strictly speaking, but is still advised as a measure to ensure comfort. Street lighting is also known to malfunction at times.

Minimum values of K, based on stopping sight distance for crest and headlight illumination distance for vertical sag curves, are given in Table 7-6.

Minimum lengths of vertical curves.

Small algebraic differences in gradients result in short vertical curve lengths, and this in turn, particularly where the two tangents are long, tend to create an impression of a kink in the road. Table 7-7 suggests minimum vertical curve lengths for purely aesthetic reasons. Where the algebraic difference is less than 0.5 %, the vertical curve can be omitted.

For aesthetic reasons, it is also necessary to fit a short length of straight tangent between two alternating vertical curves. A length of 100 m should suffice.

Table 7-6: Minimum K-values for Vertical Curves

Design speed (km/h)	Crest curves for different object heights		Sag curves
	0.15 m	**0.6 m**	
40	6	2	8
50	11	6	12
60	16	10	16
70	23	Not applicable	20
80	33		25

Table 7-7: Minimum length of vertical curves for aesthetic reasons

Design speed (km/h)	Length of curve (m)
40	80
60	100
80	140

7.3.3 Gradients

The preferred minimum gradient on streets is 0.67 %. However, in many cases, the natural terrain may dictate the need for adopting steeper gradients which can have a severe effect on the operational speed of heavy vehicles, as shown in Figure 7-3.

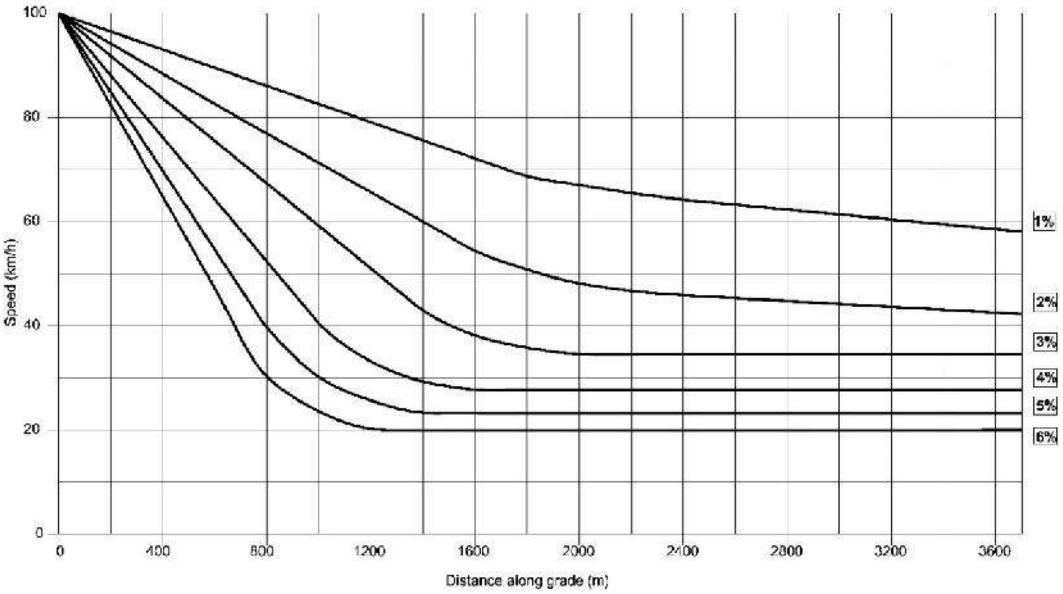

Figure 7-3: Effect of gradient on truck and bus speed

From a safety and passenger comfort perspective, streets serving as bus routes should not be too steep. Passenger comfort suffers and the frequency of accidents increases sharply when the speeds of heavy vehicles such as a bus drop by more than 15 km/h below the average running speed. Table 7-8 suggests maximum grades for bus routes.

Table 7-8: Maximum gradients on streets also serving as bus routes (%)

Design speed (km/h)	Topography		
	Flat	Rolling	Steep
40	7	8	9
60	6	7	8
80	5	6	7

Maximum gradients on lower-order mixed-use (local residential) streets could go as high as 12 %, with very short sections of 50 m or less up to 15 %. However, gradients steeper than 8 % will require careful attention to stormwater drainage. Taking camber or crossfall into account, longitudinal gradients higher than 6 % should not be adopted for unsurfaced streets. Gravel surfaces are subject to scour at water flow speeds of 0.6 m/s to 1.0 m/s, which are associated with slopes of the order of 7 % to 8 % for overland flow.

Short access loops, crescents and cul-de-sac streets should be positioned in the town planning to avoid the risk of properties at the dead-end or low part being inundated by runoff from higher-lying land, especially on steeper-sloping terrain.

It is also difficult to construct streets on gradients steeper than about 12 % by conventional means. Streets on steeper grades should thus be constructed of concrete or interlocking concrete pavers, provided they are well locked in by kerbing and transverse anchor beams.

7.4 Horizontal Alignment

7.4.1 General

Designing the horizontal alignment of an urban street is a planning rather than a detail design function. Nevertheless, the planner and the geometric designer should collaborate, with the drainage designer being involved, as required.

Alignment should be sensitive to the topography to minimise the need for cuts and fills and the restrictions earthworks place on the access of vehicles to individual stands from the street. Streets should, wherever possible, not be at right angles to contours because such streets tend to create problems in construction, maintenance, drainage and scour, as well as safety in terms of run-away vehicles, especially if the terrain has steep slopes.

The design of the street must also take account of the function of the street and the likely operating speeds. The horizontal alignment of a higher-order multi-use street or road will be focused on a destination endeavouring to follow the shortest route with long tangents and gentle curves. On lower-order mixed-use streets, the tangents may be shorter and the curves sharper, aimed at operating speeds of 40 km/h or 60 km/h.

Cognisance also has to be taken of the design requirements of utility services that would be situated within the street reserve, e.g. water mains may require deep excavations to avoid installing air release valves in the case of an undulating vertical alignment being determined by the horizontal alignment.

7.4.2 Tangents

Tangents are the straight sections of a street connecting the horizontal curves. Long tangents can cause operating speeds on such streets to increase to unacceptable levels. Hence, it is suggested that the length of uninterrupted tangents should be limited. A length of ten times the design speed appears to keep the operating speed to below that level, i.e. for a 40 km/h design speed the tangent lengths should be less than 400 m, and for a 60 km/h design speed, the tangent length should not exceed a maximum of 600 m.

In the case of an urban grid of streets, which is desirable from a pedestrian movement point of view, through traffic must be curtailed by other means such as traffic calming.

7.4.3 Curvature and Superelevation

There are a number of factors militating against the use of high rates of superelevation in street design:

- The large range of speeds encountered in an urban area
- The need to ensure ease of access to properties adjacent to streets
- The risk of top-heavy vehicles overturning at slow speeds
- Lack of length to develop superelevation.

Superelevation rates thus used in the design of low-order mix-used streets are very restricted, varying from none (negative camber), to reverse camber, i.e. 2 %, to a maximum of 4 %. On mixed-use higher-order streets 6 % should be considered the maximum rate of superelevation.

The safe minimum radius of a curve is related to the design speed, the friction between tyre and the road surface and the superelevation. The formula to calculate the radius is:

$$R = v^2/127\,(e + f)$$

where R = Radius e = superelevation (m/m)
v = speed (km/h) f = side friction factor

Table 7-9 shows combinations of minimum radii and superelevation rates for various design speeds based on the equation given above.

Table 7-9: Minimum radii for horizontal curves for paved roads (m)

Design speed (km/h)	Side friction factor	Minimum Radii for Maximum Rates of Superelevation			
		-0.02	+ 0.02	0.04	0.06
30	0.19	45	35	30	30
40	0.18	80	65	60	55
50	0.17	135	105	95	85
60	0.16	205	160	145	130
70	0.15	300	230	220	185
80	0.14	420	315	300	265

For unpaved roads (Table 7-10) the friction is usually considerably less than on paved roads. In these calculations, it has been assumed that it is 80% of the value for paved roads, but this is dependent on a tightly knit and dry surface of good quality gravel with no loose stones; in other words, a surface on which the design speed can be maintained.

A poorly bound surface with many loose particles will have a much lower value of friction, but it may be assumed that vehicles will be driven on such a surface at a speed that is much lower than the nominal design speed dictated by the sight distances and radii of curvature and hence that there is little need to make further adjustments to Table 7-10 for such surfaces.

Table 7-10: Minimum radii for horizontal curves for unpaved roads (m)

Design speed (km/h)	Side friction factor	Minimum radii for maximum rates of superelevation (m)
		0,04
20	0.19	15
30	0.165	35
40	0.15	65
50	0.12	115
60	0.16	175
70	0.15	255
80	0.14	355

Superelevation development and runoff

Streets normally have a camber with the high point on the centre line and a fall of the order of 2 % to 3 %, to either side. Superelevation is developed or run off by rotating the outer lane edge about the centre line until a crossfall across the full width of the street equal to the original camber is achieved. From this point on both lanes are further rotated around the centre line or an edge line until the full extent of the desired superelevation is achieved.

Minimum lengths for superelevation development and runoff are suggested in Table 7-11. These lengths should ensure adequate runoff of stormwater, without creating the impression of an unsightly kink in the road surface edge.

Table 7-11: Minimum lengths for superelevation development

Design Speed (km/h)	Length (m)
40	40
60	40
80	60

The superelevation development must be distributed over the tangent and the curve, preferably in the proportion of two thirds on the tangent and one third on the curve in the case of development lengths longer than 60 m. Over the shorter lengths, it could be split equally.

7.4.4 Application of Curvature

The following general principles relating to curvature should be followed when designing the horizontal alignment of a street:

- A short tangent is required between reverse curves, i.e. curves in opposite directions following on each other.
- Broken back curves, i.e. curves in the same direction with short straights in between, are to be avoided as they are contrary to driver expectations.
- Large and small radii curves should not be mixed. The 1:1.5 rule of thumb should apply, i.e. the radii of successive curves should be within this ratio to each other.
- Small deflection angles require fairly long curves to avoid the impression of a kink.

The vertical alignment of a street as any road, should be consistent with the topography and should be aesthetically pleasing. In this regard:

- Due recognition should be given to the interrelationship between vertical and horizontal alignment. A vertical curve that coincides with a horizontal curve should be contained within the horizontal curve and, ideally, have approximately the same length.
- The grade line should be smooth, with gradual changes in keeping with the topography. Numerous short lengths of vertical curves and straights should be avoided for safety and drainage reasons.
- In sags where the street user has a full view of the vertical alignment of the street, broken back vertical curves should be avoided. On crests, the broken back profile adversely affects passing opportunities.

Worked Examples

Example 1: *A Class 4 Street also serving as a bus route has to cross a small rise with tangent gradients of + 4 % and – 3 %. Establish the parameters of the vertical curve required.*

The design speed for a Class 4 street is 60 km/h;

The change in gradient, A = + 4 – (-3) = 7 %.

Enter Table 7-6: The minimum K value for a design speed of 60 km/h and an object height of 0.6 m is 10.

Apply the formula L = AK gives a vertical curve length of 7x10 = 70 m.

Table 7-7 requires a minimum length of 100 m, so use L = 100 m.

Example 2: *Determine the radius for a horizontal curve for a Class 4 Street and the superelevation required.*

Enter Table 7-9: With a design speed of 60 km/h and reverse camber, i.e. a superelevation of + 0.02, the minimum radius is found as 160 m. Checking the township layout, it is found that the street reserve cannot accommodate this radius.

Check Table 7-9 for radii commensurate with steeper rates of superelevation. It will be found that a superelevation of 0.04 requires a minimum radius of 145 m. Checking against the township layout again, it is found that the street reserve can actually accommodate a curve of 150 m radius. Hence, use 150 m as the radius.

Table 7-11 gives the minimum length for superelevation development and runoff as 40 m for the design speed in question.

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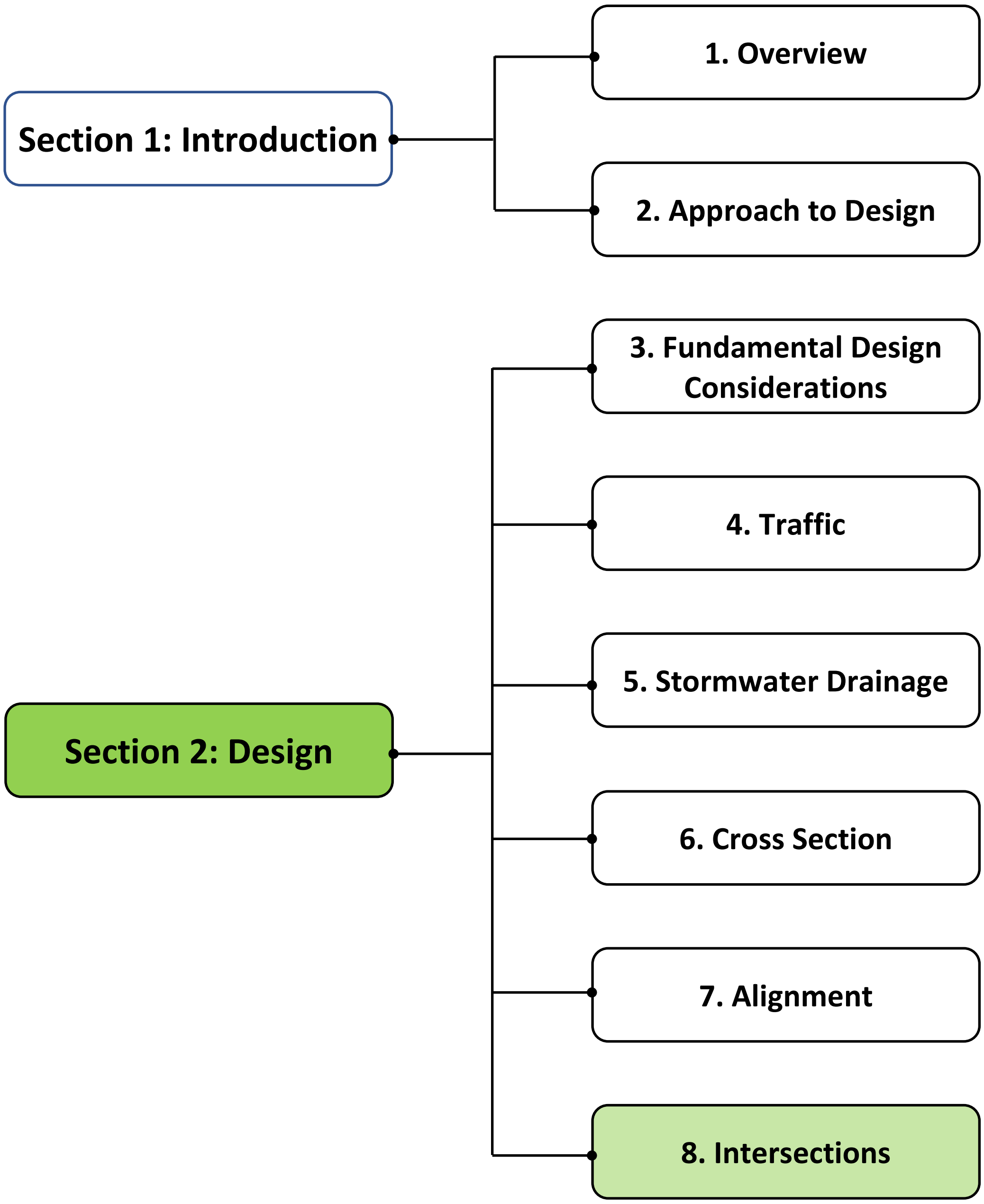
Low Volume Roads Manual
Part B – Geometric Design: Urban Roads



Chapter 8 - Intersections

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8.1 Introduction

8.1.1 Background

Intersections are an important part of the urban road and street facility because the efficiency, safety, speed, cost of operation and capacity of the facility depend on their design to a great extent. They are required to accommodate the need of pedestrians and vehicles to move in different directions that cross each other. Such movements may be facilitated by various geometric designs and traffic controls, depending on the type of intersection.

Pedestrian movements in different directions that cross each other are easily resolved in practice by people providing each other curtesy opportunities or gaps to facilitate the crossing manoeuvre. This is done virtually automatically and is hardly noticeable. This is not the case where vehicle paths or pedestrian and vehicle paths cross each other, and thus formal intersections are required to manage such movements.

The operation of an intersection requires that opposing traffic streams reduce speed or stop. This affects the capacities of the streets crossing each other and the capacity of an intersection is always lower than that of the preceding or following street sections. In consequence, it is the capacity of the intersections that determines the capacity of the transport system as a whole. Auxiliary lanes are often employed at intersections to alleviate this loss of capacity.

Vehicles travelling in the same direction are at low levels of risk. When travelling in opposing directions, the risk increases. Highest is the risk associated with vehicles travelling in directions that cross each other. Intersections are provided in the road and street network to facilitate such crossing and turning manoeuvres, which in turn require close attention to safety aspects in the design of intersections.

Manoeuvres at one intersection can influence manoeuvres at an adjacent intersection if too closely spaced. This requires attention being given to spacing as well in intersection design. Solving a congestion problem at one intersection may shift the same problem to the next intersection. It must also be recognised that every access onto a street, in essence, form an intersection, hence the need to control such access as well, particularly on higher order streets.

8.1.2 Purpose and Scope

Every intersection is a project in itself. Even when using typical geometric drawings, there is a need to consider the context, the intersecting road profiles, signage, drainage and capacity, among others.

The purpose and scope this chapter therefore are to:

- Discuss the safety considerations that affect the design of intersections. In this regard intersection sight distance stands paramount.
- Serve as a guide to identify attributes that would apply in a particular situation.
- Provide information on the design of the different types of intersections and their application, including aspects such as the use of channelization and auxiliary lanes.
- Illustrate typical intersections.

8.2 Intersection Sight Distance

Sufficient sight distance lies at the root of intersection safety. The stopping sight distance as discussed in *Chapter 7: Alignment* should always be available on all legs of an intersection. In addition, longer sight distances are required for comfortable and safe operations of vehicles entering or crossing the main street from the side street at intersections. In the earlier discussions of sight distance, the emphasis has been on the driver of a vehicle on the road or street and what he or she should be able to see. In the case of intersections, the emphasis moves to what a driver of a vehicle wanting to enter the street from the side or a pedestrian wanting to cross the street, must be able to see.

8.2.1 Sight Distance at Stop Controlled Intersections

At a stop-controlled intersection the driver of a stationary vehicle at the stop line must be able to see enough of the cross road to be able to carry out one of three operations before an approaching vehicle on the cross road reaches the intersection, even if this vehicle comes into sight as the stopped vehicle starts to move. These operations are:

- Turn to the left in advance of the vehicle approaching from the right.
- Turn to the right, in advance of vehicles approaching from the left and right.
- Move across the crossroad in advance of approaching vehicles from the left and right.

Turning movements

With regard to turning movements, intersection sight distance requirements are determined on the assumption, based on observations, that the turning vehicle will have accelerate to 85 % of the design speed before the approaching vehicle decelerating to 85 % of the design speed, reaches it. To provide a safety margin a 2 second gap between the two vehicles is further allowed for. Observations have also confirmed that there is no significant difference between the sight distance requirements for the two types of turning movements.

The stopped position of the vehicle wanting to execute the turning manoeuvre is taken as 5 m away from the nearest edge of the travelled way.

It may be noted that the traditional 2.4 m setback on the intersecting road, forming the third point defining the clear sight triangle has been increased to 5 m in recent times to allow for a cycle lane or a pedestrian crossing beyond the stop or yield line.

Crossing movement

In the case of the vehicle crossing the crossroad, the distance the crossing vehicle must complete is the sum of:

- The distance from the stop line to the edge of the crossroad carriageway
- The width of the road being crossed
- The length of the crossing vehicle.

This manoeuvre must be completed in the time it takes the approaching vehicle to reach the intersection, travelling at the design speed of the crossroad. For safety, a further two seconds is allowed, assuming this is the time a driver will spend to perceive that it is safe to cross, engage gear and set his vehicle in motion.

As in the case of the turning manoeuvres, the stopped position of the vehicle wanting to execute the crossing manoeuvre is taken as 5 m away from the nearest edge of the travelled way.

Sight diagrams

Figure 8-1 and Figure 8-2 provide information on the intersection sight distances as well as the clear sight triangles needed by the vehicle at the 5 m point for the turning and the crossing manoeuvres from stopped conditions. Obviously clear sight triangles must be available in both directions. The sketches in the two figures have been truncated for space saving reasons.

In determining clear lines of sight, the object height is taken as 1.3 m. The eye height is 1.05 m for a passenger car and 1.8 m for a truck or bus.

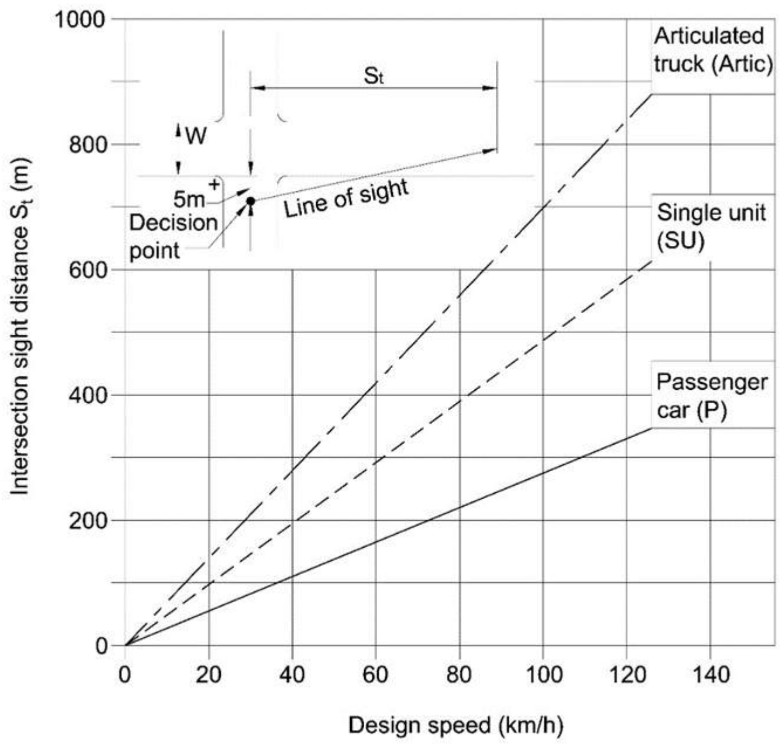


Figure 8-1: Intersection sight distance for turning manoeuvres from a stopped condition

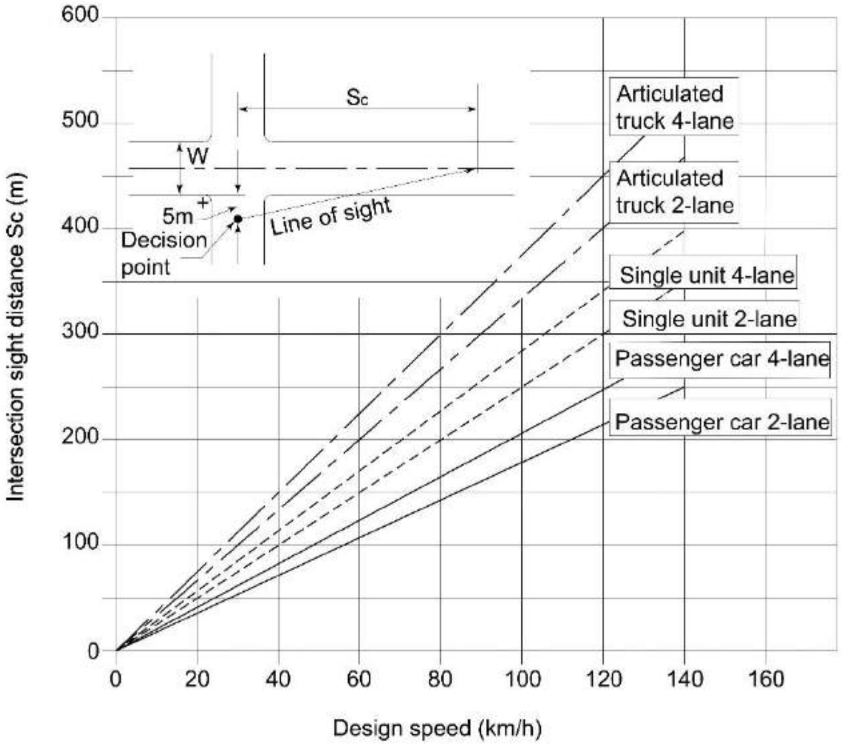


Figure 8-2: Intersection sight distance for crossing manoeuvres from a stopped condition

Note that the intersection sight distance is appreciably more than the corresponding stopping sight distance for the same design speed and hence a driver on the main road or street should have no difficulty in coming to a safe stop, should he or she perceive the vehicle from the cross road making a false movement.

