

# Section I Transportation and road pavements

*The Neighbourhood Planning and Design Guide*



Part II

Planning and design guidelines

## Symbols at text boxes



More detailed information is provided about the issue under discussion



Important considerations to be aware of are highlighted



Relevant content from a complementing resource is presented

### PART I: SETTING THE SCENE

- A The human settlements context
- B A vision for human settlements
- C Purpose, nature and scope of this Guide
- D How to use this Guide
- E Working together

### PART II: PLANNING AND DESIGN GUIDELINES

- F Neighbourhood layout and structure
- G Public open space
- H Housing and social facilities
- I Transportation and road pavements
- J Water supply
- K Sanitation
- L Stormwater
- M Solid waste management
- N Electrical energy
- O Cross-cutting issues
- Planning and designing safe communities
- Universal design

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# Section I Transportation and road pavements

*The Neighbourhood Planning and Design Guide*



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## 1.1 Outline of this section

### 1.1.1 Purpose

Settlements are integrated systems in which the various components are interconnected, and this section highlights the role of transportation in this system. Transportation (mobility and access) significantly affects the quality of living environments; therefore the aspects addressed in this section play an essential role in achieving the vision for human settlements outlined in **Section B**.

This section deals with the planning and design of roads and streets that are able to accommodate a range of transport options, including non-motorised transport (NMT), public transport and motor vehicles. Aspects that should be taken into consideration when establishing the transportation demand created by a neighbourhood development are outlined, and information regarding the related infrastructure options available is provided. Guidance is provided with respect to geometric design as well as the structural design of road pavements. For the purposes of this Guide, 'road pavement' refers to the surface material of a road (incorporating all the associated layers). 'Road' refers to any pathway (road or street) that is intended to accommodate and facilitate the movement of pedestrians, cyclists, animal-drawn carts, wheelchairs, motor cycles, motor vehicles, etc., as well as other activities that may take place in neighbourhood streets.

Section I links directly with **Section F** (Neighbourhood layout and structure), **Section G** (Public open space), **Section L** (Stormwater) and **Section O.2** (Universal design), and care should be taken to ensure that the information provided in all these sections are considered when applying the guidelines provided in any of the three sections.

### 1.1.2 Content and structure

This section (Section I) is structured to support effective decision-making related to transportation and road pavements. The decision-making framework is outlined in Figure I.1, and the structure of this section is briefly described below.

#### Universal considerations

General aspects that should be taken into consideration when making higher level decisions regarding transportation and road pavements are highlighted, including the following:

- The regulatory environment, including key legislation, policies, frameworks and strategies
- The key objectives that should be achieved as a result of the application of the guidelines provided
- Local or international approaches, mechanisms, concepts and current trends that could possibly be utilised to achieve the key objectives
- Contextual factors specific to the development project to be implemented such as the development type and setting

#### Planning considerations

Factors to consider when making more detailed decisions regarding transportation and road pavements are outlined, including the following:

## Outline of this section

- The characteristics of the development, including the nature of the proposed neighbourhood, the anticipated number of residents and specific features that would have to be incorporated or requirements that would have to be met
- The existing features of the site and immediate surroundings (built and natural environment) as determined by the physical location of the proposed development
- Options related to transportation and road pavements that are available for consideration

### Design considerations

Guidelines to assist with the design of transportation infrastructure.

### Glossary, acronyms, abbreviations and endnotes

A glossary, a list of acronyms and abbreviations, and endnotes (containing sources of information, explanatory comments etc.) are provided at the end of Section I.

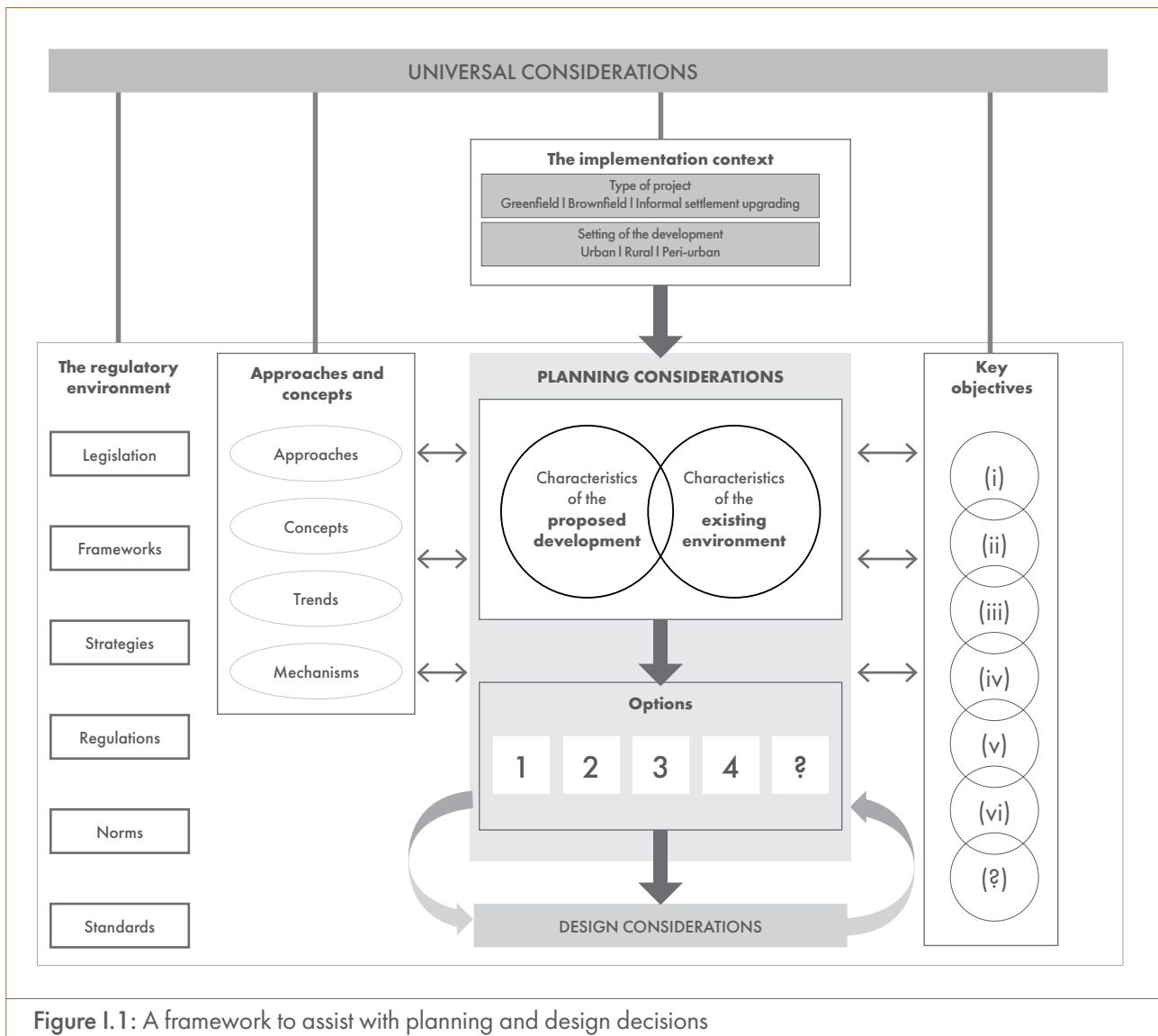


Figure I.1: A framework to assist with planning and design decisions



## 1.2 Universal considerations

### 1.2.1 The regulatory environment

A range of legislation, policies and strategies guide the planning and design of transportation facilities and services for human settlements. Legislation and policy that have direct implications for neighbourhood transportation planning and design are briefly outlined below. They are not discussed in detail, so it is important to consult the relevant documentation before commencing with any neighbourhood development project.

#### (i) Policies, plans, frameworks and strategies

A number of policies, plans, strategies and frameworks guide various aspects of transportation and related infrastructure planning and investment in South Africa, including the following:

- National Land Transport Strategic Framework 2006
- Road Infrastructure Strategic Framework for South Africa (RISFSA) 2006
- Rural Transport Strategy of South Africa 2007
- Public Transport Strategy and Action Plan 2007 (which made provision for the introduction of Integrated Rapid Public Transport Service Networks)
- National Non-Motorised Transport Policy 2012
- National Learner Transport Policy 2015
- National Transport Master Plan (NATMAP) 2016
- Draft Green Transport Strategy (2017-2050)
- Draft Revised White Paper on National Transport Policy 2017
- Draft National Road Safety Strategy (2016-2030)

Provincial Land Transport Frameworks, developed in terms of the National Land Transportation Act, inform the transportation policy environment in the various provinces. At a local level, municipal planning mechanisms include long-term development visions and city development strategies, Comprehensive Integrated Transport Plans, the Integrated Development Plan (IDP) sector plans (including Spatial Development Frameworks) and, in the case of certain municipalities, the Built Environment Performance Plans (BEPPs). Some national government departments have guidelines aimed at the local level, such as the National Treasury's Urban Network Strategy toolkit, which provides guidance for transportation planning. There are also municipal by-laws that require adherence to traffic and transportation planning and design guidelines and specifications.

#### (ii) Legislation

The National Land Transport Act (NLTA) of 2009 (with amendments) governs all urban and rural land transport planning in South Africa. It specifies the legal responsibilities of the different spheres of government and deals with the application of national principles, guidelines, norms and standards. Some of the aspects addressed in this act that should specifically be considered when implementing Section I of the Guide, include the following:

- All municipalities have to develop Comprehensive Integrated Transport Plans (CITPs). In addition to ensuring proper intermodal planning and coordination of transportation between adjacent municipalities and between different spheres of government, these CITPs must be accommodated in and form an essential part of municipal IDPs, as required by the Municipal Systems Act of 2000.