8.2.2 Sight Distance at Yield Controlled Intersections

Where access to a road at an intersection is controlled by a yield sign, determining the clear sight triangle is approached from a slightly different perspective than at a stop-controlled intersection.

Observations of driver behaviour indicate that in determining the clear sight triangle for yield controlled access to a road from an intersecting road, it can be assumed that the entering vehicle will be doing so at a speed of 25 km/h to 30 km/h, while turning in the same direction as the oncoming vehicle and accelerating. The oncoming vehicle on the main road or street must reduce speed from the design speed of the main road to that of the entering vehicle and maintain a safe following gap. The distance required to give effect to these actions is the intersection sight distance for yield control (Sy).

Figure 8-3 provides information on intersection sight distances required for a yield-controlled intersection between a lower order street with a design speed of 60 km/h and a higher-order street.

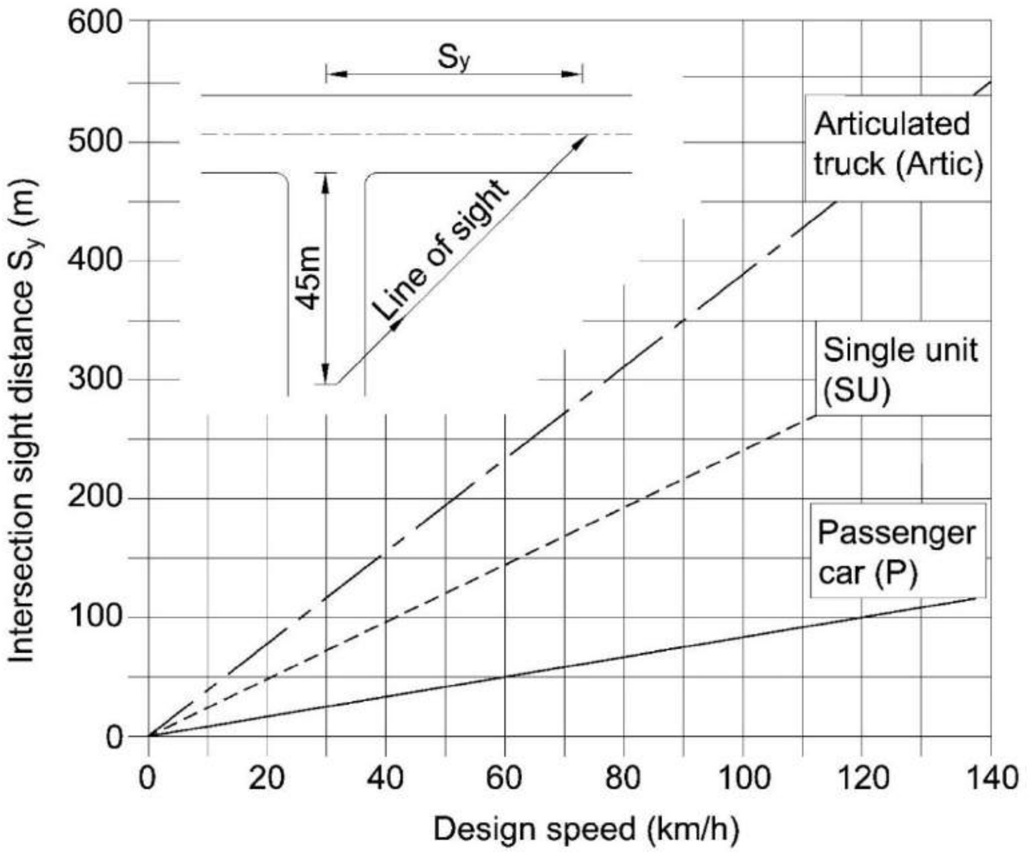


Figure 8-3: Intersection sight distance for yield conditions

In determining the clear sight triangle, the point of the sight triangle on the intersecting (cross) road or street is set back by 45 m from the edge of the travelled way of the main road. This setback is based on the distance required by the driver of the entering vehicle to perceive the need to stop, reduce speed from an assumed approach speed of 60 km/h and come to a stop should the yield-entry have to be aborted. As such, the 45 m distance is not influenced by the design speed of the main road.

The sight triangle so defined (by the distance of 45 m along the minor street and Sy - the intersection sight distance along the major street) only serves to define the area of clear lines of sight. Intersection sight distance for stopped conditions must also be available, as the vehicle that had to abort a yield entry by traffic conditions on the major road, now will have to start from a stopped condition to execute the desired manoeuvre.

For an intersection between a Class 5 street, with a design speed of 40 km/h, and another Class 5 street, the 45 m distance in Figure 8-3 would reduce to 7.5 m, but all other parameters given in the figure stay the same. This assumes that the driver being aware of the yield condition would approach the intersection at a speed of 30 km/h and only need to bring the vehicle to a stop, if it is not safe to enter.

Although the sight distance requirement (Sy) for yield conditions are appreciably shorter than those for the stopped condition (St), clear sight triangles for yield control may seldom be available in urban conditions, and this gives impetus to considering alternative intersection types such as mini circles.

8.2.3 Pedestrian Sight Distance

Intersections are intended points for pedestrians to cross streets. Pedestrians must therefore also be provided with adequate sight distance to do so safely. Pedestrian sight distance is measured from an eye height of 1.0 m to an object height of 1.3 m. It is a further point of departure that the crossing of the travelled way is to be done in one movement. The distances given in Table 8-1 should ensure a safe crossing of a two-lane street.

Table 8-1: Pedestrian sight distance requirements for a two-lane street

Design speed (km/h)	Sight distance (m)
30	45
40	55
50	70
60	85
70	100

8.3 Types of Intersections and Controls

8.3.1 Basic Considerations

Principally an at-grade intersection should only comprise a Tee or a Cross, i.e. have only three or four legs. It is a basic tenet of this manual that multi-way or multi-legged intersections, i.e. intersections with more than four legs should not be provided and that every effort should be made to redesign the layout where they occur in existing town layouts.

Skew intersections should also be avoided as they present problems with sight distance.

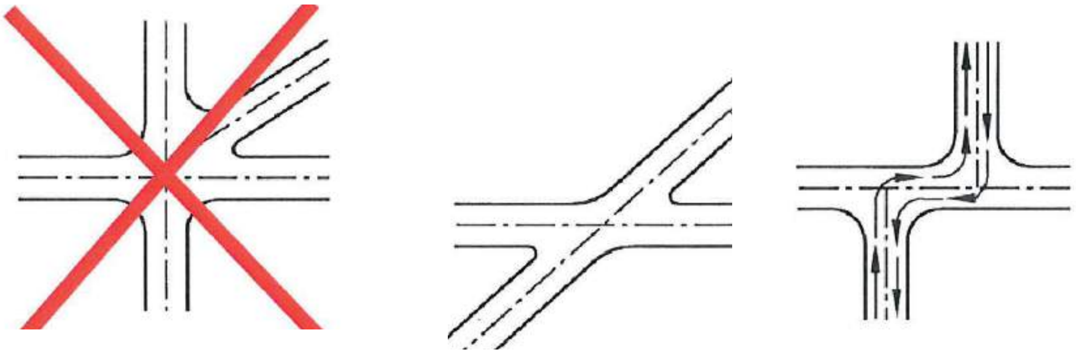


Figure 8-4: Multi-legged, skewed and staggered intersections

Staggering or offsetting intersections is one way of overcoming skewed intersections, but staggered intersections are not without their problems either, as drivers entering a through-street may turn left and then turn right at the next intersection to continue on their original direction of travel.

Traffic doing this so-called left-right stagger may have to stop on the through street awaiting a gap in oncoming traffic to complete the right turn, with associated capacity and safety risks. In the case of isolated intersections this problem can be eased by opting for a right-left stagger as illustrated in Figure 8-4 and Figure 8-5, but this is difficult to ensure in a street network type situation.

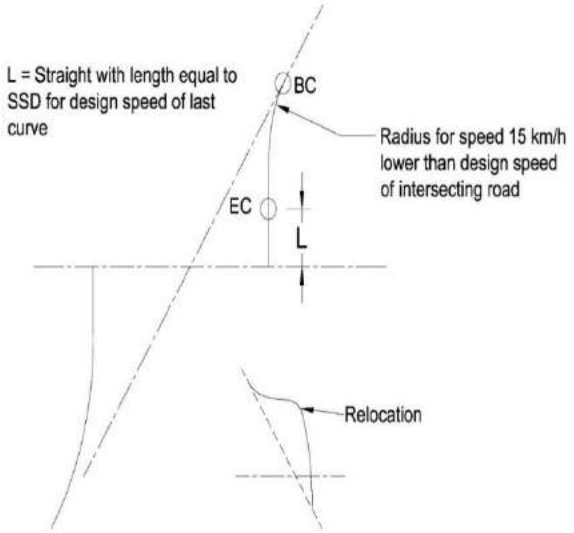


Figure 8-5: Options for correcting a too skew intersection

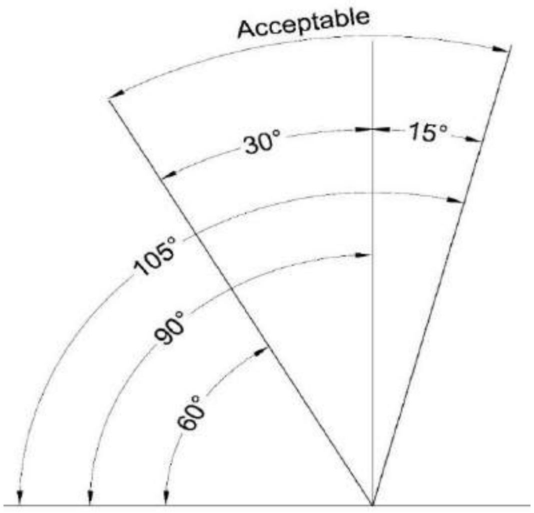


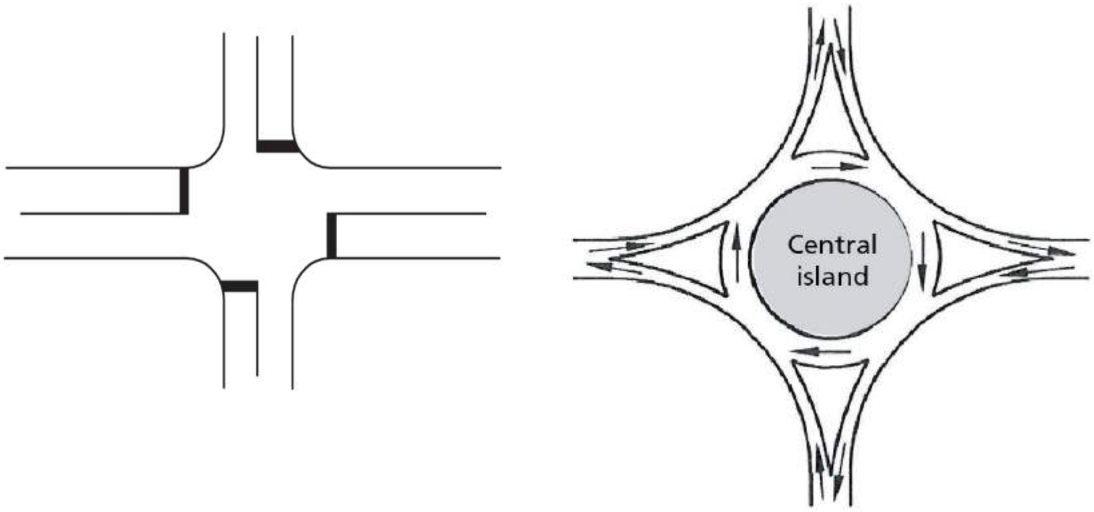
Figure 8-6: Acceptable angles of skew

Inappropriate angles of skew at intersections are a cause of great risk to safe road operations. Ideally all intersections should be at right angles although small deviations can be permitted. Acceptable angles of skew at an intersection are shown in Figure 8-6. Acceptable angles are between 60° and 105° measured from the axis of the main road as shown in the figure. The golden rule is that the driver of an intersecting vehicle should not have to turn his head more than 15 degrees to the left or 30 degrees to the right to observe oncoming traffic on the main road. The reason is that looking over his left shoulder a driver runs the risk of having his line of sight obstructed by a passenger or in the case of a large truck by the body of his vehicle. Looking over his right shoulder there is less risk of this happening.

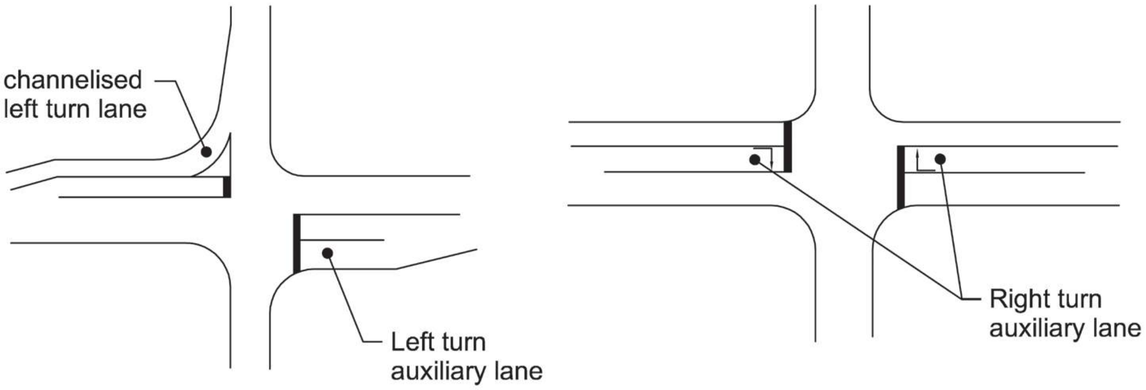
It should be noted that the requirements regarding angles of skew apply equally to three and four legged intersections comprising mini circles.

8.3.2 Types of Intersections

Basic intersection types are illustrated in Figure 8-7.



Simple **Mini circle**



Left turn auxiliary and channelized left turn **Right turn auxiliary lanes**

Figure 8-7: Intersection types

Simple intersections include in addition to the crossroads illustrated in Figure 8-7, T-junctions and staggered T-junctions. Simple intersections are suitable when volumes are low and turning lanes not warranted by vehicle delays. Most intersections on Class 4 and Class 5 streets should be of the simple type, or if difficulties are experienced with ease of access, comprise a mini circle. The more complex intersections illustrated in Figure 8-7 may be required at intersections of Class 4 streets with higher order roads and streets and are generally signalised. Should road reserve space permit, signalisation could normally be preceded by a roundabout.

8.3.3 Control

Intersections could be uncontrolled or controlled by traffic signs or traffic signals. In general, priority control by traffic signs is the most common form of intersection control. Priority control implies that one of the intersecting streets always take precedence over the other. In priority control of intersections, the through-way flow on the higher-order street is uninterrupted and control is exercised on the intersecting streets by either stop signs or yield signs.

Various types of intersection control are discussed below and illustrated in a series of figures. As all road marking and signage must conform to the requirements of the SADC Roads Traffic Signs Manual (SADC, 2012), those details are not repeated here.

8.3.4 Uncontrolled Intersections

Uncontrolled intersections are sometimes permitted on Class 5 streets, as it is argued that the low volume of traffic does not warrant control. This may be true, but sight is often lost of the commensurate need for adequate sight distance on all the legs of such intersections. For a design speed of 40 km/h as applicable to Class 5 streets, the required sight distance on both streets is 30 m. Such large clear sight triangles are not easily achievable in an urban context, as each quadrant of an intersection should contain a clear sight triangle free of obstructions that may block a driver's view of potential conflicting vehicles. The use of uncontrolled intersections must thus be approached with caution.

8.3.5 Yield-controlled Intersections

Yield control on the minor street is the most basic form of priority control at an intersection, whether three legged or four legged and generally is applied on the shorter or narrower of the two intersecting streets. A typical yield-controlled T-junction is illustrated in Figure 8-8.

For yield control, sufficient sight distance is required from the decision point on the minor street. Assuming that the vehicle on the minor street will be approaching the intersection prepared to stop or turn, and hence at a relatively low speed of 30 km/h, the distance required to bring the vehicle to a stop will be 7.5 m. The decision point thus will be 7.5 m back from the edge of the cross street. The required sight distance along the cross street is determined from Figure 8-3 as 30 m. Stopping sight distance must however also be available from the corresponding decision point 5 m back from the edge of the cross street.

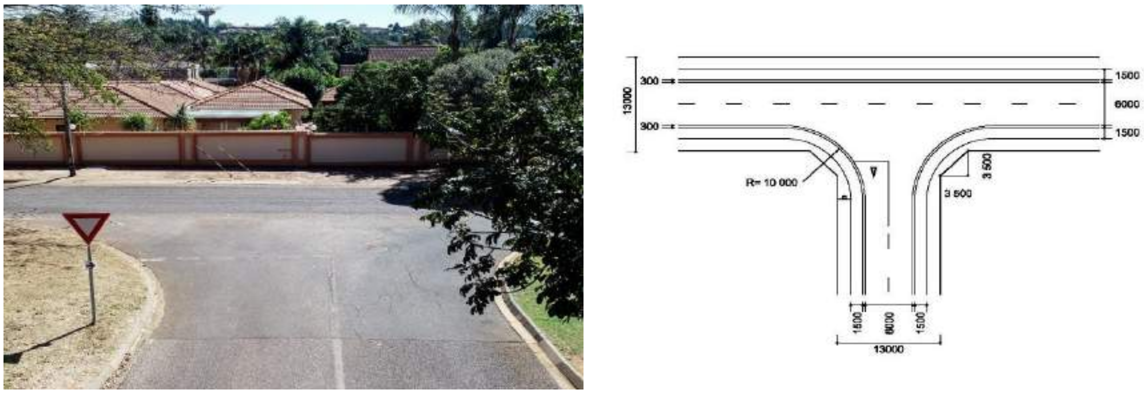


Figure 8-8: Yield controlled intersection between two Class 5 streets

8.3.6 Stop-controlled Intersections

As a rule, stop control is suitable for low traffic volume situations, where the main street is busier than the side street. Should sight distances be restricted at an intersection of two streets, or if there is a clear difference in the function of two intersecting streets, a stop control on the minor street is indicated, as shown in Figure 8-9.

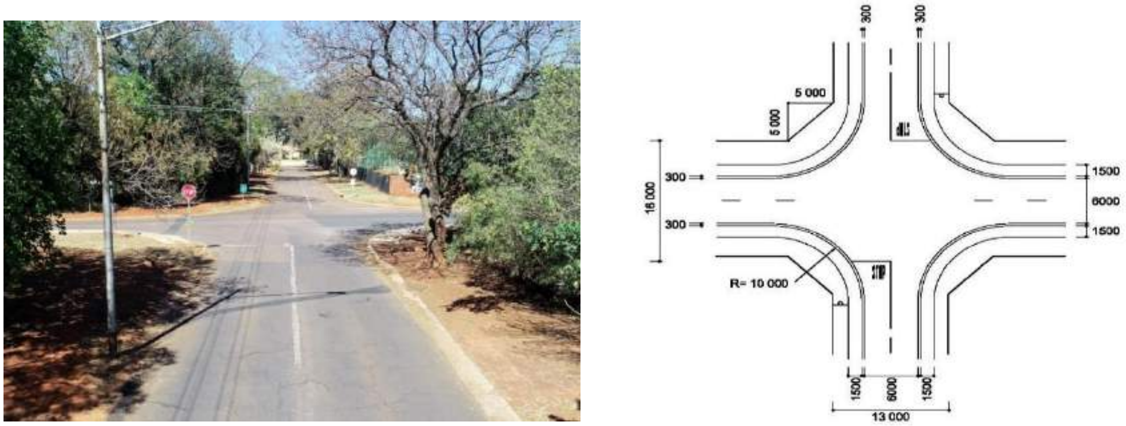


Figure 8-9: Stop-controlled Intersection between Class 5 streets and Class 4 Streets

8.3.7 Three or Four-Way Stop-controlled Intersections.

In the case of three or four-way stop-controlled intersections, the intersecting roads are viewed as of equal priority with traffic flows on the different legs more or less equal. The same level of control is exercised on all the intersecting legs, i.e. stops signs on all three or four legs. The control principle is "first come first serve", with the corollary that should two or more vehicles arrive simultaneously at the respective stop lines, priority is given to the vehicle on the right. Currently, four way stop signs have become somewhat of an anachronism with mini circles, offering a more effective alternative. Figure 8-10 shows such an intersection.

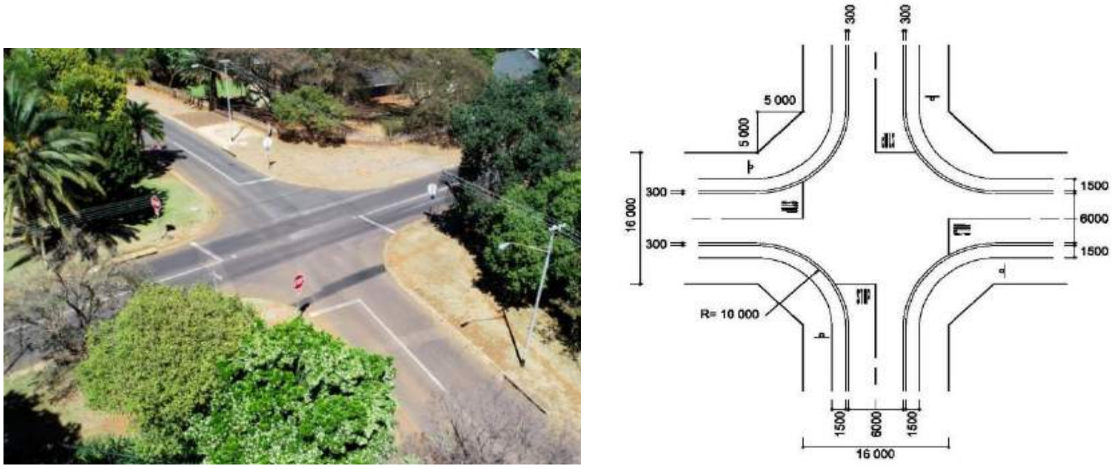


Figure 8-10: Four-way stop between two class 4 Streets

8.3.8 Three or Four-Way Yield-controlled Intersections

Multiway yield control is seldom used in view of the higher risks at the higher speeds associated with yield operations. Therefore, multiway yield control of intersections has been replaced by mini circles. To a certain extent this is also true of multiway stop control, especially where multiway stop control was originally (incorrectly) instituted as a way of traffic calming.

8.3.9 Signalized Intersections

Signalisation of intersections requires the installation of traffic lights or robots and generally are only found on higher-order mixed use (Class 3) and lower-order vehicle only (Class 2) roads and streets. However, a low volume street geometric designer may have to contend with a Class 4/Class 3 or even a Class 4/Class 2 intersection that may require signalisation. Hence signalisation is briefly dealt with herein.

The norm or warrant for signalisation of an intersection is the extent of delay experienced by traffic at a stop-controlled intersection. Various authorities have various norms, but a very straightforward and useful one stipulates that when a single waiting queue at an intersection reaches or exceeds four vehicles on average for an hour, during the peak period, traffic signals could be justified. In addition, if the sum of all the queues of vehicles on average throughout a full hour exceeds six, this would also justify signals.

However, these norms were determined before the modern roundabout was taken into consideration. Latest research shows that when a stop street reaches capacity, signalisation need not follow automatically. Mini circles and roundabouts can provide a very cost-effective steppingstone before traffic signals.