### Universal considerations

- Local land transport planning must be integrated with the land development and land use planning processes in the municipality.
- Municipalities must plan for and actively encourage the optimal use of available travel modes and specifically promote public transport by, for instance, implementing and managing modally integrated public transport networks (IPTN) and travel corridors.
- Any substantial change or intensification of land use on any property may be subject to traffic impact assessments, public transport assessments and universal access audits as required by national, provincial and municipal transport authorities.

Other pieces of legislation pertaining to road transport infrastructure include the National Road Traffic Act of 1996, the South African National Roads Agency Limited and National Roads Act of 1998, as well as provincial acts.

Legislation that is not sector-specific, but has to be considered in the planning and design of transportation infrastructure and services at a neighbourhood level, includes the National Building Regulations and Building Standards Act of 1977 (and amendments), the National Environmental Management Act of 1998 and the National Heritage Resources Act of 1999.

#### **(iii) Guidelines, manuals and standards**

To give effect to legislative requirements and policy provisions, a range of guidelines, manuals and other documents are available to assist with neighbourhood transportation planning and design. At a national level, the Department of Transport's publications include the Non-Motorised Transport (NMT) Facility Guidelines 2015 and the South African Road Safety Manual (SARSM), which is under the custodianship of the Road Traffic Management Corporation (RTMC). The South African Road Traffic Signs Manual 2012 (SARTSM) is an important guideline document for all road traffic signs, including the signing requirements at various intersection types and guidelines for the design of traffic signal systems at intersections (Volume 3).

The Technical Methods for Highways (TMH) or Technical Recommendations for Highways (TRH) series of publications are compiled under the auspices of the Roads Coordinating Body (RCB) of the Committee of Transport Officials (COTO) and published by the Department of Transport. The TRH guides provide information about current, recommended practice in selected aspects of road engineering, based on proven South African experience. The TMH manuals prescribe methods that can be used in various road design and construction procedures. Both sets of documents are relevant to roads in general, not just highways, as the titles may suggest. They address a range of topics, dealing with, for instance, traffic impact assessments (TMH 16), trip data parameters (TMH 17), road classification (TRH 26) and the use of road reserves (TRH 27).

SANRAL also publishes the South African Pavement Engineering Manual (SAPEM), which is a best-practice guideline covering a range of elements of pavement engineering. The South African Bitumen Association (SABITA) publishes a number of technical manuals, covering the selection, handling and use of bituminous materials for road construction.

Publications relevant to universal access (as it applies to transportation) include SANS 10400-S: 2011 (Facilities for Persons with Disabilities), SANS 784: 2008 (Design for access and mobility - Tactile indicators) and National Technical Requirement 1: Pedestrian Crossings (NTR1 2016), developed by the Department of Transport.

Municipalities often have their own guidelines and design standards on issues related to transport planning, non-motorised transport, traffic safety, parking provision, the provision of transport infrastructure in informal settlements, geometric standards and the like.

## 1.2.2 Key objectives

Objectives related to transportation have been formulated in various transport policy and planning publications. Increasingly, the focus is shifting towards improving access and mobility for all, regardless of the mode of transport used. Furthermore, there is a growing recognition that all users should be accommodated, including those with disabilities. The planning and design information contained in this Guide aims to support this and advocates the development of transportation infrastructure that caters not only for motor vehicles, but purposefully also accommodates pedestrians, cyclists, wheelchairs, etc. In addition to facilitating movement by means of various forms of transport, neighbourhood streets should also support a range of social, economic and recreational activities (See [Section F.4.1](#)).



### *The vision of the National Transport Master Plan (NATMAP) 2016<sup>1</sup>*

*An integrated, smart and efficient transport system supporting a thriving economy that promotes sustainable economic growth, supports a healthier lifestyle, provides safe and accessible mobility options, socially includes all communities and preserves the environment.*

A number of objectives have been identified to direct the planning and designing of neighbourhood transportation infrastructure. Transportation infrastructure should meet the following requirements:

- Improve access and mobility for all users
- Enhance the safety and security of all users
- Minimise negative impacts on the environment
- Support economic activities
- Respond to the needs of all users
- Be reliable and of an acceptable quality

#### **(i) Improve access and mobility for all**

In essence, the purpose of transport is to allow people and goods to move from one place to another. Inherent to this are two aspects, namely access and mobility. Transportation infrastructure should allow people to access their destination with relative ease, and to travel between two places within a reasonable time. Internationally, access and mobility are described in various ways, and different definitions are presented.

For the purposes of this Guide, access is interpreted as the ability to reach and utilise a particular destination. Destinations such as facilities, services, activities and opportunities are accessible if they can be approached and entered with ease by all people, including pedestrians, cyclists, people with disabilities, and those who are dependent on public transport. Access, or accessibility, can be improved in a number of ways. For instance, the accessibility of a particular destination is enhanced if it can be reached by means of a range of motorised and non-motorised transport options, and also if the time to reach destinations is reduced as a result of their location within a neighbourhood. If a number of facilities such as a clinic, gymnasium, library and shops are grouped conveniently in a neighbourhood, it may make them more accessible to the community.



### Access and mobility

*Access has to do with the question “where can I go?” It relates to the ability to reach and utilise a place, but not the act or process of moving.*

*Mobility has to do with the question “how can I get there?” It relates to the ability to move from one place to the other.*

Mobility is the ability of people and goods to move between two places, and the ease with which this can be done, regardless of the mode of transport. Mobility can be improved by providing safe and efficient infrastructure to accommodate all modes of transport, including non-motorised options. When interventions to improve mobility are planned and designed, the needs of all people, including pedestrians, cyclists, people with disabilities, and those who are dependent on public transport, should be acknowledged.

Access and mobility are interrelated. Good mobility in a neighbourhood, whether by means of motorised or non-motorised transport, could potentially improve accessibility. However, the destinations that people want to access need to be located in or near the neighbourhood. Similarly, desirable destinations may be provided, but it may be difficult to reach them due to a lack of good quality roads, pedestrian walkways, or public transport facilities.

In some cases, such as in a rural setting, access is, to a large degree, dependent on mobility. Due to the distances between, say a residential and a shopping area, effective and safe mobility infrastructure is required to allow people to access a specific destination. In other cases, accessibility may be reduced as a result of the infrastructure provided to increase vehicular mobility. Access by pedestrians or cyclists to for instance a shopping centre may be compromised as a result of busy multi-lane streets and a lack of safe pedestrian crossings and inadequate or no infrastructure to accommodate taxis and other public transport services. Access to favoured destinations could also be reduced if these destinations are located alongside a street designed to accommodate fast-travelling vehicular traffic.

### (ii) Enhance safety and security

All the components of transportation infrastructure should be planned and designed such that the risk of any user being injured or killed in an accident, or of being a victim of crime, is reduced. All users should be considered, including people with disabilities, and regardless of age. Whether people are walking, cycling, using a wheelchair or mobility scooter, travelling by motor vehicle, making use of public transport, or any other mode of motorised or non-motorised, they should be and feel safe and secure.

Aspects that should be considered to reduce physical injuries and fatalities as a result of any type of accident include, for instance, the design of pedestrian crossings, walkways and cycle lanes, the type of material used to pave streets and walkways, the type and positioning of lighting, the timing of traffic signals etc. (**Section 1.3.3**). Geometric design (**Section 1.4**) also plays an important role in creating streets that are safe for the users of motorised as well as non-motorised transport modes. Aspects such as the location and spacing of intersections, lane widths, horizontal curvature radii and sight distances could play an important role in creating a safe transport environment for all.

When developing transportation infrastructure, opportunities for crime can be reduced by applying the principles of crime prevention through environmental design (CPTED) (**Section O.1**). Furthermore, by applying CPTED strategies, safer spaces can be created that would decrease people's feelings of insecurity. It is important to ensure that the security of all users – regardless of their mode of transport – is considered. This means that all pedestrians, cyclists and other users of non-motorised transport, as well as motorists and users of public transport should be provided with a safe and secure environment.

### **(iii) Minimise environmental impact**

The emphasis on improving accessibility and mobility through fossil-fuelled transportation systems has come at a price, namely an escalation in harmful atmospheric emissions and the associated negative impact on the natural environment. Other negative effects of car-based transportation systems include noise pollution, the consumption of productive land and landscape damage resulting from the provision of transportation infrastructure.

One way of significantly reducing the negative impact of transportation on the environment is to lessen people's dependence on fossil-fuelled private motor vehicles as a mode of transport. At a settlement level, this would require the commitment and active involvement of various role players. A number of strategies need to be in place and a range of services be provided to encourage people to make use of alternative forms of transport. For instance, to reduce people's reliance on private transport, an effective, efficient, safe, reliable and affordable public transport system is essential. More importantly in the South African context, however, is the need to accommodate people making use of non-motorised transport, particularly those who have to walk or cycle almost everywhere they need to go to.

When applying the guidelines provided in Sections 1.3, 1.4 and 1.5, the possibility of promoting the use of non-motorised transport by planning and designing suitable infrastructure should be a guiding factor when making decisions. For instance, wherever possible, infrastructure should be provided at a neighbourhood level to support pedestrians, cyclists and users of other modes of non-motorised transport. The use of non-motorised transport could be accommodated (and encouraged) by for instance providing dedicated, safe cycle lanes and pedestrian walkways, designing safe pedestrian crossings, etc.