Mini circles operate slightly better than roundabouts in single lane approach situations, while a roundabout serves better for multilane approaches. When the total of queues waiting on approaches to a mini circle or roundabout exceeds 10 vehicles for an hour, traffic signals would perform better.

It must be cautioned though, that these norms are not absolute and that there are significant overlaps where more than one form of control will perform well. Engineering judgement thus remains the most important consideration.

8.3.10 Mini Circles.

The mini circle is a relatively recent development in traffic control devices. It is sometimes also referred to as a mini roundabout and is discussed in more detail as a traffic calming device in *Part C – Road Safety.* More details also appear in the *Typical Drawings* accompanying this Manual.

This Manual gives preference to the term mini circle to avoid any confusion with a full-scale roundabout. The roundabout is substantial in size, although much smaller than the traffic circles of yesteryear. The main difference between the latter two lies in the fact that the design of a roundabout is based on gap acceptance principles whereas the mini circle design accepts a first come first served approach. Incidentally, the design of a traditional traffic circle is based on traffic weaving principles, requiring long lengths of roadway between the different legs of the intersecting roads and hence resulting in very large layouts.

The mini circle slows traffic down to a safe speed in order to negotiate it, controls traffic by the “first come, first go” rule, in a similar way as four-way stops, namely in order of arrival, but yielding to the right should vehicles arrive simultaneously at their respective yield lines.

A typical mini circle is illustrated in Figure 8-11. The minicircle is situated in a suburban environment and serves an intersection between a Class 4, street and a Class 5 street.

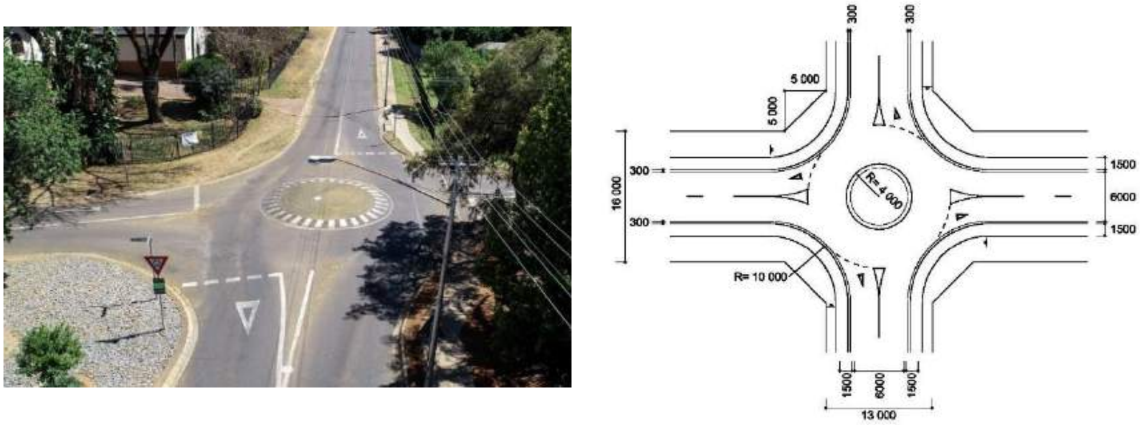


Figure 8-11: Typical mini circle

The mini circle is an efficient way of traffic control as it does away with the need for vehicles to stop at intersections and the associated waste of fuel while idling and then pulling away from stop. Mini circles are also effective in traffic calming as discussed in *Part C, Chapter 2 – Road Safety*, and as such is often used in conjunction with speed humps but is not dependent on speed humps to be effective.

Mini circles fill the large gap in traffic management where stop control is no longer ideal and traffic signals are not warranted. It is believed that mini circles are capable of handling up to 400 vehicles per hour with fair ease. As a rule of thumb, if the average queue per peak hour at a stop control exceeds two vehicles, a mini circle will improve the traffic flow and if the total peak hour average queue at a mini circle exceeds 10 vehicles, traffic signals should be considered.

Mini circle intersections have one circulating lane and can have from three to five legs. However, five legs should rather be reserved for retrofitting situations.

8.3.11 Roundabouts

Roundabouts are the next step up from mini circles and are generally more effective as they can handle two circulating lanes. Roundabouts operate on the principles of gap acceptance and yielding to the right. The dimensions of a roundabout depend on the dimensions of the intersecting roads.

Typically, it can vary from a central island diameter of 25 m for a single lane roundabout to 40 m for a two lane one, and corresponding outside or inscribed circle diameters of 40 m to 60 m. These dimensions are much larger than necessary for mini-circles and hence roundabouts are not appropriate for use in street environments.

8.3.12 Intersection Illustrations

In addition to the simple intersections illustrated above, illustrations of a few more complex intersections follow below, showing Class 5 streets and Class 4 streets intersecting with higher order streets.

Good practice calls for roads and streets only to intersect with others of the same class, or one or at the utmost two classes up or down in the movement network, with the latter being the exception rather than the rule. Some of the following illustrations fall within the ambit of such exceptions.

Certain aspects illustrated in the figures such as the use of islands, turning roadways and the like are discussed in more detail in the following sections of this Chapter.

Class 5 Street intersecting a Class 3 Street

The first illustration, Figure 8-12, involves a “semi” intersection between a Class 5 street and a Class 3 street. This situation resulted from a retrofitting exercise.

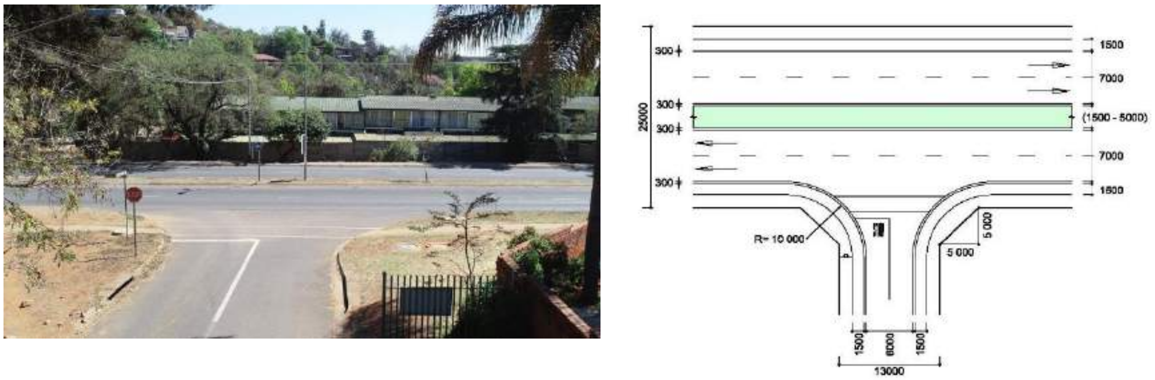


Figure 8-12: Class 5 Street intersecting a Class 3 Street

The intersection in Figure 8-12 provides access only to and from one of the two main street carriageways. Colloquially this type of intersection is often referred to as a “Left in - Left out” intersection. Being an intersection involving a Class 3 street, the pedestrian crossing is marked. It is not normal practise to mark pedestrian crossing on Class 4 and Class 5 intersections.

Class 4 Street intersecting a Class 3 Street

Figure 8-13: Class 4 Street Intersecting a Class 3 Street

The intersection in Figure 8-13 allows access to and from both carriageways of a Class 3 street, incorporating left turn slip lanes. A right turn slot on the far carriageway of the Class 3 street is not clear in the photograph but is shown in the sketch. The intersection geometry determines the street reserve space and corner splays required, provided sight distance requirements are met.

Nose positions on the median island are determined by the turning movements of the design vehicle.

Class 4 Bus Route intersecting a Class 3 Street

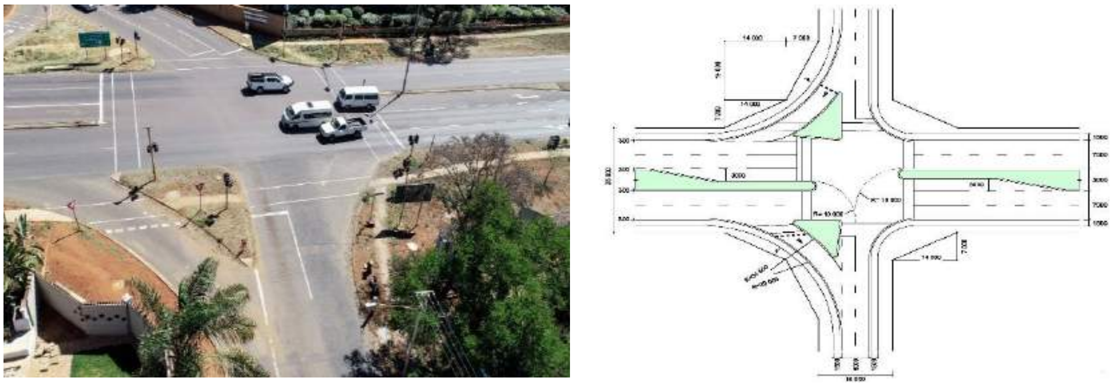


Figure 8-14: Class 4 Street, acting as bus route, intersecting a Class 3 Street

The intersection in Figure 8-14 is also giving access to local shops and is signalised. Right turning slots (auxiliary lanes) are provided on both carriageways of the main street, with a left turning roadway easing bus turning movements onto the main street. Pedestrian crossings are provided across all roadways.

Class 4 Street, acting as Bus Route, intersecting a Class 2 Road

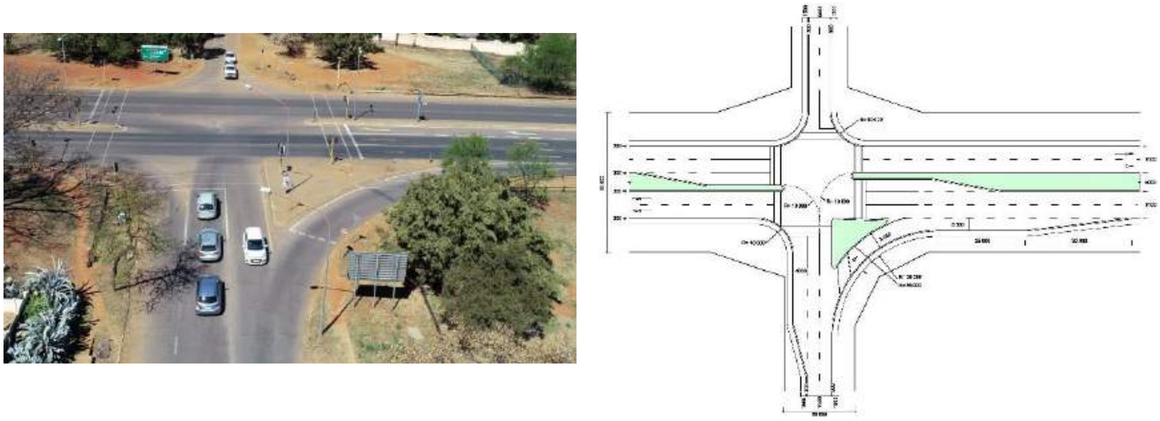


Figure 8-15: Intersection between a Class 4 street bus route and a Class 2 Road

The intersection is signalised with right turning auxiliary lanes in both directions on the Class 2 road, with a slip lane and a short auxiliary lane onto and off the Class 4 street. The channelized left turn slip lane from the main road serves the bus route.

8.4 Intersection Layout and Spacing

8.4.1 General

Intersections must serve both crossing as well as turning movements. To ease the turning movement the intersection corners are rounded, creating so-called bellmouths. The radii used to create these bellmouths should not be longer than necessary for easing the turning movement. Bellmouths that are larger than required incur unnecessary construction expenses and can lead to unsatisfactory operations. Pedestrian crossing distances increase with the corner radius and the speed of turning vehicles is higher, both detracting from pedestrian comfort and safety.

In most cases a simple radius is the preferred design for establishing bellmouths, but short radii with approach tapers and three-centre curves are often favoured by designers.

8.4.2 Bellmouths

Intersection bell-mouths on Class 5 streets (local streets), could comprise simple 10 m radius curves. However, with 1:15 tapers on either side, the curve could be reduced to a 6 m radius. Alternatively, a three-centred curve with minimum radius of 6 m and ratio of curvature of 2:1:4 could be considered. For bellmouths to be negotiated by buses, a minimum radius of 15 m is recommended. Depending on the degree of skew, skewed intersections would call for the use of different radii at the different quadrants as shown in Figure 8-16.

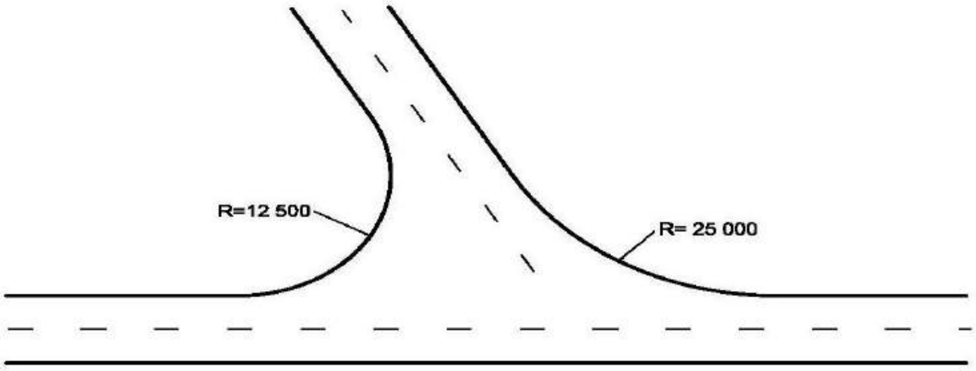


Figure 8-16: Typical skewed intersection bellmouth

Control of traffic movements is eased at skewed intersections by the use of small islands (not illustrated in Figure 8-16). Small islands also serve to reduce the area of surfacing in the case of surfaced streets and assist pedestrians in their crossing movements.

Semi-mountable kerbing is recommended for intersection bellmouths because of the more visible demarcation it provides than mountable kerbing and the lesser risk of damage to a straying vehicle, compared to a barrier kerb.

8.4.3 Channelization, Islands and Tapers

Channelization involves the use of kerbed and or painted islands in the management of traffic. Regarding low volume streets, channelization is mainly encountered in relation to mini circles Channelization and islands may also be required at intersections between Class 4 streets and higher order road and streets, particularly where pedestrian volumes are high. In this case the function is directed at the protection of the pedestrians by the provision of refuges for them while crossing traffic flows.

Walking speeds are typically of the order of 1.5 m/s, but in the vicinity of crèches, old-age homes and the like, the speed could be about 1.0 m/s. Crossing a two-lane street would thus require a gap between vehicles of about seven seconds. This should not present a problem on lower-order mixed-use streets but on higher order streets would require a refuge on the median. It is recommended that a pedestrian should not be required to cross more than four traffic lanes, or five at the utmost, including auxiliary lanes, before reaching a refuge.

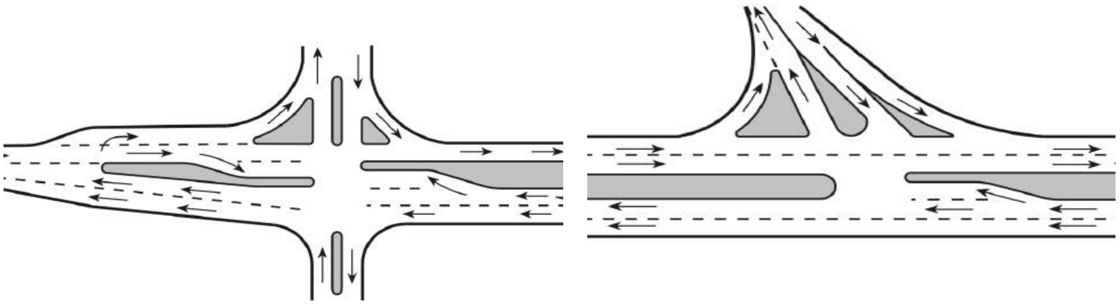


Figure 8-17: Typical examples of channelization at intersections

Refuge islands to protect pedestrians are also suitable for protecting traffic control devices. To be visible and to afford the desired protection, islands should be kerbed and of sufficient size. A minimum size of 5 m^2 is recommended. The minimum width of a median island for pedestrian protection should be 1.5 m, with 3.0 m as desirable. Pedestrian refuge islands should be provided with barrier kerbing, with suitable ramps or kerb breaks for prams, wheelchair users and other persons with walking difficulties.

Island kerbing is intrusive in the roadway and should thus be provided with rounded noses and be preceded and followed by tapering road marking. Active taper rates are to be applied to create the space for the island and passive tapers to reinstate the normal cross section.

Active and passive taper rates for various design speeds are shown in Table 8-2. Active taper refers to a taper requiring positive action by a driver, e.g. at the approach end of an island while a passive taper provides guidance at the departing end.

Table 8-2: Taper rates

Design speed (km/h)	**30**	**40**	**50**	**60**	**80**	**100**
	Passive tapers					
Taper rate (1: x)	1:5	1:8	1:10	1:15	1:20	1:25
	Active tapers					
Taper rate for painted islands (1: x)	1:20	1:23	1:25	1:35	1:40	1:45
Taper rate for kerbed tapers (1: x)	1:10	1:13	1:15	1:20	1:25	1:30

As indicated, channelized turning roadways would normally not be required on Class 4 and Class 5 street intersections but may be required at intersections with higher order streets as shown in some of the illustration above. In creating a turning roadway, a simple 25 m inner radius curve with 1:10 tapers would normally suffice at unsignalized intersections. At signalised intersections, where pedestrian refuge islands are required, the radii may have to be increased to the order of 35 m to align the pedestrian crossing with the islands. The width of the turning roadway should be of the order of 6.0 m to accommodate a single unit bus. Figure 8-18 illustrates a typical channelized turning roadway, often also referred to as a slip lane.

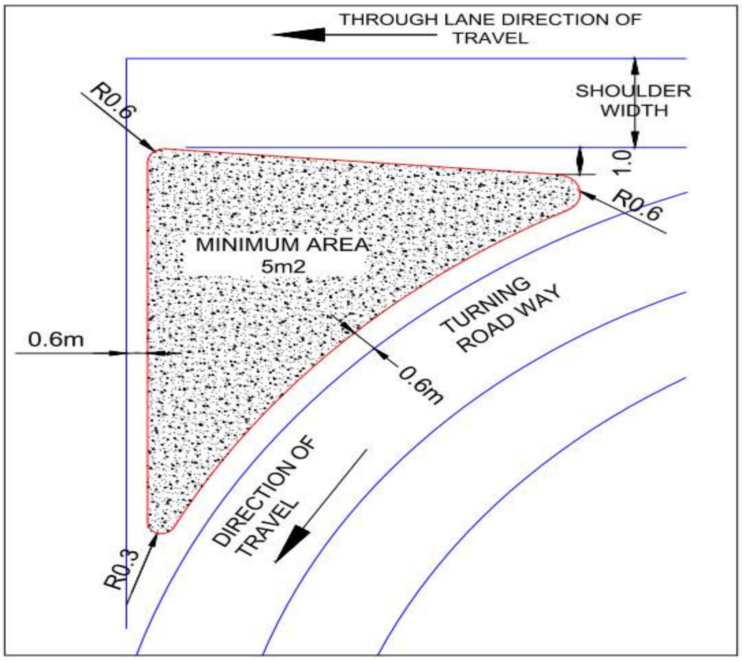


Figure 8-18: Typical channelized turning roadway and island

8.4.4 Auxiliary Lanes

Although auxiliary lanes would not often come into play in the geometric design of low volume streets, they are briefly discussed as they may have to be considered in the design of intersections with higher order streets.

Auxiliary lanes are added outside the through lanes at an intersection to counteract the loss of capacity due to the intersection. These lanes can take the form of left and/or right turning lanes or even additional through lanes. Figure 8-19 illustrates the principle of auxiliary lanes.

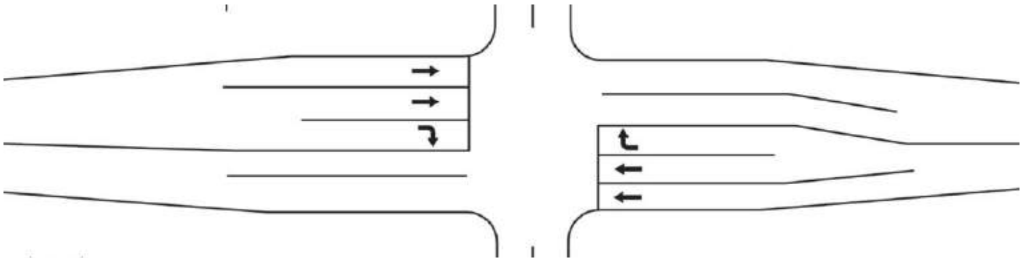


Figure 8-19: Typical intersection with auxiliary lanes

Auxiliary lane widths are normally slightly narrower than the approaching traffic lanes, with 3.3 m as norm and 3.0 m viewed as minimum.

Right turn lanes typically have a storage length of 25 m, while the storage length of a left turn auxiliary lane is typically 20 m. Assuming operational speed of the order of 70 km/h in the vicinity of traffic signals, the length of the preceding deceleration lane would be 100 m in both instances. For an operational speed of 50 km/h, the deceleration lane length would be halved.

Tapers are provided at the start and end of auxiliary lanes. At the approach end of an auxiliary lane a passive taper is required, while an active taper is needed at the termination of auxiliary lanes. The lengths of active and passive tapers for channelization and island kerbing are given in Table 8-2 above.

In establishing auxiliary lanes, it is essential to ensure that sight distance for right turning traffic is not compromised by opposing vehicles. To this end right turn lanes on either side of the intersection should be aligned face to face.

8.4.5 Corner Splays

Depending on the dimensions of the intersecting street reserves, property boundaries may have to be splayed to ensure adequate sight distance as illustrated for instance in Figure 8-8 and in Figure 8-9. A minimum splay of 3.5 m x 3.5 m is indicated, with 5.0 m x 5.0 m preferred. More complex intersections would require more complex corner splays as shown in Figure 8-11, the emphasis remaining adequate sight distance but also taking as little land as possible for street reserve purposes.

8.4.6 Intersection Spacing

On lower-order, mixed use Class 5 local streets, the goal is maximum accessibility, and as operational speeds are low there is little need to control access. However, the town planning should ensure that intersections are not so close together that waiting traffic at one intersection could generate a queue that extends beyond the next upstream intersection. Hence, it is considered desirable to maintain minimum block lengths of the order of 80 m to 100 m.

Intersection spacing with regard to traffic progression would not normally come into play on lower-order-mixed-use streets, but where an intersection on a higher order street has to be established, the spacing between intersections on such a road should not be compromised. Green wave progression on signalised roads would require spacing distances of the order of 500 m to 800 m. No intermediate intersection should also be considered within the decision sight distance of another.

In all cases the various requirements pertaining to sight distances must be adhered to. For this reason, intersections on horizontal curves are to be avoided.

8.4.7 Functional Areas at Intersections

In the design of intersections, attention is normally focused on the physical aspects. Equally important from a capacity and safety point of view, is the so-called functional areas upstream and downstream of the intersection. In this regard it is important to ensure that the influence of successive intersections does not overlap. Drivers are required to make numerous decisions and take several actions in the functional area of an intersection. An overlap between functional areas would increase the drivers' workload, resulting in an increased risk of crashes and negatively affect smooth traffic operations.

For lower-order Class 4 and Class 5 multi-use streets, a combined length of upstream and downstream functional areas of the order of 60 m is recommended.

8.4.8 Matching Grade Lines at Intersections.

Marrying the vertical alignment of the intersecting roadways can be problematic.