Another aspect to consider when making decisions aimed at reducing the impact of transportation infrastructure on the environment relates to the pavement material used. Certain materials and construction methods are more environmentally friendly than others, and it is therefore important to consider all factors before making a decision regarding the technology to be used.

### **(iv) Support economic activities**

Access to transport (and a lack thereof) plays a critical role in the extent to which people are able to participate in economic activities. For instance, transport allows people to travel to and from their places of employment, it enables job seekers to search for employment opportunities and to attend job interviews, it connects businesses to each other (e.g. to deliver services and goods) and it allows customers and clients to interact commercially with a range of businesses.

Effective and efficient transport infrastructure supports job creation and economic activity, and it is essential for growth and development. Since a large proportion of the South African population does not have access to private motor vehicles, there is a particular need for infrastructure that accommodates and supports public transport and non-motorised transport. Many people have to cycle, walk and/or make use of public transport to participate in

economic activities. Without appropriate infrastructure and an effective, efficient, safe, reliable and affordable public transport system, their ability to partake in and contribute to the economy, whether formal or informal, is severely compromised.

#### (v) Accommodate the needs of all users

Neighbourhood transportation infrastructure and services should, as far as possible, accommodate the needs of all potential users. The aim should be to provide universally accessible transport that could be used with ease by all, including people with disabilities, elderly people, children, pregnant women, etc. (See [Section O.2.](#))

Streets should meet the needs of people, not just of motor vehicles. This means that streets should be designed to enable the movement not only of motor vehicles, but also non-motorised modes of transport. Wherever appropriate, streets should allow for a range of activities to be integrated, including leisure, trading and recreation. In some communities, streets provide the space for social interaction, and this should be acknowledged in the street design. (See [Section F.4.1.](#))

Safe streets and walkways should be provided that would purposely support walking and cycling. Not only are these the only modes of transport available to many people, but if the infrastructure is provided, it may encourage others to walk and cycle, which would contribute to improving their health and wellbeing. At a neighbourhood level, pedestrians should be prioritised by incorporating pedestrian desire lines when deciding on a street layout pattern, providing safe pedestrian crossings and employing traffic calming measures.

It is always expedient to provide transport infrastructure that would allow people with a choice when they need to travel. Infrastructure should be designed to allow for changes that may occur over time. Even if there is a focus on accommodating pedestrians, it should not necessarily be assumed that certain communities do not have access to motor vehicles based on economic or other criteria. (See [Section O.2.](#))

#### (vi) Ensure quality and reliability

Good quality, reliable transportation infrastructure, as well as proper management and operation practices, are essential for achieving the majority of the other objectives discussed here. People depend on the infrastructure to travel to, for instance, healthcare and education services, recreational facilities, to do shopping and to participate in employment activities. Importantly, they need the infrastructure to be regularly maintained so as to allow them to be safe and secure when they travel, and to be universally accessible. Well-maintained infrastructure would have less harmful effects on the environment than ineffective, inefficient infrastructure.

It is therefore critical to ensure that the infrastructure is carefully planned and designed according to appropriate standards. Factors that could improve operation processes and procedures and reduce the need for constant maintenance should be considered when design decisions are made. This would assist in ensuring that the infrastructure remains effective, efficient and reliable. The use of innovative technologies should be incorporated where appropriate to improve the quality of the infrastructure and to support mechanisms implemented to improve reliability.

### 1.2.3 Approaches and concepts

This section briefly summarises possible approaches, strategies and mechanisms that could be utilised, or local or international concepts, ideas and trends that could be implemented to achieve the objectives discussed in [Section 1.2.2.](#)

### 1.2.3.1 Classification of the road and street system

The classification of the road and street system has implications for all aspects of transportation planning and design. *TRH26: South African Road Classification and Access Management Manual*<sup>2</sup> outlines a rural and urban road classification system that consists of six classes (see Table I.1). In this system, roads are classified exclusively on the basis of their function. The fact that a road has been built or managed to a particular standard does not mean that it has a particular function. Functional and not geometric or condition criteria are used for classifying roads. The appropriate hierarchy of the multi-functional street at a local level should be determined by the local needs and the context of the site, and not by simply applying a guideline. (Section F.4.)

**Table I.1:** The South African road classification system (Based on TRH26)

Class	Function	Description	Urban		Rural	
			Design speed (km/h)	Typical road reserve width (m)	Design speed (km/h)	Typical road reserve width (m)
Class 1	Mobility	Principal arterial	120	60	120	62
Class 2		Major arterial	80	40	120	48
Class 3		Minor arterial	70	30*	100-120	30
Class 4a	Access/ activity	Collector street: major	60	25	80-100	25
Class 4b		Collector street: minor	50	20	80-100	
Class 5a		Local street: commercial	40	22	60-80	20
Class 5b		Local street: residential	40	14**	60-80	
Class 6		Walkway	n/a	n/a	n/a	n/a

\* Reserve up to 62m is required to allow for Bus Rapid Transit (BRT).