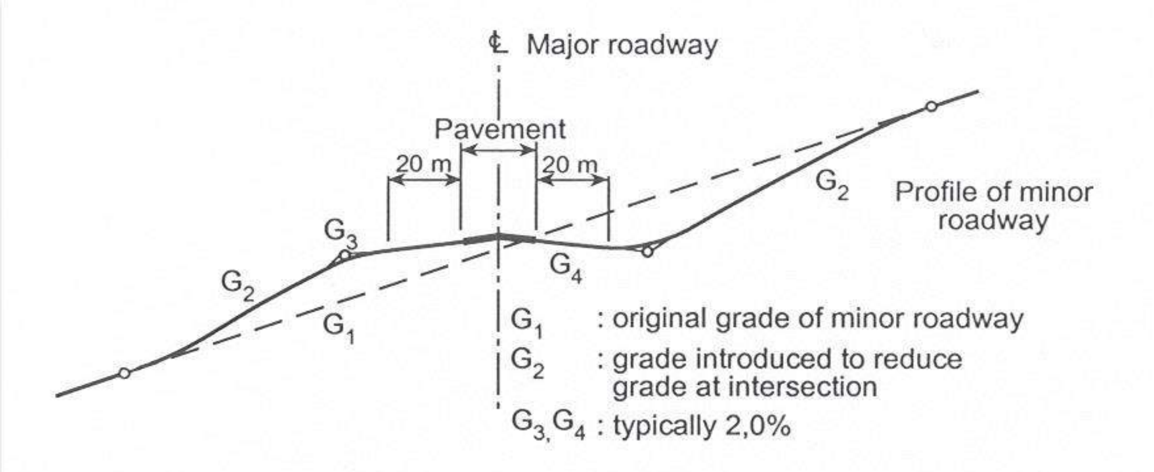
In the design and construction of intersections, it is of paramount importance to ensure that no local low spots are generated where stormwater could pool.

As mentioned before, the grades at intersections with higher order roads should preferably not exceed 3 %.

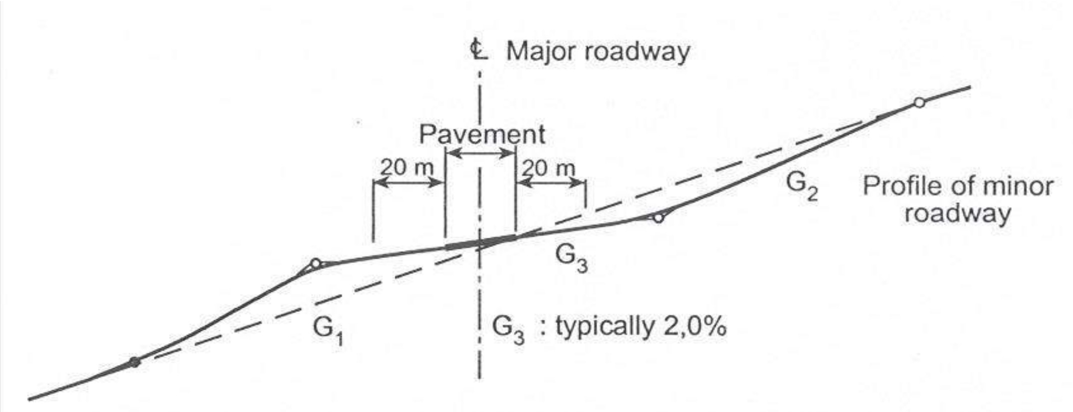
Care also has to be exercised with intersections on steep grades (6 % or more), as stopping sight distances on such grades are appreciably higher than on grades of 3 % or less. Drivers also seem to have difficulty in judging distance on steep grades.

If it is not possible to achieve grades through intersections of 3 % or less, the through road should be designed with the steeper gradient. On the cross street, local reductions in gradient could also be considered in such instances to facilitate pulling away, and a reverse curve incorporated in the vertical alignment.

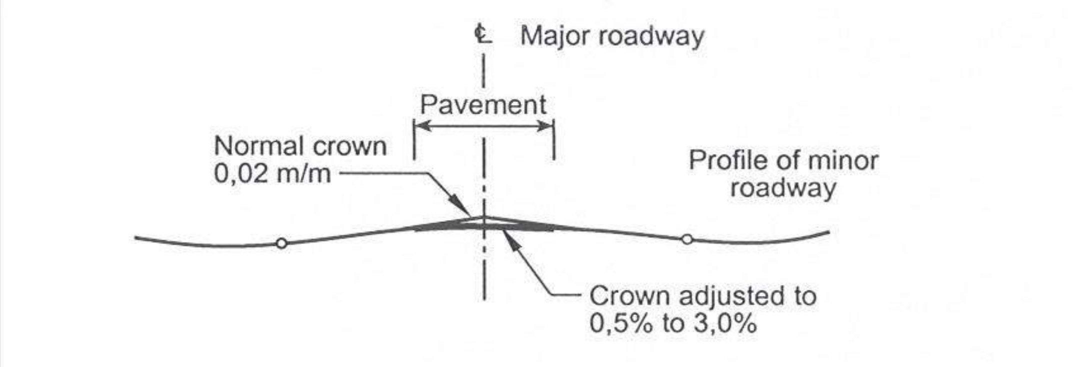
Figure 8-20 illustrates three possible methods for matching grade lines, with preference given to the second and third examples.



Minor roadway profile changed to fit crown of major roadway



Crown removed on major roadway to accommodate minor roadway (typical consideration, if intersection may be signalised)



Crown reduced on major roadway to accommodate minor roadway

Figure 8-20: Matching grade lines

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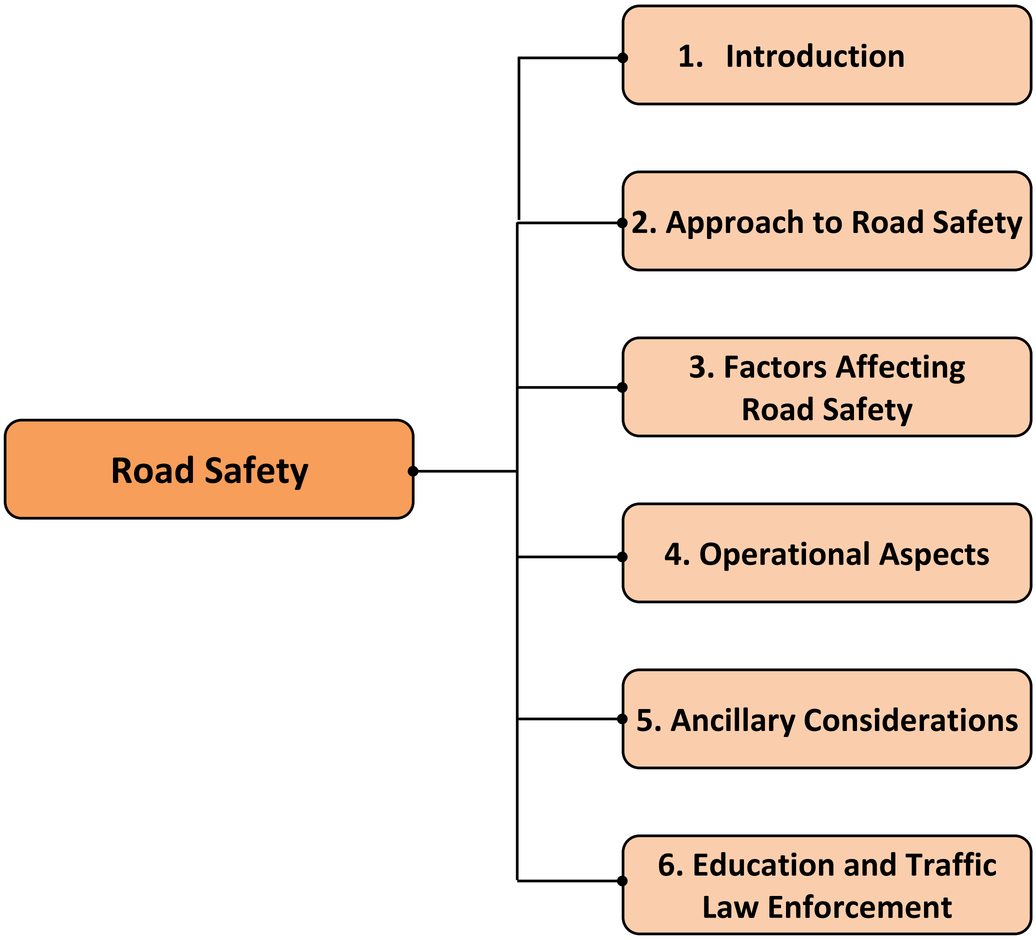
Part C

Road Safety

Low Volume Roads Manual
Part C – Road Safety



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1 Introduction

1.1 Background

Road safety is of prime importance for all Malawians and not only road users. The consequences of accidents impact significantly on the national economy in terms of property damage, loss of earnings or production and hospital costs resulting from physical injury, in addition to the emotional consequences of pain, suffering and death. Unfortunately, the road accident statistics in Malawi, in common with many other countries, show that death rates from road accidents are 30 to 50 times higher than in the countries of Western Europe, despite much lower traffic densities. Economic analysis has shown that this high level of road accidents is equivalent to a reduction of between 2% and 3% of GDP. These figures highlight the importance of extending road safety measures to LVRs in a holistic and proactive manner, as presented in this Part C of the Manual.

The safety issues on LVRs tend to be different to those on high volume roads, mainly because there are usually a higher number of vulnerable road users present such as, pedestrians, cyclists (including bicycle taxis), motorcyclists and animal-drawn carts that are generally not adequately catered for. In some rural areas, bicycles account for up to 60 % of all local travel. Bicycle-taxis are a common means of transport in Malawi, servicing trading centres, small towns and villages. Moreover, motorcycles have become a popular form of transport and their use has unfortunately resulted in a high incidence of accidents. Thus, specific design considerations are required to deal with the challenge of catering for a mix of traffic modes in both rural and urban environments.

Figure 1-1: Vulnerable road users

It is also important to recognise that road safety issues in rural and urban environments tend to be quite different due to the nature of the layout of the road system. Thus, different solutions are required to address the road safety challenges in these differing environments. For example, urban LVRs generally tend to be at the higher end of the scale with regard to traffic volume, whereas rural LVRs generally tend to be more at the lower end of the scale. Thus, the class of LVR will influence the level of road safety measure(s) that will be required. Moreover, paved and unpaved LVRs, whether in urban or rural environments, also require different approaches with regard to the application of road safety measures such as signage, markings and traffic calming.

Similarities between urban and rural LVRs include aspects such as street lighting, road safety audits, road safety inspections and public transport stops, small structures and more, although the extent of the application will be different for urban and rural environments.

In addition to road design, a range of techniques for directly influencing road user behaviour is also required, including education, publicity and traffic law enforcement.

1.2 Purpose

The main purpose of Part C of the Manual is to promote safer road planning and design practices in Malawi by bringing safety to the forefront of the minds of planners and engineers in the country. In so doing, Part C highlights important aspects of design that affect road safety and provides guidance on dealing with them in a holistic and integrative manner in both low volume rural and urban environments of the country. Part C does so in a manner that is not only appropriate to the specific needs of Malawi but also with a recognition of the need to strike a rational balance between road investment, safety and service level.

1.3 Scope

After presenting the approach to road safety on LVRs in rural and urban environments in Malawi, Part C then considers the main factors that affect road safety followed by various complementary, good-practice measures, such as road safety audits, road safety inspections, traffic calming, road signage and markings that are typically undertaken to reduce accidents on LVRs. Part C also addresses street lighting, rail crossings and bridges and ancillary matters, such as public transport facilities, landscaping and waste removal, and, finally, road safety education and traffic law enforcement.

1.4 Structure of the Manual

Part C is divided into six chapters as shown in Table 1-1. There is also an extensive bibliography that provides links to many of the topics discussed in the document. Because the chapters are relatively short and the issues interrelated, a bibliography is provided after the last chapter of Part C.

Table 1-1: Structure and Content of the Manual

Part C – Road Safety	
Section	**Chapter**
Road Safety	1. Introduction 2. Approach to Road Safety 3. Factors Affecting Road Safety 4. Operational Aspects 5. Ancillary Considerations 6. Education and Traffic Law Enforcement

Appendices	
Appendix A	**Glossary of Terms**

1.5 Benefits of Using the Manual

There are several benefits to be derived from adopting the approaches advocated in the Guideline, including:

- Recognition of the multi-casual nature of road accidents and adoption of the Safe Systems approach for managing all the elements that contribute to improved road safety.
- The application of Road Safety Audits and Road Safety Inspections to ensure that LVRRs are designed and constructed to comply with minimum operational road safety requirements.
- Engendering a better understanding of the road safety needs in a mixed traffic environment where the different road users have to share limited road space.
- Recognition of the importance of road maintenance to ensure safe operational conditions.
- The involvement of communities and law enforcement officers to educate road users and enforce traffic laws.

1.6 Sources of Information

In addition to providing general information and guidance, the Manual also serves as a valuable source document because of its comprehensive lists of references from which readers can obtain more detailed information to meet their particular needs. A bibliography can be found at the end of each chapter of the Manual. Where the sources of any tables or figures are not specifically indicated, they are attributed to the authors.

1.7 Updating of the Guideline

As LVR technology is continually being researched and improved, it will be necessary to update the Manual periodically to reflect improvements in practice. All suggestions to improve the Manual should be in accordance with the following procedures:

- Any proposed amendments should be sent to the RA, motivating the need for the change and indicating the proposed amendment.
- Any agreed changes to the Manual will be approved by the RA, after which all stakeholders will be advised accordingly.

1.8 Departure from Standards

There may be situations where the road safety practitioner may be compelled to deviate from a road safety requirement presented in this Manual. Where this is necessary, the practitioner must obtain written approval and authorization from the RA. The practitioner shall submit the following information to the RA.

- The aspect of the road safety requirement from which departure is desired.
- A description of the road safety requirement, and the extent of departure from that requirement.
- The reasons for the departure from the requirement.
- Any mitigation measure(s) to be applied for reducing the risk of accidents.

2 Approach to Road Safety

2.1 General

Several approaches aimed at achieving sustainable road safety have been successfully adopted internationally to ensure that the roads or streets and their environments, are optimally designed to cater for all road users. This includes concepts such as *'Safe Systems' and 'Complete Streets',* as discussed below.

2.2 Sustainable Road Safety

2.2.1 General

A sustainably safe road traffic system aims at preventing deaths, injuries and damage to vehicles and property by systematically reducing the underlying risks of the entire traffic system. Human factors, as discussed in Chapter 3, are the primary focus. By starting from the needs, competences, limitations and vulnerability of people, the traffic system can be realistically adapted to achieve maximum safety.

2.2.2 'Safe Systems' Approach

The concept behind the 'Safe Systems' approach is to build a road transport system that tolerates human error and minimises casualties following road accidents. The guiding principles to this approach are:

- **People make mistakes.** Humans will continue to make mistakes, and the transport system must accommodate these errors. The transport system should not result in death or serious injury as a consequence of errors on the roads.

- **Human physical frailty**. There are known physical limits to the amount of force the human body can take before it is injured.

- **A 'forgiving' road transport system.** A 'Safe System' ensures that the impact forces in accidents do not exceed the limits of human tolerance. Speeds must be managed so that humans are not exposed to impact forces beyond their physical tolerance. System designers and operators need to take into account the limits of the human body in designing and maintaining roads, vehicles and speeds.

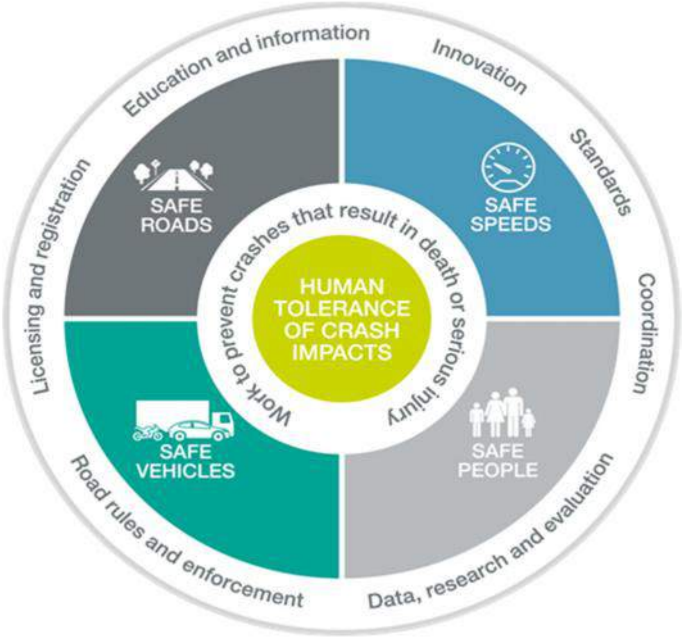


Figure 2-1: 'Safe Systems' approach

The four key elements of the 'Safe Systems' approach are 'Safe People', 'Safe Roads and Roadsides', 'Safe Speeds', and 'Safe Vehicles', as illustrated in Figure 2-1. In contrast to traditional road safety approaches that primarily focus on road users and risky behaviours, the 'Safe System' approach provides a systematic method to reduce accident occurrence and subsequent injuries in the event of an accident.

2.2.3 Complete Streets

The 'Complete Streets' concept aims at providing space for all road users in urban environments – the car, pedestrians and cyclists – in a segregated manner, as illustrated in Figure 2-2. The concept thus has a positive impact on urban road safety. Layout details of 'Complete Streets' are covered in Part B as well as in international manuals, some of which are listed in the bibliography.

Figure 2-2: Typical idealised layout of a local residential street (Class 5)

2.3 Road Safety Audit and Inspection

2.3.1 General

The undertaking of Road Safety Audits (RSA) and Road Safety Inspections (RSI) are critical to ensure that all road safety aspects are incorporated into and maintained from inception through the project life cycle, as illustrated in Figure 2-3.

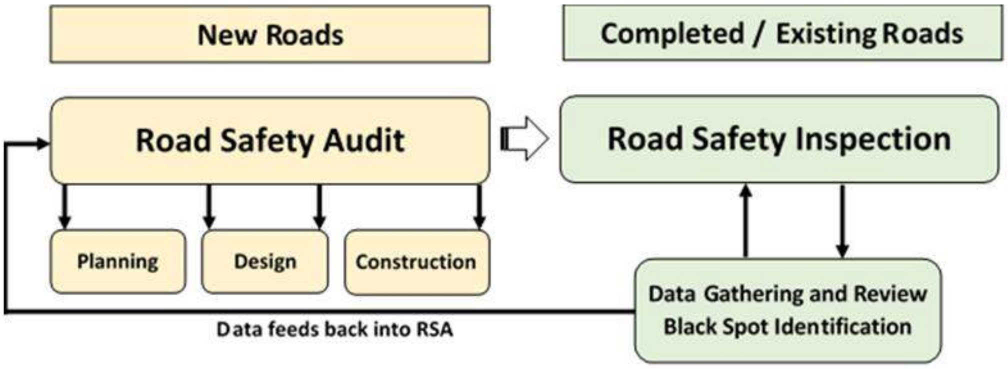


Figure 2-3: Road safety audit and inspection

2.3.2 Road Safety Audits

General

Safety should be given special attention at all stages of the road design process. Malawi has adopted an effective means of achieving this goal by use of Road Safety Audits (RSA), which may be defined as a formal procedure for assessing accident potential and safety performance in the road network. The road safety audit assesses the operation of a road from the perspective of all road users, including pedestrians, cyclists, motorcyclists, truck/bus drivers, public transport users, etc.

The main aim of a RSA is to ensure that necessary provisions for road safety have been taken into account in the project design and sustained throughout the entire duration of its operation. This means that road safety should be considered throughout the entire project cycle, from the planning, design, construction, pre-opening and during operation of the road. A RSA can contribute significantly to the effort in reducing the risks of occurrence of accidents.

The RSA should be carried out by an independent auditor, who is not involved in the design or in the construction of the road. The auditor should be a qualified individual with expertise, experience and training in road safety engineering and design. Road designers apply quality assurance techniques to ensure that all aspects of road design have been incorporated. However, whilst this activity includes checking on road safety issues, it is different from a RSA, because it is not done independently, which is of paramount importance. For further information, reference is made to *The Malawi Road Safety Engineering Manual*.

Figure 2-4: Multi-disciplinary audit team assessing an existing road safety system

The cost of a RSA and the consequent cost of changing a design are invariably, significantly less than the cost of remedial treatments after the works are constructed.

Planning

It is often possible to improve road safety characteristics at markedly little or no extra cost, provided the road safety implications of design are considered at the planning stage. This requires adherence to a number of key principles inherent in the design processes and standards of this Manual, but well worth stating clearly. They are:

- Undertaking appropriate traffic counts
  - Ensuring that traffic counts are also taken of motorcycles and NMT e.g. pedestrians, bicycles and animal-drawn carts. Such information will be influential in planning aspects of the geometric layout of the road, such as shoulder widths.
- Catering for all road users
  - Includes non-motorised and vulnerable road users such as pedestrians, cyclists, motorcyclists, disabled persons, animal-drawn carts, etc.
  - Has implications for almost all aspects of road design, including carriageway width, shoulder design, side slopes and side drains.
- Creating a forgiving road environment
  - Forgives a driver’s mistakes or vehicle failure to the extent possible without significantly increasing costs.
- Providing a clear and consistent message to the driver
  - Roads should be easily “read” and understood by drivers and should not present them with any sudden surprises.
- Encouraging appropriate speeds and behaviour
  - Traffic speed can be influenced by altering the “look” of the road, for example, by providing clear visual clues such as changing the shoulder treatment or installing prominent signing.
- Reducing conflicts
  - Conflict cannot be avoided entirely but can be reduced by design, including staggering junctions or channelizing pedestrians to safer crossing points.
  - Ensures that demands beyond the driver’s ability to manage, are not placed upon the driver.

Design

The geometric design of rural and urban roads, which is addressed in Parts A and B of the Manual, deals with the technical aspects of design. However, in dealing with LVR safety, the road safety aspects must be incorporated as part of the design criteria during the development of the detailed design of the project. Generally, there are three main aspects of road design which have a direct effect on road safety:

- Road alignment (horizontal and vertical)
- Road width
- Sight distance

The effect of the above factors depends on their combined influence.

Horizontal alignment: This is one of the factors which controls the speeds of vehicles. The greater the curvature (sinuosity of the road in degrees/km), the lower the speed tends to be, and the lower the speed, the safer the road.

Accidents may arise where straight sections of the road are followed by sharp bends without due warning to the drivers. In such cases, a driver will feel comfortable travelling at a relatively high speed on the straight sections, and the sharp bends will present an unexpected hazard. In such a situation, typical safety countermeasures that would appear to be both feasible and effective include:

(a) Increasing the radius of curvature of the sharp bend to accommodate a higher speed.

(b) Adopting traffic calming countermeasures, such as rumble strips, road humps and road signage, to reduce the driver's speed.

The above options present different costs and different levels of effectiveness. Ideally, a cost-benefit analysis of the two options should be undertaken to decide on the preferred option. However, in practice, there are often insufficient accident statistics and accident analyses on LVRs on which to base such a decision. Thus, a pragmatic decision will have to be made taking account of such factors as:

- the severity of the problem;
- ease of implementing the option, and, importantly,
- the amount of traffic likely to use the road over its design life.

Accidents tend to occur when speeds are high and the circumstances unfavourable. In the example opposite, the curve radius should be 850 m. However, because of the high cost of improving the curve, cheaper measures have been adopted, including the placement of two sets of rumble strips on the approach to the curve, followed by a road hump just prior to the start of the curve, and the installation of a guardrail.

It is important not to locate the road hump too far away from the last set of rumble strips, about 50 m is appropriate so that the driver does not have time to start accelerating after the last set of rumble strips before decelerating again to cross over the road hump.

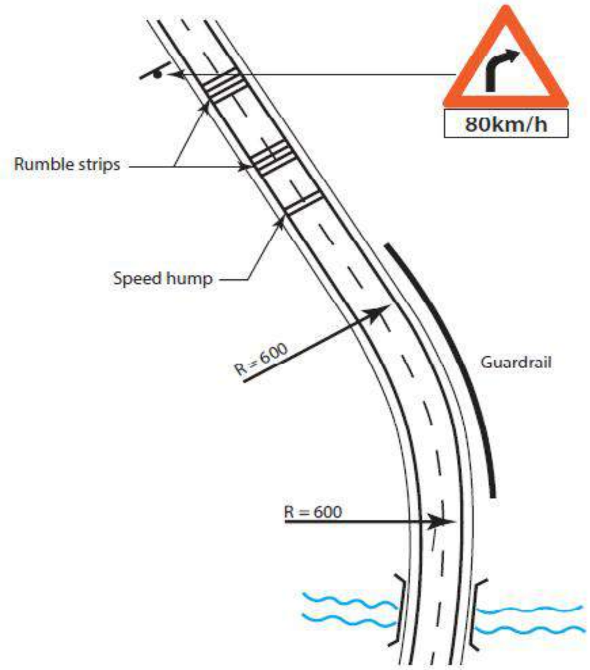


Figure 2-5: Adoption of traffic calming measures before a sharp bend

Vertical alignment: Like horizontal alignment, this factor also controls vehicle speed. The greater the rise and fall of the road, the lower the speed and, hence the safer the road, unless the length of the summit (crest) vertical curve suffers from inadequate sight distance. Such a situation would then give rise to possible collisions between oncoming vehicles. Typical countermeasures would include:

(a) Increasing the length of the vertical curve by flattening the crest of the curve. This would incur earthworks costs, the extent of which would depend on the length of the vertical curve required.