\*\* Reserve of 10.5m is typical if street is less than 100 m long.

Road classification plays an important role when making decisions regarding aspects related to accessibility and mobility, intersection spacing and control, public transport infrastructure provision, and the balance required between different road types to structure an efficient network. Several of these issues are addressed in *TMH 16 South African Traffic Impact and Site Traffic Assessment Standards and Requirements Manual* (2014).

According to TRH26, public transport systems have their own classification system, ranging from strategic public transport routes (SPTR), integrated rapid transit (IRT), bus rapid transit (BRT) and high occupancy vehicle (HOV) priority lanes, to local distribution routes and termini. In neighbourhoods, most public transport routes, and possibly even strategic bus routes, will be on access/activity streets where pedestrian facilities and bus stops are mostly found.

### 1.2.3.2 Transport demand management

Transportation demand management (sometimes referred to as travel demand management, traffic demand management or mobility management) refers to the application of different strategies to reduce the demand for travel or to redistribute the demand for travel in space and/or in time.

The overall aim of travel demand management is to increase the efficiency of a transportation system by giving priority to travel based on the value and cost of each trip. Higher-value trips and lower-cost modes are prioritised

through a number of interventions. For example, buses are regarded as having higher value to the system (they transfer more people per trip) and should thus receive priority over private vehicles. Public transport, ridesharing, cycling and walking generally cost society less per trip than low occupancy private cars when considering roadway costs, congestion, harmful emissions and traffic accidents, and they should therefore receive priority over private vehicles.

The management of the demand for transport can include a number of interventions that have a cumulative impact on the efficiency of the system and ultimately improve the liveability of settlements. Some of these interventions are aimed at improving transport options available to users, while others provide users with incentives to change routes, modes, destinations or the schedule of their trips. Also included in transport demand management are interventions that reduce the need for physical travel such as improved internet-based communication systems.

### **1.2.3.3 Transport-oriented Development**

Transport-oriented Development (TOD) refers to the concentration of a mix of medium- to high-density, pedestrian-friendly developments around or close to public transport stops, terminals and stations. The intention of this approach is to reduce the need to use motorised modes by making trips walkable, to improve access to public transport and reduce commuting time. Importantly, by increasing the concentration of people in the immediate vicinity of the transport stop, the necessary passenger demand thresholds for public transport can be achieved.

Transport-oriented developments are site-specific and dependent on the proximity of public transport stops, terminals and stations. For such developments to be successful, streets should be safe and convenient for all, including pedestrians, cyclists and people with disabilities. The developments should incorporate a mix of land uses including residential, retail, recreational and entertainment.

### **1.2.3.4 Complete streets**

Complete streets are streets for people, not just cars. The concept is based on the notion that, under certain conditions, the entire road reserve should be regarded as public open space and should be planned, designed, operated and maintained to accommodate all users safely and conveniently. This means that everyone should feel comfortable using the street, regardless of their age and mode of transport, including pedestrians, cyclists, wheelchair users, motorists, public transport users, etc.

The approach is aimed at neighbourhood streets, and its application in practice would be determined by the local context. Complete streets don't all look the same, but they could typically include the following elements:

- Pedestrian and cycling infrastructure such as walkways, bicycle lanes, bicycle storage facilities, public furniture, landscaping, frequent and safe street crossing opportunities, kerb extensions, etc.
- Bus lanes and comfortable and accessible public transportation stops
- Appropriate traffic-calming measures to enable safe access and use of the street as social space

### **1.2.3.5 Non-Motorised Transport**

Non-Motorised Transport (NMT) refers to all forms of transport that are not motorised, including walking, cycling, animal-drawn transport, cycle rickshaws, skateboards, hand carts and wheelchairs. For shorter distances, NMT is usually the most efficient means of transport, but its use is influenced by land use, topography, travel needs and the layout of infrastructure and services. The planning and design of NMT infrastructure and services have received



attention through theoretical concepts such as complete streets (**Section 1.2.3.4**) and by promoting the adoption of a 'pedestrian first' hierarchy of users (**Section F.4.1.3**). More information is available in the *Non-Motorised Transport (NMT) Facility Guidelines* published by the Department of Transport.<sup>3</sup>

## 1.2.4 The implementation context

This section highlights the contextual factors that should be considered when making decisions regarding transportation infrastructure, specifically related to the type of development and its setting. Also refer to **Section D.2.1** (Type of development) and **Section D.2.2** (The setting/location of the planned development).

### 1.2.4.1 The type of development

#### (i) Greenfield development

There are usually no or little formal (motorised) transport activities directly on a greenfield site. However, in urban and peri-urban settings there is likely to be transport activity in the surrounding area. This transport activity may have to be quantified as part of the transport inventory. In addition, the transport road network and public transport services and infrastructure in the areas around and through the project site will also have an impact on the transport planning and design of the greenfield project. An important issue to consider when doing street layout planning for a greenfield site is the presence of desire lines, where pedestrians crossing the site show their preferred routes even in the absence of formal transportation infrastructure.