(b) Adopting traffic-calming measures, such as rumble strips, road signage and road markings to reduce the driver's speed (see Figure 2-6 below).

The preferred option would be based on consideration of the cost-benefit issues discussed above in relation to inadequate horizontal curvature.

Figure 2-6: Use of edge markings to improve road safety on vertical crest curve

Road width: Road width has an impact on accident risk by affecting speed. Generally, the wider the road, the higher the speed and vice versa, i.e. the narrower the road, the lower the speed. However, international studies have shown that sufficiently wide LVRs generally have a better safety record than too narrow ones. The key question is – what is a sufficiently wide LVR? The answer to that question depends crucially on the estimated number of average interactions (head-on meetings) per day, which is reproduced below from *Part A – Geometric Design: Rural Roads* (Table 2-2).

Table 2-1: Indicative interactions/km (per day/hour)

AADT	300		100	
Speed (km/h)	Avg. Interactions/km		Avg. Interactions/km	
	Per Day	Per Hour	Per Day	Per Hour
40	46	3.8	5.0	0.4
60	31	2.6	3.5	0.3
80	23	1.9	2.5	0.2

As clearly shown in Table 2-1, many vehicles travelling on LVRs will only very infrequently meet an opposing vehicle. Thus, the need for overly wide roads cannot be justified and should be decided based on the road standard (LVR1 to LVR5), anticipated ADT and average vehicle speed over the length of the LVR or, at least, major sections of it. It is on that basis that the road widths (travelled way plus shoulders) have been determined for the various classes of LVRs, as presented in *Part A – Geometric Design: Rural Roads (Chapter 5: Cross Section).*

Where the incidence of motorcycles and NMTs is high, shoulders are recommended for all but the lowest design class and will normally be paved when the carriageway is paved. Apart from their structural function, they are also intended to perform several safety functions, such as:

- To provide additional manoeuvring space on roads of lower classification and traffic flows.
- To provide parking space at least partly off the carriageway for broken down vehicles.
- To reduce the tendency of non-motorised traffic to travel on the carriageway.

Sight distance: Sight distance has, together with road width, an impact on road safety. Both of these factors should be adequate for the standard of road, traffic (ADT) and average travel speed expected on a LVR. A combination of narrow road widths and inadequate sight distance must be avoided by consideration of such measures as:

- Widening of the road, especially at sharp bends.
- Adoption of shoulders, especially where there are high levels of NMT users.
- Adoption of appropriate traffic-calming measures.

The preferred option would be based on consideration of the issues discussed above in relation to inadequate horizontal or vertical curvature.

Motorcycle safety: This topic deserves special attention since motorcycles are a common and popular means of transport in Malawi and, in some areas, constitute the main means of transport. However, motorcycles are also a dangerous means of transport in comparison with other motorised means and need to be specifically catered for during the design process. Having only two wheels in contact with the ground, their small size, lack of protection and overloading, makes them more susceptible to loss of control and puts drivers and their passengers at greater risk of serious injury.

Injuries suffered in accidents involving motorcycles on rural roads are more severe than those involving other modes. Poor road user behaviour, generally as a result of a lack of training and a lack of law enforcement in rural areas, is the most common contributory factor in motorcycle accidents on rural roads. Speed is widely recognized as a key risk factor in road traffic accidents for all forms of transport. On low-volume rural roads, motorcycle speeds are often not high, but speed-related motorcycle accidents do often occur. Unevenness of the unpaved road surface, loose gravel material, powdered dust, corrugations, ruts, etc. greatly increases the risk of accidents with motorcycles and bicycles.

The following safety measures are considered important, over and above safety measures generally applied:

Figure 2-7: Motorcycle taxi on rural road

- Speed humps must be properly designed not to create obstacles that can cause a motorcycle driver or cyclist to lose control.
- Avoid the use of sharp horizontal bends to minimize the risk of motorcyclists either running off the road if approached at too high a speed or colliding with other road users due to poor visibility. Widen sharp horizontal bends as a safety mitigation measure.
- Adequate road width is critical for motorcycle safety. The road must be wide enough for a motorcycle to pass a four-wheeled vehicle safely without being forced to leave the road. A minimum travelled way width of 3.5 m on the lowest road class (LVR1) is recommended.
- Road shoulders must be regularly maintained to ensure a safe riding surface. The shoulders, as with the travelled way, should be free from vegetation, potholes, corrugation, rutting, loose gravel, oversized material or slippery-when-wet surfaces often caused by the use of substandard (very plastic) materials.

- The slopes of the shoulders should preferably match that of the main carriageway. It is recommended that unpaved shoulders should have a maximum camber of 5% slope.

Construction
Special measures must be taken to ensure the safe passage of traffic during construction, including:

- Adequate signage to warn drivers sufficiently in advance of the construction zone.
- Deployment of flagmen/women and/or stop-go lights to provide a clear demarcation of the movement of vehicles.
- Temporary speed humps.
- Watering of unfinished works and detours to minimise dust emission.
- Protection to project workers.

The measures to be taken by the contractor are normally specified in the contract documents and must be adhered to.

2.3.3 Road Safety Inspections

General
Once a road is fully operational, Road Safety Inspections (RSIs) must be carried out on an ongoing basis to ensure the safe performance of the road. RSIs are carried out to identify traffic hazards related to the road environment characteristics and to propose interventions to mitigate the detected hazards. Guidelines for RSIs include inspection of important road safety elements such as quality of traffic signs, road markings, quality of the road surface characteristics, adequacy of sight distances and the absence of permanent or temporary obstacles, presence of roadside traffic hazards, etc.

It is important that a system is established to ensure that information gathered during RSI are fed back into the RSA guidelines. Preferably the RSA and RSI should be carried out by the same personnel, but a formal feedback system will ensure that the institutional memory is not lost with the change of personnel.

The RSI will be instrumental for the identification of potential “Black Spots” and for providing feedback to the maintenance organisation on issues that need attention, as discussed below. For further information, reference is made to *The Malawi Road Safety Engineering Manual*.

Black Spot identification and treatment
Black Spots are places on a road that are considered to be dangerous because accidents tend to occur much more frequently, for whatever reason, than on the road in general. Black spots are normally identified through the analyses of accident data that is collected by the Police. The local community can also provide information regarding the location of accidents.

The situation at the black spot must be analysed, and the most appropriate countermeasures identified, e.g. speed reduction measures, widening of the road at horizontal curvature, provision of NMT facilities such as walkways and space for bicycle traffic, location of public transport stops, safety at drainage canals, pavement related causes for accidents, etc.

Maintenance
Regular maintenance of rural road infrastructure not only prolongs the life of the road but, importantly, ensures that safety hazards are minimized. In situations as listed below, lack of maintenance could affect road safety:

- Vegetation growth at intersections and sharp curves.
- Tree roots damaging the pavement and causing traffic to swerve.
- Potholes in the roadway causing the swerving of vehicles.
- Gravel roads with uneven riding surface, loose gravel, corrugation, ruts, high dust emissions, etc.

- Faded, dirty, damaged, vandalised or missing traffic signs.
- Blocked drains that could causing flooding and slippery surface.
- Faint road markings, especially the loss of visibility of road humps.
- Damaged bridge rails and guardrails.
- Scoured road shoulders (edge drop), especially on roads that are not lit at night.
- Lack of maintenance of breakaway posts.

As illustrated in Figure 2-8, failure to carry out adequate road maintenance can impact adversely on road safety in that it prevents road users, particularly cyclists, motorcyclists and animal-drawn carts, from using the shoulders when required to move off the road due to on-coming motorized traffic. Thus, maintenance must focus on keeping the road safe and serviceable and ensure that the intended purpose and design of the road is maintained. Maintenance programmes can also enable incremental improvements in road safety through adequate attention to pavement conditions, barriers, signs and line-marking, sight-distance and visibility constraints and road debris.

Figure 2-8: Example of poorly maintained concrete strip road

3 Factors Affecting Road Safety

3.1 General

Because of its multi-dimensional nature, road safety cannot be discussed in isolation of a number of related factors. As illustrated in Figure 3-1, road safety is linked to, and influenced by, various factors including road design, road construction, road maintenance and related pavement condition, as well as the road environment and road user behaviour.

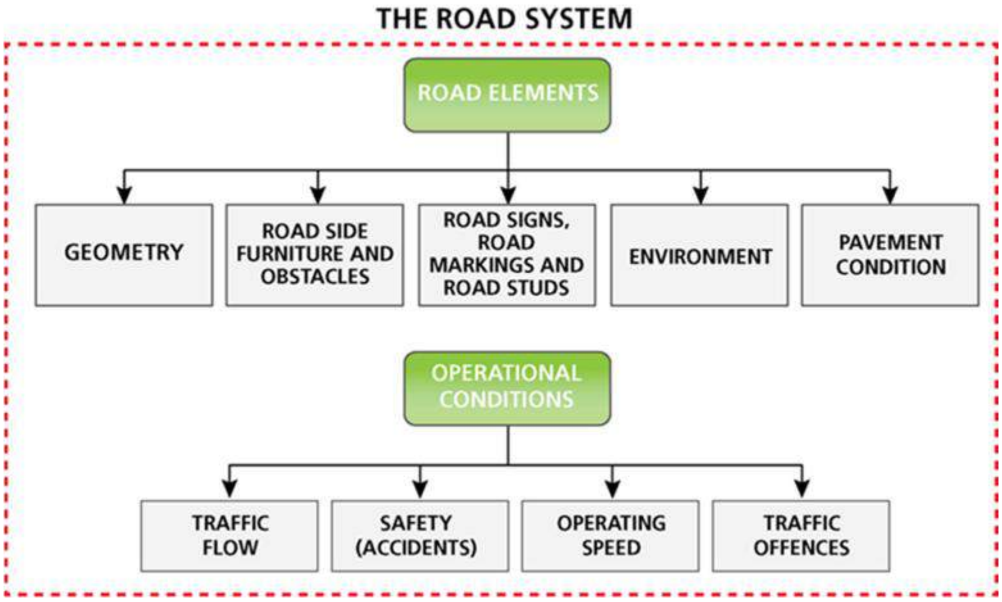


Figure 3-1: Elements of the road system and operational conditions

Many of the road elements and operational conditions are also interrelated. For example, as illustrated in Figure 3-2, overloading has an important influence on pavement condition and is influenced by law enforcement, while speeding is also influenced by the road geometry and traffic law enforcement. Both overloading and speeding, in turn, have an influence on safety in terms of accidents whilst the environment, coupled with the maintenance standard applied, affects pavement condition and, in turn, road safety.

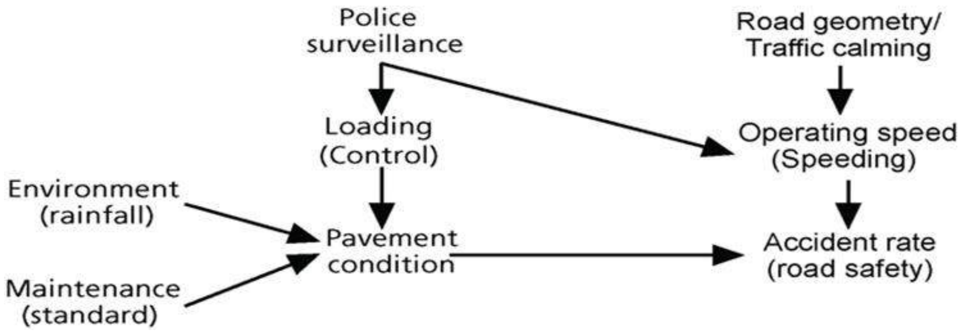


Figure 3-2: Interrelationship between road elements and operational conditions

3.2 The Nature of Accidents

Road accidents, including those on LVRs, are generally unpredictable and tend to be multi-causal in nature, involving human factors, the road environment and vehicle factors. They are more often caused by a combination of these factors, with human factors typically contributing to an estimated 95% of all accidents, the road environment about 28%, and vehicles about 8%, as shown in Figure 3-3.

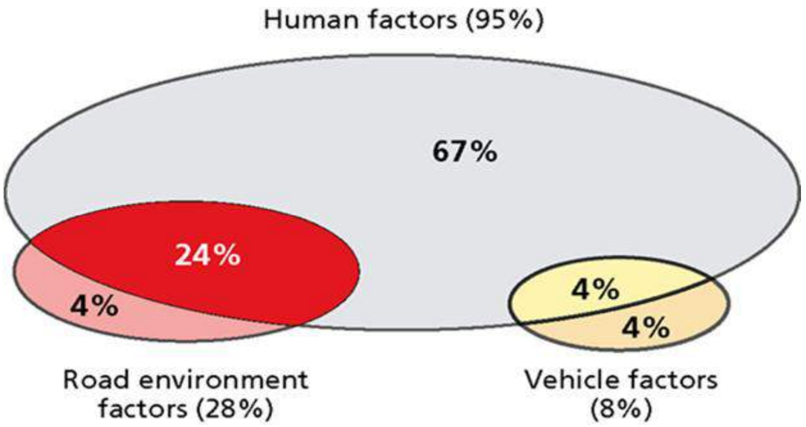


Figure 3-3: Multi-causal nature of road accidents

It is apparent from Figure 3-3 that tackling the challenge of poor road safety requires proactive strategies that treat the main contributing factors. The "human factor" is concerned with the general and stable reactions of common road users and deals with identifying road characteristics that are not according to human threshold limit values and therefore, potentially, trigger accidents. A road should confirm what drivers expect based on previous experience and should present clear clues as to what is expected of them. If these expectations are violated, problems are likely to occur which, in the most severe cases, may lead to accidents. Therefore, the objective is to design the road and its immediate environment in a manner that is conducive to the prevention of accidents and to a reduction of damage potential when accidents occur.

Information, training and traffic law enforcement will contribute to improving human behaviour, but the physiological and psychological aspects can only be addressed through improved road design.

3.3 Typical Factors Contributing to Accidents

The following are typical contributing factors to accidents that occur on LVRs roads where vulnerable road users are put in a high-risk situation:

- Inadequate planning and designing for road safety due in part to the non-inclusion of pedestrian and slow-moving traffic in traffic surveys, and consequent failure to take proper account of the operational environment.
- The provision of relatively steep cambers, typically 5% - 7% on gravel roads, in order to shed water off the road. This camber may provide little difficulty to motorised vehicles which tend to travel along the centre of the road. However, it can be very dangerous for cyclists and motorcyclists who often carry very large/heavy loads and, as a result, are unable to easily manoeuvre out of the way of fast-approaching traffic.
- The right-of-way outside the side drain may be obscured by vegetation and buildings. In such situations, there is potentially a considerably increased risk to pedestrians, particularly young children, as there is little warning to motorised traffic when pedestrians or animals decide to cross the road.

Figure 3-4: Typical problems encountered on rural roads

- A combination of poor motorcycle driver behaviour, such as the use of inappropriate speed, and poor road condition, such as a potholed or slippery surface, cause the motorcyclist to lose control.
- Relatively fast-moving motorised traffic competing for limited road space with slower-moving vulnerable road user modes and pedestrians.

A comprehensive list of factors contributing to road accidents is shown in Table 3-1 below.

Table 3-1: Factors contributing to road accidents

Human factors	Road environment	Vehicle factors
• Misjudgement, overtaking, inattention, distraction o Untrained and inexperienced drivers o Distracted driving, e.g. eating, use of mobile phones o Driving with overloaded bicycle, motorbike or car o Distracted walking, e.g. use of mobile phones • Jaywalking or walking in the roadway • Speeding o Inappropriate/excessive speed • Drink-driving and drink-walking o Driving under the influence of alcohol/drugs o Intoxicated pedestrians/cyclists • Negligence by drivers, pedestrians or cyclists o Non-use of seatbelts, child restraints or helmets o Sheer disregard/lack of knowledge of road traffic rules and regulations • Fatigue o Driving for excessively long periods without adequate rest.	• Poor road design o Inadequate road capacity o Failure to separate pedestrians/NMTs from motorised traffic o Inadequate sight distance particularly blind crest curves o Sharp horizontal curve immediately after a sharp crest o Sharp curves requiring a reduction in speed of more than 20 km/h o Road geometry that does not encourage and enforce a reduction of speed on hazardous sections o Inadequate road signage and markings o Hazards close to the edge of the road o Animals crossing over or straying onto the road o Inappropriate choice of road surfacing o Unmarked changes in road surfaces (particularly from paved to unpaved) • Poor maintenance o Deterioration of surfacing and pavement structure o Deterioration of road signs and markings o Deterioration of passive safety installations	• Unroadworthy vehicles o Poor brakes, no horn, no lights o Steering deficiencies

3.4 Measures for Reducing Road Accidents

Although LVRs are inherently quite safe due to the low traffic volumes, there is significant potential for reducing the incidence of accidents through the adoption of low-cost engineering measures at hazardous locations. However, a systematic approach must be adopted to identify the contributing factors of road accidents so that the most appropriate treatments are selected and implemented.

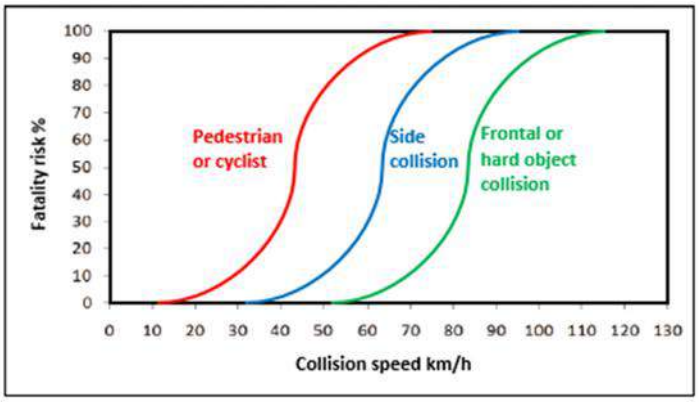
There are a variety of measures for reducing road accidents, as discussed in this chapter, including:

- The undertaking of road safety audits and road safety inspections.
- Adoption of appropriate traffic calming measures.
- Traffic segregation of NMT from motorised traffic.
- Appropriate traffic signs and road markings.
- Road safety education and traffic law enforcement.

4 Operational Aspects

4.1 General

Speed is the primary factor in most vehicle accidents – increasing both risk and severity. As drivers move faster, they have less time to respond to road conditions and any resulting collision causes more damage. As illustrated in Figure 4-1, vulnerable road users' fatality risk increases dramatically when speeds are greater than 30 km/h. In the case of side-, frontal- or hard object impacts, these risks increase dramatically at 50 km/h and 70 km/h respectively.



Source: World Bank Road Safety Facility (Undated)

Figure 4-1: Relationship between fatality risk and vehicle speed

In areas where vulnerable road users come into conflict with other traffic, there will be a need to introduce appropriate speed reduction and other road safety measures to ameliorate this situation. Such measures can be applied through the selective use of traffic management and other techniques to improve traffic operations and thereby create safer road networks.

Typical road safety measures that may be adopted in both rural and urban environments include:

- Traffic calming
- Traffic segregation
- Road signs and markings
- Guardrails and pedestrian barriers
- Road furniture
- Street lighting
- Roadside control

The general approach is based upon recognition of the following underlying principles:

- Reducing speeds in built-up areas or potentially hazardous locations.
- Segregation of pedestrians, cyclists and other slow-moving traffic from faster moving vehicles.

4.2 Prioritisation of Road Safety Countermeasures

Although the prevention of loss of life, injuries and damage to property (in order of priority) should be the guiding principle of road design, the stark fact is that the cost of attempting to achieve this goal must be balanced against the benefits. International research has established quite favourable cost-benefit ratios for various traffic safety measures, but invariably these ratios are for much higher traffic levels than those found on LVRs. Thus, there will be a threshold for how much it is worth spending on road safety improvement in low traffic environments. For LVRs, the focus should, therefore, be on the application of low-cost, but effective, road safety measures.

The process for prioritising and selecting road safety countermeasures for implementation can range from a quantitative benefit/cost ratio (data permitting) to a qualitative rating process using, for example, high, medium and low ratings. The purpose of the countermeasure evaluation and prioritisation is to review the potential countermeasures and select the most feasible one based on criteria such as:

- Anticipated safety effectiveness
- Construction and maintenance costs
- Environmental impacts
- Stakeholder input and community expectations

In practice, because of the relatively low number of vehicle interactions on LVRs, particularly on the LVR1 and LVR2 classes, the more expensive types of traffic safety countermeasures may well not be justified on an economic cost-benefit basis.

4.3 Traffic Calming

4.3.1 General

Traffic calming typically comprises the use of a combination of physical measures that can reduce the negative effects of motor vehicle use, alter driver behaviour, and thereby improve conditions for NMT users. Such measures focus on reducing speeds by use of self-enforcing traffic engineering techniques or through road design.

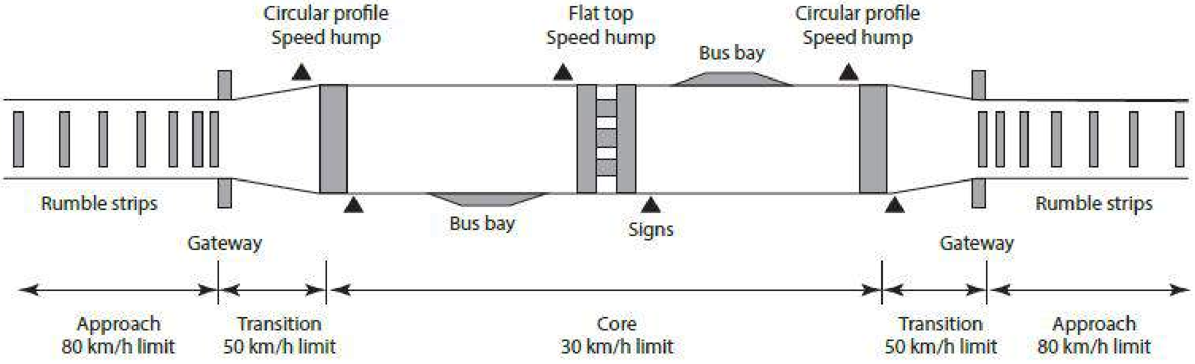
The application of traffic-calming measures is an effective way to control speed. The problems connected to them are normally due to poor design, e.g. the humps may be too high or too short or both, whilst the rumble strips may be too high or incorrectly spaced or both. When used in combination with each other, the spacing between them must also be appropriate. Failure to observe these shortcomings can even generate accidents. Thus, special attention must be paid to their design and, during construction, to their drainage, which must be carefully studied to avoid ponding during heavy rains. The designer should consult recognised international traffic calming guideline documents, some of which are listed in the bibliography.

4.3.2 Traffic-calming Measures

The requirement for installation of traffic-calming measures applies to both rural and urban environments. However, the mode of application is normally different:

- In urban areas (including through villages which in this context are defined as “urban” areas), the aim is usually to slow down vehicles to acceptable (and posted) speed limits and to ensure that this reduced speed is maintained through the length of the road (section) or street.
- On the open rural roads, the aim is to force vehicles to reduce their speed before encountering spots on the road which are not designed for the normal travelling speed (due to the high cost of doing so), or in front of junctions with other roads.

In a rural environment, a “gateway” can be used to signal to the drivers that they are entering a low-speed environment. The “village treatment scheme” in Figure 4-2 is, in principle, no different from an urban street, with the same type of measures being used in both cases. The only difference between rural and urban in this regard is that in the urban setting there is no need for a “gateway”.



Notes: 1. Layout not to scale
2. ▲ indicates appropriate road sign
3. Road cross section dimensions and speed limits are indicative only and should be amended to suit site conditions

Figure 4-2: Village treatment scheme

Generally, it is desirable to apply traffic-calming measures in areas where horizontal sight distance is restricted because of sharp bends or other factors such as the absence of corner splays, buildings close to roadway edge, or other limiting factors. Other areas that should be considered include pedestrian sensitive areas such as schools, local shops, community facilities, clinics and service centres.

Measures that are considered appropriate for low volume rural and urban roads and include:

- rumble strips
- speed humps, speed cushions, flat-top humps, speed bumps
- mini circles (urban only).

4.3.3 Rumble Strips

These are transverse strips that are placed across the road. Their main purpose is to alert motorists of a hazard, dangerous road location or whatever requires their special attention, by causing a tactile vibration and audible rumbling, without the need for the driver to reduce speed.

Rumble strips are typically used in the following ways:

- before a hump, speed cushion, flat-top hump or bump used singly or in combination, in both driving directions;
- at an approach to a dangerous junction; or
- to give emphasis to a warning sign, e.g. before a sharp bend or at a railway crossing.

The following principles should be observed when using rumble strips:

- They should be placed in groups of 3 – 5 strips.
- The maximum thickness of the strips shall be 10 mm – 15 mm (strips higher than this could be a hazard for motorcyclists and, in extreme situations, unnecessarily severe for vehicles).
- The strips can be of varying designs: Wide and flat 500 mm wide or narrow ± 100 mm wide.
- The length of the strips shall be that of the road, including the shoulders.
- The first (or only) set shall be placed 30 m – 50 m before the hazard (e.g. a hump).

A common problem is the construction of rumble strips that are excessively high and cause irritation to road users who then tend to avoid them. In the example to the right in Figure 4-3, the strips are so severe that vehicles are forced to stop before attempting to cross over them.

Figure 4-3: Examples of well designed (left) and poorly designed (right) rumble strips

4.3.4 Speed Humps

Speeds humps are the common name for a family of traffic calming devices that use vertical deflection to slow motor-vehicle traffic by making it uncomfortable to drive over them at excessive speed and thereby improving road safety conditions. Variations include circular hump, flat-top hump (speed table) and speed cushions.

For the purpose of this Manual, the following descriptions are used:

- **Circular humps** span the whole width of the travelled way and are designed so that vehicles can pass over them at a low speed without having to come to a halt first and without undue discomfort to the drivers and passengers as well as damage to the vehicles. Different designs can be applied to allow for different speeds, e.g. 30, 40 or 50 km/h. Figure 4-4 shows the design allowing a comfortable ride over the hump at 40 km/h. Openings should be provided on both sides of the hump for stormwater passage.

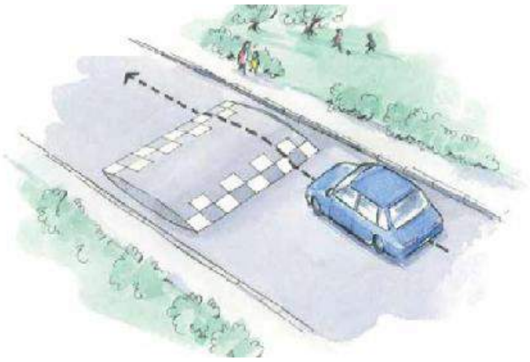


Figure 4-4: Circular hump

- **Speed cushions** are circular humps that are designed to be slightly wider than a car, so drivers need to slow down and drive over the centre of the cushion. However, the relatively narrow cushion allows unimpeded passage of large vehicles (e.g. buses, fire engines etc.) with a wider distance between the wheels than small cars.

Figure 4-5: Speed cushions

- **Flat-top humps** (also referred to as Speed tables) are speed humps with a wide, flat top to accommodate a pedestrian crossing. The width of the flat, middle section varies from 3 – 10 m, depending on the type of traffic. If large buses are using the road, the width of the flat part should be a minimum 7 m to reduce the pivoting effect and discomfort for the passengers.

  Flat-top humps are usually designed for speeds of 10 km/h – 20 km/h below the speed limit. A modified circular shape of the ramps, similar to those for circular humps, is recommended.

Figure 4-6: Flat-top hump

Source: Vegdirektoratet (Norway) Håndbok V128

- **Speed bumps** are essentially the same as speed humps, but they are intentionally constructed higher and with steeper up/down ramps, thus forcing vehicles to come to a halt before crossing over them. Speed bumps can be justified in particularly hazardous locations such as on both sides of level railway crossings.

If properly designed, and supplemented with ample warning signs, these countermeasures are by far the most effective speed management measures that can be placed on low volume paved roads. They are very effective in controlling speeds to 50 km/h or less, depending on their profile, without causing significant discomfort to drivers and passengers, or damage to vehicles. Unfortunately, however, due to poor design, this is often not the case and the intended objective of their use is not attained in practice.

In an urban environment, including villages, the maximum distance between speed humps should be as shown in Table 4-1, to ensure that most of the vehicles do not exceed the desired (and posted) speed limit.

Table 4-1: Recommended distance between speed humps

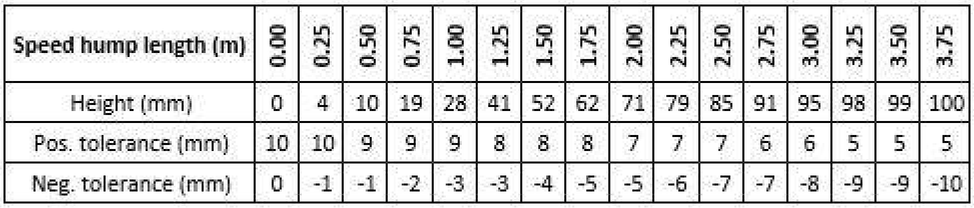
Speed limit km/h	Recommended distance between speed humps
30	± 75 m
40	± 100 m
50	± 150 m

Below are shown examples of speed humps designed for various speed limits.

Table 4-2: Key dimensions for speed humps for various speed limits

Speed limit km/h	Radius	Height	Length
30	20 m	0.10 m	5.0 m
40	53 m	0.10 m	7.5 m
50	113 m	0.10 m	11.0 m

Table 4-3: Design measurements for speed hump for 40 km/h



Speed hump length (m)	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75
Height (mm)	0	4	10	19	28	41	52	62	71	79	85	91	95	98	99	100
Pos. tolerance (mm)	10	10	9	9	9	8	8	8	7	7	7	6	6	5	5	5
Neg. tolerance (mm)	0	-1	-1	-2	-3	-3	-4	-5	-5	-6	-7	-7	-8	-9	-9	-10

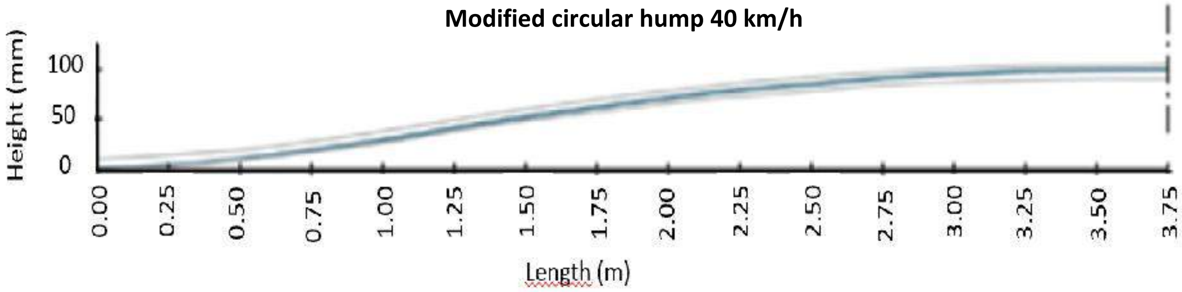


Figure 4-7: Profile of speed hump 40 km/h

Source: Vegdirektoratet (Norway) Håndbok V128

A key requirement for installation of speed humps, speed cushions and flat-top humps is that they are properly marked, preferably with thermoplastic paint, to ensure that they are visible to the drivers, particularly at night. Failure to do so, and to maintain the marking, will create hazards and may cause accidents rather than preventing them.

- **Mini circles** are essentially raised circular islands constructed in the centre of residential street intersections. They retain all of the standard features of a full-scale roundabout including yield on entry, deflection, flare and low design speed, but are less expensive to construct. They reduce vehicle speeds by forcing motorists to manoeuvre around them. However, they must be properly designed to benefit pedestrians and cyclists.

Figure 4-8: Mini circle intersection used as a speed reducing measure on the through-road

4.3.5 Speed Humps on Unpaved Roads

Although traffic levels on unpaved roads in villages generally tend to be lower than on paved roads, traffic speeding, combined with dust emissions, are a major problem for which appropriate traffic calming measures are also required. Such measures are, in principle, similar to those for paved roads in terms of signage. However, special measures need to be taken to embed road humps in the gravel substrate so as to anchor them and minimize their horizontal movement under the action of traffic (see a typical layout in Figure 4-9).

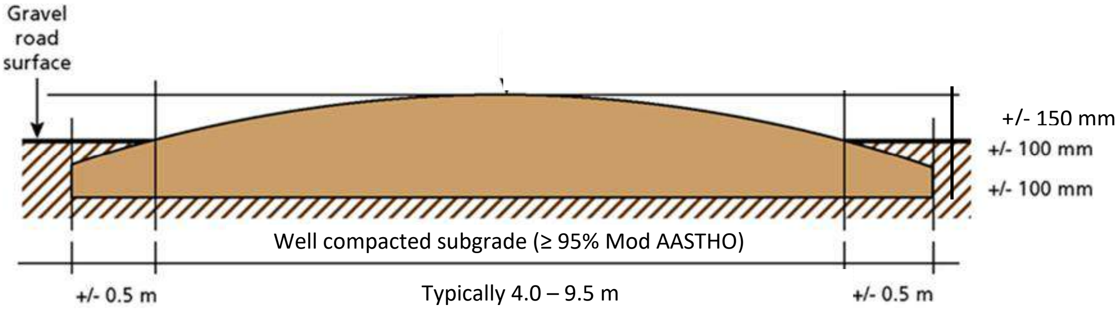


Figure 4-9: Longitudinal profile of a circular speed hump

4.3.6 Other Speed Reducing Design Features

In addition to or in combination with the above measures, other design features following the "Complete Streets" concept, can be applied, as illustrated below.

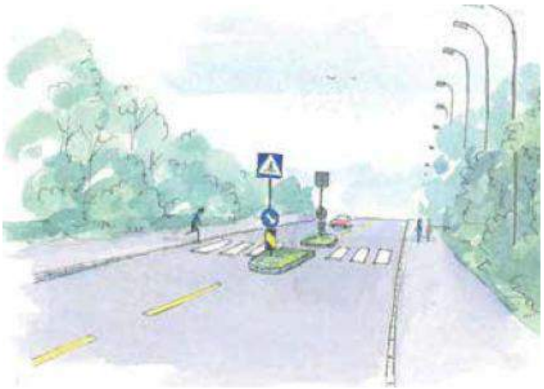


Figure 4-10: Pedestrian crossing with refuge island

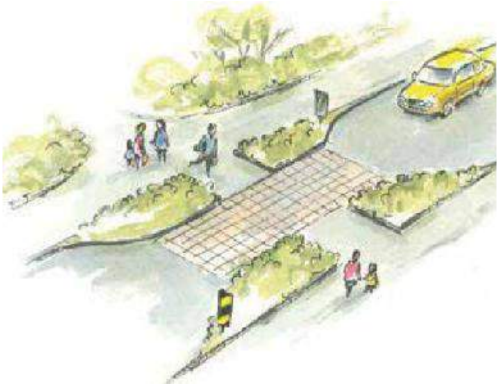


Figure 4-11: Narrowing road at pedestrian crossing

Figure 4-12: Narrowing from two to one lane

Figure 4-13: Chicane combined with landscaping

Source: Vegdirektoratet (Norway) Håndbok V128

4.4 Traffic Segregation

Where roads pass through rural settlements or urban areas, substantial conflict usually exists between non-motorised and motorised traffic and often poses a major road safety problem. The situation is exacerbated when these roads are also used as footpaths which place pedestrians at considerable risk of personal safety to fast-moving motorised traffic. In such a situation, the segregation of these different modes of traffic can significantly reduce the incidence of accidents.

Various means of traffic segregation can be considered for reducing accidents in rural and urban areas. These include:

- Demarcating areas where pedestrians can walk (e.g. sidewalks) by using relatively inexpensive bollards which should have a diameter of less than 100 mm not to endanger motorists during an accident.
- Channelization of pedestrian traffic through railings separating the sidewalk from the travelled way.
- Providing segregated footpaths on narrow bridges or next to the carriageway in rural- and peri-urban areas, to offer safe access for pedestrians.
- Providing sealed shoulders where a segregated footpath is not possible.
- Providing bicycle lanes by allocating part of a road to bicycles or by building off-road paths.
- Providing a separate, protected footpaths on bridges.

It must be appreciated, however, that the above options are cost-increasing and need to be justified based on a cost-benefit analysis (see section 4.2 above – *Prioritisation of Road Safety Countermeasures).*

Typical examples of the above traffic segregation options are shown in Figure 4-14.

Segregated footpath off main road

Segregated footpath on narrow bridge

Segregated shoulder using barrier kerb

Segregated footpath using simple poles

Figure 4-14: Typical examples of traffic segregation

4.5 Road Signs and Markings

4.5.1 General

Road signs and markings are an important road safety feature on LVRs by guiding and providing the driver with the information necessary to negotiate conflict points or hazardous locations on the road network. The installation and preservation of signs and markings represent a significant financial investment for road agencies, both to apply and maintain. Thus, the value, cost and necessity of road signs and markings on LVRs, other than regulatory signs required by the Road Traffic Signs Manual, must be fully considered in order to make optimum use of available budgets.

General guidance on the application of traffic signs and markings on the national road network in Malawi is provided in the *SADC Road Traffic Signs Manual* and the *Malawi National Guidelines for Road Traffic Signing*. However, such guidance needs to be adapted to the requirements of LVRs in order to achieve a balance between the cost and safety effectiveness of their application.

4.5.2 Road Signs

Road signs provide an important road safety function by providing essential information to drivers for their safe and efficient manoeuvring on the road. The main types of signs that are used on both rural and urban roads include:

- Danger warning signs
- Regulatory signs
- Information signs
- Prohibitory signs
- Give way and priority signs

Signage is especially useful on rural gravel roads where road markings cannot be applied. In particular, warning signs should be provided where there are unexpected changes in the driving conditions, for example, where:

- The geometric standards for a particular class of road have been changed along a section of road, for example, a sharp bend, a sudden narrowing of the road, or an unexpectedly steep downhill gradient;
- A bend occurs after a long section of straight road;
- There is an unexpected school crossing or rail level crossing;
- A drift or other structure is not clearly visible from a safe distance; or
- The driver is approaching traffic-calming measures such as speed humps.

Road sign theft and vandalism is a major problem in Malawi. *The Malawi Road Safety Engineering Manual* elaborates on some measures to reduce this phenomenon, such as:

- Welding the nuts on the bolts.
- Using large concrete foundations.
- Drilling holes in the sign plate.
- Using (composite) plastic or aluminium sign plates.
- Applying a clear protective film to the sign to prevent scraping off of the colour film.
- Filling signpost pipes with concrete or using plastic signposts.

4.5.3 Road Markings

Like road signs, road markings also provide an important road safety function. For example, they:

- Delineate the pavement centre line (where applied) and edges.
- Clarify the paths that vehicles should follow (in the case of paved rural LVRs).
- Indicate the alignment of the road by the use of marker posts.

The types of road markings that can be used on rural and urban roads, in general, are as follows:

- Longitudinal markings (Centre-, lane- and edge lines)
- Transverse markings
- Pedestrian markings
- Worded markings
- Arrows and symbols
- Marking of islands and pedestrian refuges.

As regards the use of road markings on LVRs, international research reveals the following:

- Centre line markings should only be applied when the width of the travelled way (sealed width in cases where shoulders are not provided) is ≥ 5.5 m, as also recommended in the Malawi Guide to Traffic Signing.
- On narrower roads (< 5.5 m travelled way), centreline markings are not warranted as they do not contribute to improved road safety and, in addition, tend to encourage drivers to drive close to the edge of the sealed width which contributes to potential conflict with NMT users and early edge breaks and an increased maintenance burden.
- Edge line markings are desirable on all roads to guide the drivers, especially at night-time on unlit roads. However, they are costly to apply and maintain and, other than in isolated sections, may be unwarranted on the lower road classes (ADT < 200 vpd).
- Edge marker posts are desirable on isolated sections of the lower road classes roads (ADT < 100 vpd), where it would not be warranted to use any road markings, to alert drivers to potentially hazardous situations (sharp bends, sub-standard road curvature, etc.).

Based on the above, Figure 4-15 and Table 4-4 show the recommended use of road markings on the various LVR classes considered in this Manual. Full details of road markings in terms of dimensions and configuration can be found in the Malawi Guide to Traffic Signing.

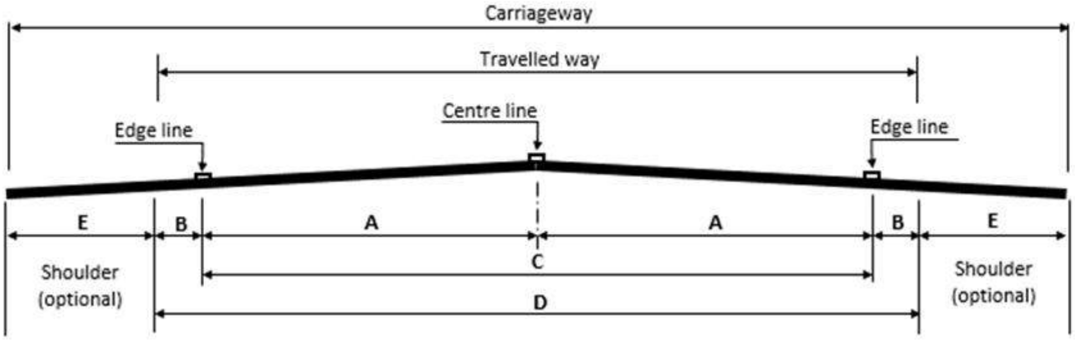


Figure 4-15: Road markings in relation to road width (see Table 4-4)

Table 4-4: Recommended road marking scheme in relation to road width

LVRR class	Traffic vpd	Travelled way[3]				E (optional)	Dashed centre-line	Dashed edge-line	Edge marker posts	Surface
		A	B	C	D					
LVR 5	> 400	3.0	0.25	6.0	6.5	Varies	Yes[1]	Yes[1]		P/UP
LVR 4	200-400	2.75-3.0	0.25	5.5-6.0	6.0-6.5		Yes[1]	Yes[1]		P/UP
		2.5-2.75	0.25	5.0-5.5	5.5-6.0		No	Yes[1]		P/UP
LVR 3	100-200	2.0-2.25	0.25	4.0-4.5	4.5-5.0		No	Yes[1]		P/UP
LVR 2	50-100				3.5-4.5		No		Yes[2]	P/UP
LVR 1	< 50				3.5		No		Yes[2]	UP

P = Paved, UP = Unpaved (gravel), D = Sealed width

Notes: 1. Total route, 2. Isolated sections, 3. Where no shoulders: Travelled way = Carriageway

Source: (FHWA, 2016)

Figure 4-16: Example of road marking on rural LVR

Figure 4-16 illustrates road markings on a LVR that serve a dual purpose, namely:

- To encourage vehicles to travel within the central, narrow lane and to only move outside of the broken edge lines when approaching a vehicle travelling in the opposite direction. This will prolong the life of the pavement in general and contribute to a reduction in edge breaks and the associated maintenance burden.
- To indicate to the drivers that the area outside the edge lines is primarily reserved for pedestrians and bicycles.

4.6 Road Furniture

4.6.1 General

Road furniture is a generic term for various road-related assets within the road reserve, including bus laybys and shelters, guardrails, pedestrian barriers, traffic signals, traffic signage, rail crossings and other small structures such as pedestrian bridges across rivers or streams.

Road furniture plays an important role as part of a functional road and street system because it guides and protects all road users in the following ways:

- Guardrails and barriers prevent vehicles from driving onto sidewalks or straying off the road.
- Pedestrian barriers, on the other hand, prevent jaywalking and channelize pedestrians towards pedestrian crossings and intersections.
- Traffic signage and markings assist drivers by providing messages about the road layout ahead or potential danger spots such as railway level crossings.
- Bus laybys are also an important roadside feature to provide for safe passenger pick-up or drop-off.
- Bus shelters provide protection for passengers, especially during inclement weather conditions.
- Narrow bridge structures also pose a danger to pedestrians and cyclists. This danger can be alleviated by the addition of a small walkway structure as an extension of the bridge deck.

4.6.2 Guard Rails and Pedestrian Barriers

Safety barriers are expensive and are seldom justified on LVRs. However, they may be required in highly dangerous situations, for example:

- on sharp bends on mountainous roads that cannot be made safe by other means;
- on urban LVRs that cross major drainage channels
- Where sharp drop-offs occur next to the roadway are present.

The types of safety barriers and application vary. The most commonly used are raised kerbed islands, wooden or steel posts, steel guardrails, and concrete barriers. Raised kerbed islands are generally applicable to paved roads and widely used for segregating motorised and non-motorised traffic. Wooden and steel posts are the cheapest forms of barriers, however, generally not the most effective. Steel guardrails are one of the most effective types of safety barrier and most commonly used. They are cost-effective to install compared to concrete barriers. However, in the long-term, their repair and maintenance are generally more expensive. Road signs or marker posts should be used to warn motorists of potential hazards. In high-risk areas, guard rails may be used to protect road users from a roadside hazard.

4.7 Roadside Environment

The roadside environment plays a role in influencing the severity of accidents. The area where vehicles end up after an accident typically extends to some 9 m from the travelled way. The area of the heaviest impact extends up to 3 m from the roadside. It is therefore important that a clear roadside area should be provided to allow for recovery of errant vehicles and to avoid collisions with roadside objects.

Factors which contribute to increasing accident risk as well as the extent of the damage, include the location of the following in relation to their proximity to the travelled way:

- Roadside furniture, including road signs, information signs, lamp posts.
- Roadside obstacles, including large trees, shrubs, culvert headwalls, poorly designed guardrails.
- Deep, narrow (lined) drains.

Whilst fulfilling potentially important safety functions, both roadside furniture and obstacles can have negative implications. Thus, the correct design and location of roadside furniture and the avoidance of roadside obstacles in the road verge can significantly reduce accident rates on LVRs.

Big trees to close to the road

Badly designed bridge railing

Inappropriate design of side drain

Well designed side drain

Figure 4-17: Illustration of various roadside features

4.8 Street Lighting

4.8.1 General

Street lighting is an essential component to ensure a safe and secure road environment. Many people often travel to work in the darkness, whether during the early morning or late evening. The lighting of the road and street system increases the safety of all road users, especially for pedestrians and cyclists, to make them more visible to drivers. The provision of lighting is particularly essential at potentially hazardous locations and where security may be a problem.

Street lighting is generally neither warranted nor affordable on rural roads. However, in urban areas, including villages, it would be preferable to provide street lighting along roads and streets, at crossings and public transport facilities such as taxi ranks and bus stops.

4.8.2 Lighting Options

Various lighting options are available for use on LVRs. These range from halogen, sodium vapour, metal halide, light-emitting diode (LED) and, more recently, solar LED lighting. A brief description is given below. Street lighting manuals should be consulted for more information.

Halogen (Mercury Vapour) lamps: These are the most commonly used lamps for pole lighting and street lighting.

Sodium Vapour lamps: These lamps are more energy-efficient options compared to halogen lamps as they provide double the amount of brightness for the same amount of wattage. They are also ideal for pole lighting. Drawbacks with these lamps include:

- Their brightness is highest in the centre (just below the pole) and is lesser on the outside.
- They are mostly yellow or orange in colour compared to the whiter light from other types of lighting.

Metal Halide Lamps: These bulbs are as energy-efficient as Sodium Vapour lamps and also provide a whiter light, but their life is shorter.