#### (ii) Brownfield development

Brownfield developments occur at sites where there is current land use and transport activity associated with the site. Transportation infrastructure may be located on the site and may be used as is or be in need of improvement and upgrading. If the project entails infill development or redevelopment, many of the existing land use activities and associated trips may remain, and the trips may even increase. The development of brownfield sites often implies higher population densities, which will have direct implications for the type and capacity of transportation infrastructure.

#### (iii) Informal settlement upgrading

Informal settlement upgrading projects are usually complex undertakings that require extensive community participation. Acceptability and perceptions may be important factors to consider when making decisions regarding transportation options. Space is usually limited in informal settlements and developments are often done in situ. An in-situ layout involves creating spaces between existing top structures for the purposes of access as well as installing pipes and cables for infrastructure services. This would require the existing movement tracks, pathways and desire lines through the informal settlement to be identified and mapped before layout proposals are made. In an informal settlement upgrading project, the provision of NMT infrastructure will be an important aspect to consider.

### 1.2.4.2 The setting of the development

#### (i) Rural

Development sites in rural areas will vary in nature depending on the location, for instance whether it is situated in a rural town or a dispersed settlement. Rural settlements do not show the strong weekday morning and afternoon trip

peaks found in urban areas, therefore the infrastructure design requirements are likely to be different, even though the transport planning process is the same as for peri-urban and urban areas. Public transport service provision is an important aspect of planning in rural areas, although it might be with low trip demand and low frequency services. There is a general lack of adequate NMT infrastructure in rural areas, which needs to be addressed as NMT users in rural areas not only include pedestrians and cyclists, but also animal-powered vehicles.

### (ii) Peri-urban

Peri-urban areas often serve a dormitory function and mostly lack the investment to drive employment growth that will require their inhabitants to travel long distances to access employment opportunities, social services and education. This strong functional relationship with adjacent urban settlements requires an efficient transportation system. However, peri-urban areas are sometimes neglected in the planning and design of transportation infrastructure and services. Quite often, municipal public transport systems only operate within the 'urban' areas of settlements and residents of peri-urban areas are mostly dependent on private motor vehicles, provincial bus services or unregulated public transport such as mini-bus taxis.

### (iii) Urban

Congestion is one of the prevalent transport problems in large urban areas. This aspect is strongly related to long commuting times and harmful environmental impacts of the transportation system, especially through the use of private cars. In urban areas typical weekday morning and afternoon public and private transport trip peaks are associated with existing land uses in the area. The public transport passenger demand drops dramatically in the off-peak periods, resulting in unused system capacity. With the high rate of urbanisation, the capacity of transportation systems in the peak periods remains an issue, while low-density development poses challenges related to transportation network coverage. The structural design of pavements generally does not differ between urban and rural contexts, except in the selection and design of the surfacing layer and drainage.

## 1.3 Planning considerations

This section deals with the planning of transportation infrastructure. In this context, the term “planning” means making informed decisions regarding the type of transportation infrastructure to be provided, and then choosing the most appropriate options based on a thorough understanding of the context within which the planned development will be implemented.

As part of the planning process, it is important to consider the neighbourhood layout and structure (refer to **Chapter F**) while also considering the type of project, the potential residents of the neighbourhood and the transportation trips, modes and network distribution. The features and requirements of the proposed project should always respond to the context within which the planned development will take place (**Section 1.3.2**). The planning phase is concluded by considering different transportation options (**Section 1.3.3**), specifically related to geometric design and then road pavements.

The transportation planning process starts with the definition of the study area, which is the area to be included in the transportation study. It is unlikely to be just the boundaries of the new project or neighbourhood. Transportation and traffic impacts can occur remotely from the development site. The careful definition of the study area ensures that a detailed understanding of the regional and local context of the project is developed, including the scale; the urban, rural or peri-urban nature of the study area; the socio-demographic status of the inhabitants; existing transport infrastructure and services; and other planned and existing developments in the area.

### 1.3.1 Characteristics of the proposed development

Decisions regarding transportation infrastructure and services need to be guided by an assessment of the characteristics of the proposed development and an understanding of the requirements or needs that will have to be met. Factors that should be considered are discussed below.

#### 1.3.1.1 The nature of the proposed development

Various factors related to the nature of a development could influence decisions regarding the provision of transportation facilities and services. For instance, an extensive transportation master plan could be required for large neighbourhood development schemes. This is unlikely to be the case for smaller developments and improvement schemes for existing streets that are likely to be less complex, and, in some cases, a scheme layout is generally all that is required. Smaller projects may also not require detailed transportation design, as existing infrastructure might have spare capacity available. In these cases, the focus of the transportation planning would be to link into and integrate with existing systems. Large (or mega) projects may have to consider a range of transportation modes and require the inclusion of various public transport and NMT facilities. For mobility and access design purposes, population density and land use mix are critical considerations, as the efficiency of public transport facilities and services are dependent on user thresholds. Mixed use (i.e. a mix of residential and other land use types), mixed-income projects and projects that are primarily residential in nature would also need different approaches to the provision of transportation infrastructure and services. Similarly, inner city, infill projects would be different from, for instance, an informal settlement upgrading project. The nature of a project therefore needs to be clearly understood to make informed decisions regarding appropriate transportation options and facility and service provision.