Light Emitting Diodes (LEDs): This is the latest and most energy-efficient option available on the market for street lighting. Their brightness is much more uniform, and they can give up to 50% savings over Sodium Vapour lamps. They are less susceptible to producing glare and can reduce visual fatigue for drivers and pedestrians. LEDs are also available as a solar-powered solution as discussed below and can be an attractive, cost-saving lighting option.

Renewable energy sources - solar (and wind-powered) streetlights: Solar-powered streetlights use new LED technology which delivers a bright, white light at no running costs other than maintenance (Figure 4-18).

Solar streetlights can have a positive effect with regards to safety in the village environment, where people tend to socialize along the major road during early evening hours.

Figure 4-19: Renewable energy sources - LED solar street lighting in villages

Figure 4-18: Sodium lamp (nearside) and LED (far side)

4.9 Rail Crossings

4.9.1 General

The national rail network in Malawi extends from the Zambian border at Mchinji in the west via Lilongwe to Blantyre and Makhanga in the south. The Nacala Corridor railway line, cutting through the southern part of Malawi, links Moatize in Mozambique to the deep-water port at Nacala on the Indian Ocean.

It is important that road designers and road safety practitioners understand the basic design and road safety requirements to safeguard rail crossings where they intersect LVRs.

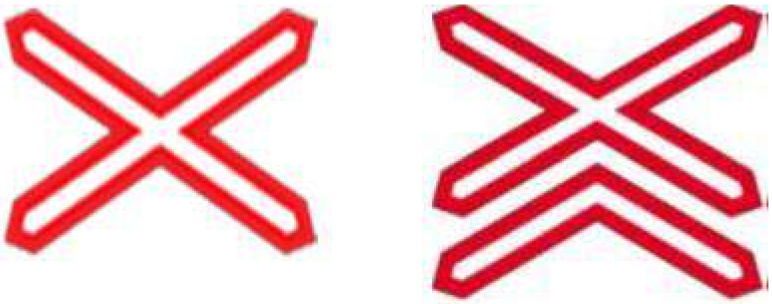
The legal requirements for level crossings are prescribed in the *SADC Road Traffic Signs Manual, Chapter 14* and the *Malawi Guide to Traffic Signing*. The main requirements are summarised below.

4.9.2 Requirements for Level Crossings

The road signs to be provided at urban level crossings are:

- The RTM1 Stop Line must be marked on the road to indicate to the drivers where to stop in conjunction when the red lights are flashing.
- The signal must be used with Regulatory Sign R1
- Warning signs W403 (single line) and W 404 (double line) are to be displayed.

The actual layout requirements for rural level crossings will differ on the respective classes of LVRs. A regulatory stop sign (Sign R1) supplemented by a warning sign W403 (single line) or warning sign W404 (double line) must, however, be provided at all level crossings on gravel roads, regardless of LVR class.



W403 – Single track

W404 – Double track or more

Figure 4-20: Signage for level crossings

The Southern African Railways Association (SARA 2012) published processes and procedures for network operators and road authorities for the conducting of physical assessments of public and private level crossings. Should a level crossing be encountered in township development, these processes and procedures should be closely followed. Physical assessments shall be conducted at least once every five years, jointly between the network operator and the road authority. The physical assessment records shall be retained for review by the relevant national regulating authority.

4.9.2 Layout of Level Crossing

Detailed layout details for different urban and rural level rail crossing types are provided for in the SADC Road Traffic Signs Manual, Volume 2 (2012). The urban and rural level crossing types covered are:

- Rural level crossings: Classes A to E rural road crossings
- Urban level crossings: Classes B to D urban street crossings.

Figure 4-21: Typical layout and details of urban level crossing

4.10 Bridges

Bridges are not often provided on LVRs. Instead, causeways, drifts and similar type structures are generally the more appropriate form of stream crossings. However, when bridges are provided on LVRs they invariably have restricted carriageway widths, and the space available for pedestrians and cyclists to cross safely in the presence of vehicles is often restricted.

The following road safety measures should be considered at bridge crossings:

- Provision of railings and a dedicated crossing space (preferably a raised walkway) for pedestrians to cross when vehicles are also using the bridge, as illustrated in Figure 4-22.
- Properly signed approached and safe waiting areas with clear sightlines across the bridge should, therefore, be provided at both ends.
- Provision of warning signs is recommended where a bridge or drift is narrower than the approaching road.
- Provision of bollards and/or masonry blocks on both sides of low-level structures, such as drifts and causeways, to mark their location when they are covered with water. In addition, the bollards should be fitted with reflectors for night-time driving.
- Provision of guard rails at the approaches to the structures.

Figure 4-22: Bridges with separate walkway

5 Ancillary Considerations

5.1 General

Streets as facilities serving a variety of needs should also accommodate various ancillary aspects, including public transport facilities, landscaping and public services like waste removal, as discussed below.

Public transport provides an important service to residents in urban as well as rural areas. Low volume urban streets are rather narrow and, ideally, bus (to the extent that large buses are used) and minibus routes should not be allowed on local streets (Class 5). These modes should only be operating on collector streets (Class 4) or higher classes.

5.2 Public Transport Facilities

5.2.1 Bus Stop Laybys

Various bus layby configurations are possible, depending on the available road space. This includes laybys next to the roadway on the verge or a stop on an existing lane with or without a waiting shelter. The actual street layout and space available will determine which option is feasible.

Typical dimensions for bus bays are illustrated in Figure 5-1. However, the street geometry would probably not allow for laybys on Class 4 roads, and public transport vehicles will most probably have to stop within the roadway. The typical layout dimensions for these lane stops are given in Figure 5-2.

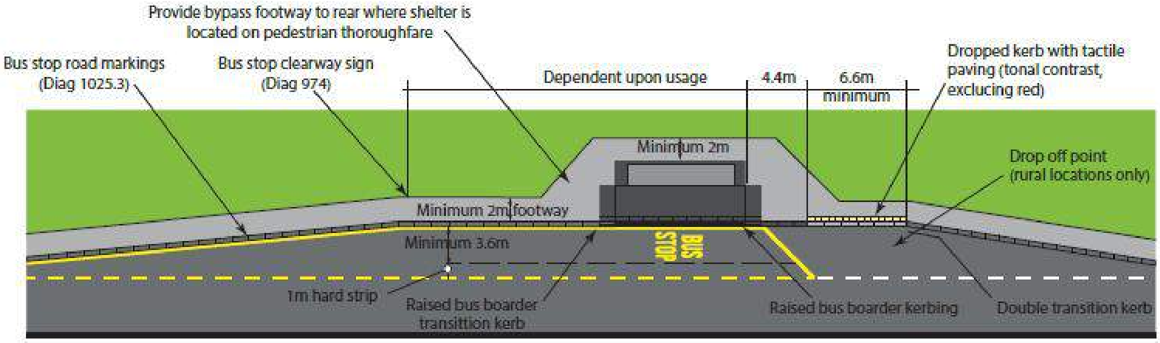


Figure 5-1: Typical bus bay layout

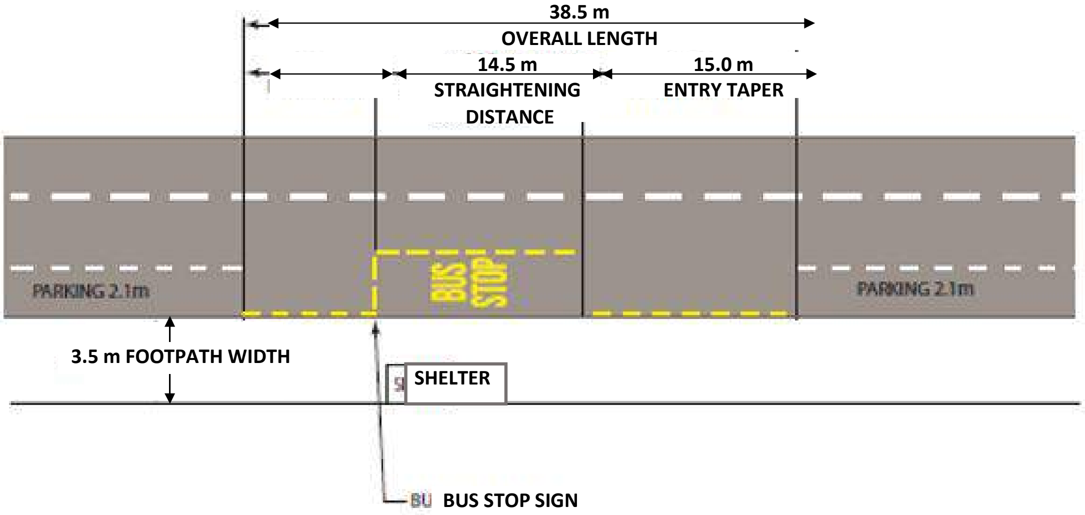


Figure 5-2: On-street bus stop layout

5.2.2 Positioning Public Transport Stops

From a road safety perspective, the preferred position of public transport stops is always beyond a pedestrian crossing or an intersection, so that a person is not obscured from the driver's view. The preferred location of bus stops for different street configurations is shown in Figure 5-3. There are also other traffic flow considerations to be taken into account when locating a bus stop. The advantages of typical bus stop location types are given in Table 5-1.

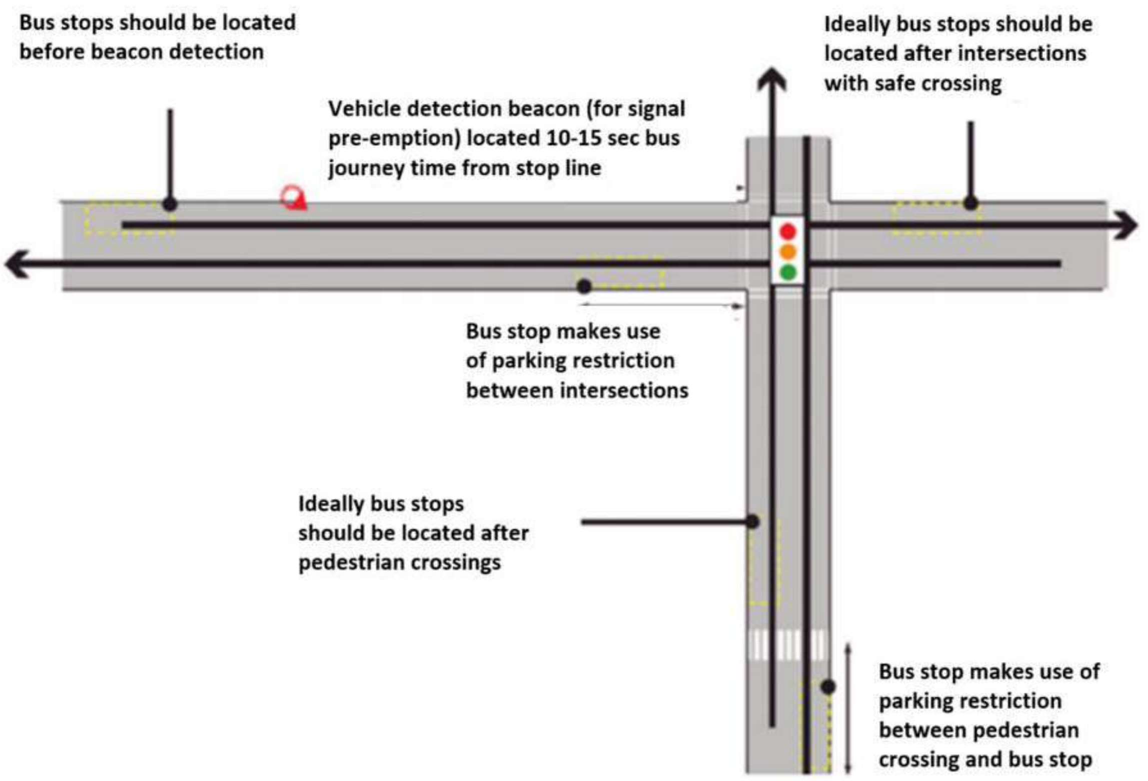


Figure 5-3: Positioning of bus stops

Table 5-1: Advantages of typical bus stop location types

Far-side stop	Near-side stop	Midblock stop
1. Minimises conflicts with right-turning vehicles. 2. Minimises sight line conflicts for drivers and pedestrians. 3. Encourages pedestrians to cross more safely behind the bus.	1. Minimises traffic interference during peak traffic flow hours. 2. Passengers are able to board the bus closer to the crosswalk.	1. Minimises sight line obstructions for both driver and passengers. 2. Because the stop is located away from intersection activity, conflicts with intersection traffic are minimized. 3. A more spacious waiting area may be provided because the stop is located outside inter-section sidewalk congestion.

5.2.3 Bus Shelters

To decide what type of bus shelter to use in a particular area requires an analysis of existing and anticipated conditions, as well as some knowledge of the characteristics of good shelter location and design. Some of the basic aspects to consider are:

- Is a bus shelter needed?
- Where should it be located?
- How should it be designed?
- How should it be maintained and managed?
- Are there funding options?

Where possible, it is desirable to provide shelters for passengers waiting at bus stops. Some of the basic requirements are:

- They should be designed to accommodate the maximum number of passengers normally waiting, and to provide adequate protection from the weather, sun as well as rain.
- They should be well lit and ventilated, and approaching buses should be visible from inside the shelter.
- Where waiting times may be long, it may be desirable to provide seating.

Figure 5-4 shows the current bus shelter standard in use in Malawi that complies with the basic requirements listed above. Such shelters should preferably be constructed of concrete to avoid vandalism.

Figure 5-4: Typical bus shelter design

5.2.4 Public Transport Connectivity with Residential Areas

Public transport stops should be connected to the adjoining residential area by sidewalks. The cross-sectional requirements pertaining to sidewalk widths are discussed in *Part B – Chapter 6*.

5.3 Landscaping

Street trees are an integral part of the street design as they contribute to the sense of place. In general, the size of a tree or plant selected should be proportional to the width of the street reserve. As a rule of thumb, the full-grown tree canopy should be of the order of 1/4 of the reserve width for the best effect. The full-grown canopy size will also determine longitudinal spacing, but larger spacing may be required on narrower streets, of the order of 15 m to 20 m.

From a geometric design and/or road safety point of view, there a number of considerations pertaining to landscaping. These include:

- Vegetation must not obscure intersection and curvature sight distance lines. The sight distance requirements stipulated in *Part B - Chapter 8*, must be met at all times.
- Trees are potential obstructions by virtue of their size and their location in relation to vehicular traffic. Generally, existing trees with an expected mature trunk size of greater than 200 mm should be considered fixed objects. Geometric design practice shall be applied to maintain adequate sight distances and clear zone setbacks.
- Designers should consider the impact of root growth, with preference given to species with tap-root systems rather than carpet-root systems. Tree root pits or continuous planting strips may need to be considered to restrict or screen root growth. Vegetation should not interfere with the function of the pavement, shoulders, longitudinal barriers, end treatments, drainage systems, traffic signs, signals, utilities and other highway structures and appurtenances.
- Groundcover within the street reserve, especially grass, is an important measure against erosion and to prevent soil and other grit to wash onto the roadway that could reduce the skid resistance of the road surface. When large numbers of pedestrians are using the sidewalks, the area used for walking should be paved not only for the convenience and safety of the pedestrians but also to prevent the loss of ground cover.
- From a security point of view, dense vegetation within the road reserve is not desirable as it creates opportunities for criminal elements to hide and attack people using the street.
- Preferably, all landscaping should involve the design engineer, a landscaping specialist, and a road authority official knowledgeable in landscaping.

5.4 Waste Removal

In some communities, the waste removal service by the local authority does not include the individual servicing of properties; instead, waste is being collected from strategically located collection sites. Where this is the case, a suitable site should be identified during the town planning and geometric design stages, with due allowance being be made for the manoeuvring of waste collection trucks. Such sites should be paved, with preference given to interlocking paving blocks. The maximum grades on routes to be followed by waste removal vehicles should not exceed 1:12.

From a safety perspective, waste removal vehicles should be able to enter and exit collection sites facing forward, hence the sites should be of sufficient size to accommodate a full turn if separate entrance and exits are not provided. The street space should not be used for such manoeuvring. Reversing of waste collection vehicles is a dangerous operation and requires the use of reversing assistants to support the driver. Injuries to collection crews or member of the public by moving waste collection vehicles are invariably severe or fatal; one in three such accidents occur when vehicles are reversing. If turning space is necessary, the site layout should at least accommodate a turning circle of 18.5 m kerb-to-kerb or 21 m boundary-to-boundary, in addition to stacking space for waste.

Gates or arches on the vehicle route to collection sites should provide for a clear width of 3.75 m and a clear height of 4.5 m. Clearance of at least 5m above the height of a standard collection vehicle will be required in the areas where bins are to be emptied to allow for the bin lifting mechanism.

6 Education and Traffic Law Enforcement

6.1 General

In many countries, road safety responsibilities are fragmented, and very little coordination exists. This is especially relevant when it comes to the 3Es in road safety (Engineering, Enforcement and Education). Strong inter-relationships exist between these elements, and deficiencies in one of them can be compensated for by the strengthening of the other two elements. The Safe Systems Approach, as mentioned earlier in Chapter 2, is the desired road safety tool to achieve the necessary coordination between the different road safety elements.

6.2 Improving Road Safety Awareness

6.2.1 General

Road safety awareness on urban and rural LVRs can be improved through a number of measures of which education, publicity campaigns and traffic law enforcement have been proven to yield favourable results.

6.2.2 Education

Road safety education and community participation are important tools to raise awareness of problems and behaviour related to traffic and road safety. It involves teaching children, who are often the most vulnerable group, as well as adults, to be safer road users by developing:

- Knowledge and understanding of road traffic.
- Behavioural skills necessary to survive in the presence of road traffic.
- An understanding of their own responsibility for keeping themselves safe.
- Knowledge of the causes and consequences of road accidents.
- A responsible attitude to their own safety and to the safety of others.

The key characteristics of community road safety education (in addition to scholar training) are:

- Reliance on the involvement of the community so that measures are identified, initiated and supported at the local level.
- Involvement of schools, teachers and children.
- Inclusion of all demographic groups (e.g. young, elderly, economically active, unemployed, physically impaired, etc.), including persons that do not reside permanently within the community (e.g. truck drivers).

Figure 6-1: Road safety training

6.2.3 Publicity Campaigns

Publicity campaigns are an important way to help improve road safety. They can be used to increase awareness of road safety issues (including existing issues as well as new laws), increase awareness about the penalties for breaking road rules and try to change peoples' attitudes to road safety issues. However, publicity campaigns alone will not make people change their behaviour. When trying to change behaviour it is also necessary to educate people about why they need to change. This can be part of the publicity or part of a wider education programme. It is also necessary to combine publicity and education with the enforcement of penalties.

Effective publicity campaigns require careful thought and planning. The International Road Assessment Programme (iRAP) states that publicity campaigns must consider seven elements that should be covered when planning a campaign:

- Behaviour to target
- Audience to target
- Appeals to motivate the audience
- Message content
- Audience activation
- Media selection
- Campaign timing.

6.3 Traffic Law Enforcement

Traffic law enforcement is meant to achieve the safe and efficient movement of all road users, including non-motorised traffic and pedestrians. In this regard, enforcement of traffic rules (such as speed limits, stop signs and rules at pedestrian crossing facilities) can be used to significantly improve road user behaviour and safety. However, the objective should be to improve the behaviour (and safety) of the majority of road users, rather than to simply 'catch' (and punish) a few. Moreover, such strategies should not be used as a simple means of raising money - but to improve safety. The role of traffic law enforcement is important to ensure that road users are behaving correctly in the road environment. In addition, it has been proven in practice that the physical and noticeable presence of traffic law enforcement officers on the roads and streets has a major beneficial effect on road user behaviour. Coupled to an authoritative but friendly admonition for minor transgressions, it goes a long way to instill trust, influence behaviour and improve road safety in general. However, clamping down on serious transgressions remains essential.

The following aspects of traffic law enforcement will generally ensure that road users comply with traffic laws:

- Its ability to create a meaningful deterrent threat to road users.
- Increasing penalty severity and the quick and efficient administration of punishment.
- Increasing the actual level of enforcement activity.
- The use of periodic, short-term intensive enforcement operations (blitzes).
- The use of automated enforcement devices, such as camera surveillance.
- The use of publicity to support enforcement operations.
- The use of legal sanctions, such as license suspension and revocation procedures.
- The use of point demerit schemes.

In essence, traffic law enforcement requires a judicial approach of visibility, education, admonition and punishment.

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Appendix A
Glossary of Terms

Glossary of Terms

A

AADT Annual Average Daily Traffic is calculated by counting the number of vehicles passing a roadside observation point in a year and dividing this number by 365. The number given is the sum of both directions.

Abutment An end support of a bridge or similar structure. These are often designed

Access 1 The driveway by which vehicles and/or pedestrians enter and/or leave property adjacent to a road.

Access 2 To come to or reach a destination.

Access Control The condition whereby the road agency either partially or fully controls the right of abutting landowners to direct access to and from a public street or road.

Adverse Cross Fall A slope on a curved pavement that generates forces detracting from the ability of a vehicle to maintain a circular path.

Alignment The geometric form of the centreline (or other reference line) of a carriageway in both the horizontal and vertical directions.

Alignment Co-ordination (Co-ordinated Alignment) A road design technique in which various rules are applied to ensure that the combination of horizontal and vertical alignment is both safe and aesthetically pleasing.

Aquaplaning Full dynamic aquaplaning occurs when a tyre is completely separated from the road surface by a film of water.

Arterial Highway designed to move relatively large volumes of traffic at high speeds over long distances. Typically, arterials offer little or no access to abutting properties.

Auxiliary Lane A portion of the carriageway adjoining the through traffic lanes for speed change, or for others purposes supplementary to the through traffic movement.

Average Daily Traffic (ADT) Total volume of traffic during a given time period in whole days, greater than one day but less than one year, divided by the number of days in the period.

Average Recurrence Interval (ARI) The Average Recurrence interval (ARI) is the average interval of interval time during which an event will be equalled or exceeded once. It should be based on a lengthy period of records of the event. Statistically it is the inverse of the Average Exceedance Probability. The term replaces recurrence interval.

Average Running Speed The distance summation for all vehicles divided by the running time summation for all vehicles. Also referred to as space mean speed whereas time mean speed is simply the average of all recorded speeds.

Axis of Rotation The line about which the pavement is rotated to super-elevate the roadway. This line normally maintains the highway profile.

B

Barrier An obstruction placed to prevent vehicle access to a particular area.

Barrier Kerb A kerb with a profile and height sufficient to prevent or discourage vehicles moving off the carriageway.

Barrier Sight Distance The limiting sight distance below which overtaking is legally prohibited.

Bicycle or Motorcycle Taxi The use of a bicycle or motorcycle to transport people for gain.

Black Spot A site on a road where accidents happen at regular intervals.

Braking Distance The distance required for the braking system of a vehicle to bring the vehicle to a stop from the operating speed.

Bridge A structure erected with a deck for carrying traffic over or under an obstruction and with a clear span of six metres or more. Where the clear span is less than six metres, reference is to a culvert.

Broken-back Curve Two curves in the same direction with a tangent shorter than 500 metres long connecting them.

Bus Bay An auxiliary lane of limited length at a bus stop or terminus, usually indented into the shoulder or verge.

Bus Stop An area in which one or more buses load and unload passengers. It consists of one or more loading areas and may be on line or off line.

C

Camber The slope from a high point (typically at the centre line of the highway) across the lanes of a highway. Negative camber refers to a central low point, usually with a view to drainage of a small urban street or alley.

Capacity The maximum number of vehicles that can pass a point on a highway or in a designated lane in one hour without the density being so great as to cause unreasonable delay or restrict the driver’s freedom to manoeuvre under prevailing roadway and traffic conditions.

Carriageway The lanes of the cross-section. The carriageway excludes the shoulders.

Catch Drain A surface channel constructed along the high side of a road or embankment, outside the batter to intercept surface water.

Catchment Area The area that will contribute to the discharge of a stream after rainfall at the point under consideration.

Catchwater Drain Located above a cut face to ensure that storm water does not flow down the cut face causing erosion and deposition of silt on the roadway.

Centre Line The basic line that defines the axis or alignment of the centre of a road or other works.

Channel Grading Where side channels are designed to gradients that differ from those of the road centre line, typically on either side of the highest points on crest curves and the lowest points on sag curves where the centre line gradient is less than 0.5 percent.

Channelization The use of pavement markings or islands to direct traffic through an intersection.

Channelized Intersection An intersection provided with channelized islands.

Clear Zone An area adjacent to the traffic lane that should be kept free from features potentially hazardous to errant vehicles.

Clearance The space between a stationary and/or moving object.

Clearance Profile Describes the space that is exclusively reserved for provision of the road or street. It defines the minimum height of the soffit of any structure passing over the road and the closest approach of any lateral obstacle to the cross-section.

Climbing Lane A special case of an overtaking lane located on a rising grade, allowing faster vehicles to pass trucks and other vehicles.

Coefficient of Run-off The ratio of the amount of water that runs off a catchment area to the amount that falls on the catchment.

Collector A road characterised by a roughly even distribution of its access and mobility functions.

Commercial Vehicle A vehicle having at least one axle with dual wheels and/or having more than two axles.

Complete Street A street that accommodate all street users, allow for the safe movement of people and goods, giving priority to the most efficient modes of transport, respond to the neighbourhood character, create a vibrant public realm, contribute to a healthy and sustainable environment and create harmonious streetscapes in a cost-effective way.

Compound Curve A curve consisting of two of more arcs of different radii curving in the same direction and having a common tangent point or being joined by a transition curve.

Context Sensitive Design (CSD) Is defined as a project development process, which include geometric design, and attempts to address safety and efficiency while being responsive to, the street or road's natural and human environment. It addresses the need for a more systematic and all-encompassing approach in project development which recognizes the interdependency of all stages in the process. In short, the term CSD refers as much to an approach or process as it does to an actual outcome.

Criterion A yardstick according to which some or other quality of the road can be measured. Guideline values are specific numerical values of the criterion. For example, delay is a criterion of congestion.

Critical Length of Grade The maximum length of a specific upgrade on which a loaded truck can operate without an unreasonable reduction in speed. Very often, a speed reduction of 15 km/h or more is considered "unreasonable".

Cross-section The transverse elements of the longitudinal elements**.**

Crossfall The slope, measured at right angles to the alignment, of the surface of any part of a carriageway.

Crosswalk A demarcated area or lane designated for the use of pedestrians across a road or street.

Crown The highest point on the cross section of a carriageway with two-way cross fall.

Crown Run-off (Also referred to as tangent runout) The rotation of the outer lane of a two- lane road from zero cross fall to normal camber (NC).

Culvert A structure, usually for conveying water under a roadway or parallel to a street.

Curvilinear Alignment The alignment is a continuous curve with constant, gradual and smooth changes of direction.

Cut Section of street or road below natural ground level. Sometimes referred to in other documents as a cutting or excavation.

Cycle Lane A portion of the roadway which has been designated by road markings, striping and signing as being exclusively for the use of cyclists.

Cycleway A facility provided for cyclist movement and segregated from vehicular traffic by a kerb, or provided for on a separate right-of-way.

D

Deceleration Lane An auxiliary lane provided to allow vehicles to decrease speed.

Decision Sight Distance Sometimes referred to as anticipatory sight distance, allows for circumstances where complex decisions are required or unusual manoeuvres have to be carried out. As such, it is significantly longer than Stopping Sight Distance

Depressed Median A median lower in elevation than the carriageway and so designed to carry portion of the storm water falling on the road.

Design Domain The range of values of a design criterion that are applicable to a given design, e.g. lane widths of more than 3.3 metres.

Design Hour The hour in which the condition being designed for, typically the anticipated flow, is expected to occur. This is often the thirtieth highest hour of flow in the design year, or the peak hour traffic determined by modelling.

Design Hourly Volume (DHV) The hourly traffic volume selected for design purposes.

Design Life The period during which the quality of a structure (e.g. riding quality of a pavement) is expected to remain acceptable.

Design Period A period considered appropriate to the function of the road. It is used to determine the total traffic for which the pavement is designed and does not concern the geometric design.

Design Speed A speed fixed for the design and correlation of those geometric features of a street or road, that influence vehicle operation. Design speed should not be less than the operating speed.

Design Traffic The volume of traffic in the design year in equivalent vehicles, used for determining the required lane configurations of a street or road, normally taken as the design hourly volume.

Design Vehicle A hypothetical road vehicle whose mass, dimensions and operating characteristics are used to determine geometric requirements.

Design Year The last year of the design life of the road or any other facility, often taken as twenty years although, for costly structures such as major bridges, a longer period is usually adopted.

Directional Distribution (split) The percentages of the total flow moving in opposing directions, e.g. 50:50, 70:30, with the direction of interest being quoted first.

Discharge The volumetric rate of water flow.

Divided Road (divided carriageway) A road with a separate carriageway for each direction of travel created by placing some physical obstruction, such as a median or barrier, between the opposing traffic directions.

Drainage Natural or artificial means for the interception and removal of surface or subsurface water.

Driveway A road providing access from a public road to a street or road usually located on an abutting property.

E

Eighty-fifth Percentile Speed The speed below which 85 per cent of the vehicles travel on a given road

F

Footway Separate pedestrian facility.

Frangible Term is used to describe roadside furniture designed to collapse on impact. The severity of potential injuries to the occupants of an impacting vehicle is reduced, compared to those that could occur if the furniture was unyielding.

Freeway Highest level of arterial characterised by full control of access and high design speeds. (Class 1 road)

Frontage Road A road adjacent and parallel to but separated from the highway for service to abutting properties and for control of access. Sometimes also referred to as a service road.

G

Gap The elapsed time between the back of one vehicle passing a point on the road or highway and the nose of the following vehicle passing the same point. A lag is the unexpired portion of a gap, i.e. the elapsed time between the arrival of a vehicle on the minor leg of an intersection and the nose of the next vehicle on the major road crossing the path of the entering vehicle.

Grade The straight portion if the grade line between two successive vertical curves.

Grade Separation The separations of road, rail or other traffic so that crossing movements, which would otherwise conflict, are at different elevations.

Gradient The slope of the grade between two adjacent Vertical Points of Intersection (VPI), typically expressed in percentage form as the vertical rise or fall in metres/100 metres. In the direction of increasing stake value, upgrades are taken as positive and downgrades as negative.

Guardrail A rail erected to restrain vehicles that are out of control. It could also take the form of a set of vertical strung and anchored cables.

Guideline A design value establishing an approximate threshold, which should be met if considered practical. It is a recommended value whereas a standard is a prescriptive value allowing for no exceptions.

H

High Occupancy Vehicle Lane (HOV) A lane designated for the exclusive use of buses and other vehicles carrying more than two passengers. The actual number varies between authorities.

High-speed Typically where speeds of 80 km/h or faster are being considered.

Horizontal Curve A curve in the plan or horizontal alignment of a carriageway.

Horizontal Sight Distance The sight distance determined by lateral obstructions alongside the road and measured at the centre of the inside lane.

Human Factors Design This represents a paradigm shift from a Newtonian physics approach to design to a more complex process of the modelling of driver behaviour. In short, design is now also predicated on what the driver’s capabilities are and wishes to do as opposed to only what the vehicle can do.

I

Intensity of Rainfall The rainfall in a unit of time.

Intersection A place at which two or more roads intersect at grade or with grade separation.

Intersection (at-grade) An intersection where carriageways cross at a common level.

Intersection Angle 1 An angle between two successive straights on the centreline of a carriageway.

Intersection Angle 2 The angles between the centrelines of two intersecting carriageways.

Intersection Leg Any one of the carriageways radiating from and forming part of an intersection.

Intersection Sight Distance The sight distance required within the quadrants if an intersection to safely allow turning and crossing movements.

K

Kerb Concrete, often precast, or hewn stone element adjacent to the carriageway and used for drainage control, delineation of the pavement edge or protection of the edge of surfacing. Usually applied only in urban areas.

Kerb Clearances A distance by which the kerb should be set back in order to maintain the maximum capacity of the traffic lane.

Kerb Ramp The treatment at intersections for gradually lowering the elevation of sidewalks to the elevation of the street surface.

K-Value The length required for a 1% change of grade on a parabolic vertical curve.

L

Lane (Traffic) A portion of the paved carriageway marked out by kerbs, painted lines or barriers, which carries a single fine of vehicles in one direction.

Lane Separator A separator provided between lanes carrying traffic in the same direction to discourage or prevent lane changing, or to separate a portion of a speed change lane from through lanes.

Lateral Friction The force which, when generated between the tyre and the road surface assists a vehicle to maintain a circular path.

Lay-by A place at the side of a road where a vehicle can stop for a short time without interrupting other traffic.

Level of Service (LOS) A qualitative concept, from LOS A to LOS F, which characterises acceptable degrees of congestion as perceived by drivers. Capacity is defined as being at LOS E.

Line of Sight The direct line of uninterrupted view between a driver and an object of specified height above the carriageway in the lane of travel.

Longitudinal Friction The friction between vehicle tyres and the road pavement measured in the longitudinal direction.

Low Speed Typically where speeds of 70 km/h or slower are being considered.

M

Median A strip of road, not normally intended for use by traffic, which separates carriageways for traffic in opposite directions.

Median Island A short length of median serving a localised purpose in an otherwise undivided road.

Median Lane The traffic lane nearest the median.

Median Opening An at-grade opening in the median to allow vehicles to cross from a roadway to the adjacent roadway on a divided road.

Minimum Turning Path The path of a designated point on a vehicle making its sharpest turn.

Minimum Turning Radius The radius of the minimum turning path of the outside of the outer front tyre of a vehicle.

Modelling A mathematical process to replicate traffic movements by computation

Modal Transfer Station The public facility at which passengers change from one mode of transport to another, e.g. rail to bus, passenger car to rail.

Movement Networks Movement networks comprise public right of ways, incorporating roads and streets as well as footways and cycleways which provide in a continuous and friendly manner for all human travelling needs. Movement networks recognises the multi-faceted nature of local residential streets, morphing into public transport orientated wider area movement facilities operating at higher speeds for the efficient transport of people and goods.

Mountable kerb A kerb designed so that it can be driven across.

Mountainous Terrain Longitudinal and transverse natural slopes are severe and changes in elevation abrupt. Many trucks operate at crawl speeds over substantial distances.

N

Non-motorized transport All road users that are not using motorized transport,including pedestrians, cyclists and animal drawn carts**.**

Non-Mountable Kerb A kerb so designed to discourage being driven across

Normal Cross Section The cross section of the carriageway where it is not affected by superelevation or widening.

Normal Crown (NC) The typical cross-section on a tangent section of a two-lane road undivided road.

O

O-D Survey Origin-Destination survey. This is a survey carried out to study the patterns and movements of road users so as to guide a road planner/designer on who and what to cater for.

Off-tracking The radial off-set between the path traced by the centre of the front axle and the centre of the effective rear axle on a turning vehicle.

One-way Road A road or street on which all vehicular traffic travels in the same direction.

Operating Speed Refer: Speed.

Outer Separator The portion of road separating a through carriageway from a service road or frontage road.

Overpass A grade separation where the subject road passes over an intersecting road, and/or pedestrian crossing and/or animal crossing.

Overtaking The manoeuvre in which a vehicle moves from a position behind to a position in front of another vehicle travelling in the same direction.

Overtaking Distance The distance required for one vehicle to overtake another vehicle.

Overtaking Lane An auxiliary lane provided to allow for slower vehicles to be overtaken. It is lined-marked so that all traffic is initially directed into the left-hand lane, with the inner lane being used to overtake.

Overtaking Zone A section of road on which at least 70 per cent of drivers will carry out overtaking manoeuvres subject to availability of adequate gaps in the opposing direction.

P

Passenger Car Equivalents(units) (PCE or PCU) A measure of the impedance offered by a vehicle to the passenger cars in the traffic stream. Usually quoted as the number of passenger cars required to offer a similar level of impedance to the other cars in the stream.

Passing The manoeuvre by which a vehicle moves from a position behind to in front of another vehicle, which is stationary or travelling at crawl speeds.

Passing Sight Distance The total length of visibility, measured from an eye height of 1,05 metres to an object height of 1,3 metres, necessary for a passenger car to overtake a slower moving vehicle. It is measured from the point at which the initial acceleration commences to the point where the overtaking vehicle is once again back in its own lane.

PC (Point of Curvature) Beginning of horizontal curve, often referred to as the BC.

PI (Point of Intersection) Point of intersection of two tangents.

PRC (Point of Reverse Curvature) Point where a curve in one direction is immediately followed by a curve in the opposite direction.

Property Line The boundary between a road reserve and the adjacent land.

PT (Point of Tangency) End of horizontal curve, often referred to as BC or EC.

PVC (Point of Vertical Curvature) The point at which a grade ends and the vertical curve begins, often also referred to as BVC.

PVI (Point of Vertical Intersection) The point where the extension of two grades intersect. The initials are sometimes referred to as VPI.

PVT (Point of Vertical Tangency) The point at which the vertical curve ends and the grade begins. Also referred to as EVC.

R

Rainfall Intensity The rate of rainfall (mm/h).

Rate of Rotation The rate of rotation required to achieve a suitable distance to uniformly rotate the cross fall from normal to full superelevation.

Reaction Distance The distance travelled during the reaction time.

Reaction Time The time between the driver’s reception of stimulus and taking appropriate action.

Re-alignment An alteration to the control line of a road that may affect only its vertical alignment but, more usually, alters its horizontal alignment. A method of widening a road reservation.

Relative Gradient The slope of the edge of the carriageway relative to the grade line.

Renewable energy lighting sources: The provision of street lighting in villages or along LVRs through the use of solar energy or wind energy driven devices.

Residual Median The remnant area of the median adjacent to right turn lanes.

Reverse Camber (RC) A superelevated section of roadway sloped across the entire carriageway at a rate equal to the normal camber.

Reverse Curve A section of road alignment consisting of two arcs curving in opposite directions and having a common tangent point or being joined by a short transition curve.

Road Accident An incident in which a single vehicle, or two or more vehicles are involved in an accident that could include human injury or death.

Road Furniture A generic term used for various road related assets within the road reserve, including bus laybys and shelters, guardrails, pedestrian barriers, traffic signals, traffic signage, rail crossings and other small structures such as pedestrian bridges across rivers or streams.

Roadway A route trafficable by motor vehicles; in law, the public right-of-way between boundaries of adjoining property. The roadway includes the carriageway and the shoulders.

Road (Street) Furniture A general term covering all signs, streetlights and protective devices for the control, guidance and safety of traffic, and the convenience of road users.

Road Prism The lateral extent of the earthworks.

Road Reserve Also referred to as Right-of-way. The strip of land acquired by the road authority for provision of a road.

Road Safety Audit A structured and multidisciplinary process leading to a report on the crash potential and safety performance of a length of road or highway, which report may or may not include suggested remedial measures.

Road Safety Inspection Road Safety Inspections (RSIs) to be carried out on an ongoing basis once a road is fully operational to ensure the safe performance of the road.

Roadside A general term denoting the area beyond the shoulder breakpoints.

Roadside Safety Barrier A device erected parallel to the road to retain vehicles that are out of control.

Rolling Terrain The natural slopes consistently rise above and fall below the road grade with, occasionally, steep slopes presenting some restrictions on highway alignment. On general, rolling terrain generates steeper gradients, causing truck speeds to be lower than those of passenger cars.

Roundabout An intersection designed on the principle of gap acceptance and where all traffic travels in one direction around a central island.

Run-off That part of the water precipitation onto a catchment which flows as surface discharge from the catchment area past a particular point.

S

Sag Curve A concave vertical curve in the longitudinal profile of a road.

Safe Systems: An approach to build a road transport system that tolerates human error and minimises casualties following road accidents.

Section Operating Speed The 85th percentile speed of cars traversing a section of road alignment.

Semi-Mountable Kerb A kerb designed so that it can be driven across in emergency or on special occasions without damage to the vehicle.

Servitude A servitude is a registered right that a person has over the immovable property of another. It allows the holder of the servitude to do something with the other person’s property, which may infringe upon the rights of the owner of that property.

Shared Path A paved area particularly designed (with appropriate dimensions, alignment and signing) for the movement of cyclists and pedestrians.

Shoulder Usable area immediately adjacent to the traffic lanes provided for emergency stopping, recovery of errant vehicles and lateral support of the road pavement structure.

Shoulder Breakpoint The hypothetical point at which the slope of the shoulder intersects the line of the fill slope. Sometimes referred to as the hinge point.

Side friction (f) The resistance to centrifugal force keeping a vehicle in a circular path. The designated maximum side friction (max) represents a threshold of driver discomfort and not the point of an impending skid.

Sidewalk The portion of the street cross-section reserved for the use of pedestrians.

Sideways Friction The resistance to sideways motion of the tyre of a vehicle on a road surface.

Sight Distance

- **Approach Sight Distance (ASD)** The distance required for a driver to perceive marking or hazards on the road surface and to stop.
- **Car Stopping Sight Distance (SSD)** The distance required for a car driver to perceive an object on the road and to stop before striking it.
- **Entering Sight Distance (ESD)** ESD is the sight distance required for minor road drivers to enter a major road via a left or right turn, such that traffic on the major road is unimpeded.
- **Manoeuvre Sight Distance** The distance required for an alert car driver to perceive an object on the road and to take evasive action.
- **Minimum Gap Sight Distance (MGSD)** The minimum sight distance based on the gap necessary to perform a particular movement.
- **Overtaking Sight Distance** The sight distance required for a driver to initiate and safely complete an overtaking manoeuvre.
- **Railway Crossing Sight** Triangle The clear area required for a truck driver to perceive a train approaching an uncontrolled railway crossing and to stop the truck.
- **Safe Intersection Sight Distance (SISD)** The distance required for a driver in a major road to observe a vehicle entering from a side road, and to stop before colliding with it.
- **Sight Distance Through Underpass** The distance required for a truck driver to see beneath a bridge located across the main road, to perceive any hazard on the road ahead, and to stop.
- **Sight Triangle** The area in the quadrants of an intersection that must be kept clear to ensure adequate sight distance between the opposing legs of the intersection
- **Stopping Sight Distance** The sight distance required by an average driver, travelling at a given speed, to react and stop.
- **Truck Stopping Sight Distance** The distance required for a truck driver to perceive an object on the road and to stop before striking it.

Simple Curve A curve of constant radius without entering or exiting transitions.

Skid Resistance The frictional relationship between a pavement surface and vehicle tyres during braking or cornering manoeuvres. Normally measured on wet surfaces, it varies with the speed and the value of ‘slip’ adopted.

Slope

- The inclination of a surface with respect to the horizontal, expressed as rise or fall in a certain longitudinal distance.
- An inclined surface.

Speed

- **Operating Speed** The speed at which 85 percent of car drivers will travel slower and 15 percent will travel faster.
- **Operating Speed of Trucks** The 85th percentile speed of trucks measured at a time when traffic volumes are low.
- **Section Operating Speed** The value at which vehicle speeds on a series of curves tend to stabilise and is related to the range of radii on the curves.

Speed-change Lane A subdivision of auxiliary lanes, which cover those lanes used primarily for the acceleration or deceleration of vehicles. It is usual to refer to the lane by its actual purpose (such as deceleration lane).

Speed Profile The graphical representation of the 85th percentile speed achieved along the length of the highway segment by the design vehicle.

Standard A design value that may not be transgressed, e.g. an irreducible minimum or an absolute maximum. On the sense of geometric design, not to be construed as an indicator of quality, i.e. an ideal to be strived for.

Standard Axle A single axle with dual wheels loaded to a total mass of 8.16 tonnes.

Superelevation A slope on a curved pavement selected so as to enhance forces assisting a vehicle to maintain a circular path.

Superelevation Run-off (Also referred to as superelevation development) The process of rotating the outside lane from zero crossfall to reverse camber (RC), thereafter rotating both lanes to the full superelevation selected for the curve.

Sustainable Safety A safe road traffic system that aims to prevent deaths, injuries and damage to vehicles and property by systematically reducing the underlying risks of the entire traffic system.

Swept Path The area bounded by lines traced by the extremities of the bodywork of a vehicle while turning.

Swept Width The radial distance between the innermost and outermost turning paths of a vehicle.

T

Table Drain The side drain of a road adjacent to the sidewalk or shoulder, having its invert lower than the pavement base and being part of the formation.

Tangent The straight portion of a highway between two horizontal curves.

Tangent Run-off See crown runoff.

Tangent Run-out The length of roadway required to accomplish the change in crossfall from a normal crown section to a flat crossfall at the same rate as the superelevation runoff.

Terrain Topography of the land.

- **Level Terrain** Is that condition where road sight distance, as governed by both horizontal and vertical restrictions, are generally long or could be made to be so without construction difficulty or major expense**.**
- **Undulating Terrain** Is that condition where road sight distance is occasionally governed by both horizontal and vertical restrictions with some construction difficulty and major expense but with only minor speed reduction.
- **Rolling Terrain** Is that condition where the natural slopes consistently rise above and fall below the road grade and where occasional steep slopes offer some restriction to normal horizontal and vertical roadway alignment. The steeper grades cause trucks to reduce speed below those of passenger cars.
- **Mountainous Terrain** Is that condition where longitudinal and transverse changes in the elevation of the ground with respect to the road are abrupt and where benching and side hill excavation are frequently required to obtain acceptable horizontal and vertical alignment. Mountainous terrain causes some trucks to operate at crawl speeds.

Time of Concentration The shortest time necessary for all points on a catchment area to contribute simultaneously to run-on at a specified point.

Traffic A generic term covering all vehicles, people, and animals using a road.

Traffic calming Speed reducing measures implemented to force drivers to reduce speed at unsafe road conditions.

Traffic Composition The percentage of vehicles other than passenger cars in the traffic stream e.g. 10 per cent trucks, 5 per cent articulated vehicles (semi-trailers) etc.

Traffic Control Signal A device that, by means of changing coloured lights, regulates the movement of traffic.

Traffic Island A defined area, usually at an intersection, from which vehicular traffic is excluded. It is used to control vehicular movements and as a pedestrian refuge.

Traffic Lane A portion of the paved carriageway marked out by kerbs, painted lines or barriers, which carries a single line of vehicles in one constant direction.

Traffic segregation The vertical or horizontal separation of motorized and non-motorized road users.

Traffic Sign A sign to regulate traffic and warn or guide drivers.

Transition Length for increasing or decreasing the number of lanes.

Transition Curve A curve of varying radius used to model the path of a vehicle as it enters or leaves a curve of constant radius used for the purpose of easing the change in direction.

Transition Length for Alignment The distance within which the alignment is changed in approach from straight to a horizontal curve of constant radius.

Transition Length for Crossfall The distance required rotating the pavement crossfall from normal to that appropriate to the curve. Also called superelevation development length.

Transition Length for Widening The distance over which the pavement width is changed from normal to that appropriate to the curve.

Turning Lane An auxiliary lane reserved for turning traffic.

Turning Roadway Channelized turn lane at an at-grade intersection.

Turning Template A graphic representation of a design vehicle’s turning path for various angles of turn. If the template includes the paths of the outer front and inner rear points of the vehicle, reference is to the swept path of the vehicle.

Typical Cross Section A cross section of a street showing typical dimensional details, utility services and street furniture locations.

U

Underpass A grade separation where the subject road passes under an intersecting road, pedestrian crossing or railway.

Urban Road or Street Characterised by adjacent property development, traffic volumes in keeping with the nature of the adjacent development, moving at relatively low speeds and pronounced peak or tidal flows. Usually within an urban area but may also be a link traversing an unbuilt up area between two adjacent urban areas, hence displaying urban operational characteristics.

V

Value Engineering A management technique in which intensive study of a project seeks to achieve the best functional balance between cost, reliability and performance.

Verge That portion of the road reserve outside the road prism

Vertical Alignment The longitudinal profile along the design line of a road.

Vertical Curve A curve (generally parabolic) in the longitudinal profile of a carriageway to provide for a change of grade at a specified vertical acceleration.

W

Walkway A facility provided for pedestrian movement and segregated from vehicular traffic by a kerb, or provided for on a separate right-of-way.

Warrant A guideline value indicating whether or not a facility should be provided. For example, a warrant for signalisation of an intersection would include the traffic volumes that should be exceeded before signalisation is considered as a traffic control option.