### 1.3.1.2 The residents of the area to be developed

Decisions related to the mode of transport and its capacity and coverage should be guided by information regarding the potential residents and users of the planned infrastructure and services. Traveller needs could be informed by various attributes of the neighbourhood inhabitants, including incomes, trip patterns for all modes to and from the neighbourhood, public transport dependence, car ownership levels and the needs of disabled persons. Usually, the detailed socio-economic characteristics of the residents of the new development are not known when a development is planned and designed. It can also be difficult to predict who and how many residents will make use of transportation infrastructure and services. However, it may be possible to make assumptions regarding the possible nature of the future residents and users of transportation by assessing the surrounding neighbourhoods or similar developments in comparable locations or contexts. It is important to consider the following:

- The total number of residents that would have to be accommodated, taking into consideration that actual numbers may be higher than anticipated due to the fact that the provision of houses and services may attract more people than originally planned for.
- The number of households and the types of housing to be provided in the development. This will have an impact on the transport demand and influence the modes used.
- The range of residents with special needs that would have to be accommodated, e.g. people living with disabilities, including physical, dexterity and sensory impairment. Transportation infrastructure and services should, as far as possible, be accessible to all residents and users.
- The age of residents and those that may use transportation facilities (i.e. gender ratios, age profile and size). An aging population might, for example, increase the number of public transport users who might require easier access to vehicles. Trip patterns might also differ (in terms of timing or destination) between the youth and the elderly. Other dimensions have been shown to influence travel choices such as gender, and occupation, which may be used for even finer segmentation of the beneficiaries.
- Income and employment levels and spending patterns might give an indication of car ownership or dependence on public transport.
- The number and location of schools, social and recreational facilities and retail facilities to be provided in the neighbourhood. This will inform the number of trips generated and the distribution of trips along the movement network. This will also give an indication of the opportunities for transport-oriented development.

As discussed in **Section F**, layout and transportation planning should apply a user hierarchy where pedestrians are considered first. Most residents start and/or end their trips using an NMT mode. They therefore require the opportunity to use safe, direct and secure NMT routes to their destinations. The premise of this approach is that, if the most vulnerable user of the system is provided for first, provision for the rest (cyclists, public transport users, specialist vehicles like ambulances and finally, ordinary motor vehicles) will be far easier. This will also lead to a design that increases the attractiveness of walking, cycling and using public transport.

## 1.3.2 Characteristics of the existing environment

Decisions regarding transportation infrastructure and services need to be guided by an assessment of the context within which the development will be located. Factors that should be considered are discussed below.

### 1.3.2.1 The physical location of the proposed development

Constraints and opportunities posed by the project site could influence the transportation infrastructure and service to be provided.

### (i) Topography

The topography of the project site is a key factor when making decisions regarding the direction, hierarchy and layout of the roads and streets. A site that is characterised by slopes has a significant impact on the provision of municipal engineering services, especially stormwater management. It could also affect the provision of NMT facilities, as the gradient should ideally not be more than 5% for pedestrian and cycle routes. Gradients also affect stopping distances that have to be provided for motorised vehicles, as well as road pavement design and appropriate road surfacing.

In addition, the structural design of roads may also be influenced by topography: where roads and streets cross height contours at an angle, or even perpendicularly, drainage design becomes a challenge and in such cases function rather than structure may require that a road or street be paved or provided with effective erosion protection. A sloping site could mean that additional costs would have to be incurred when constructing a street. The maximum gradient for the use of road surface asphalt paving is 14%. Streets that are steeper than this might have to opt for block or concrete pavement with accompanying support beams.

Topography also affects unpaved streets: In rolling and mountainous terrain there may be steep gradients that result in the erosion of street gravel and, in particular, erosion of their drainage facilities, with direct implications for their safety and functional use. A gradient of 5% is an average value above which erosion problems may occur on unpaved streets, and slopes steeper than this would warrant additional attention and protection. Gravels in the upper range of the Plasticity Index (PI) could effectively reduce erosion, but local conditions should be considered in the detailed evaluation.



Water drainage is an important factor to consider when assessing the topography of a development site. Water is one of the primary causes of premature failure, accelerated distress and reduced structural capacity of road infrastructure, and it is therefore essential that attention be paid to stormwater management from the outset (see **Section L**).

### (ii) Climate

Climate has an impact on the structural design of road pavements. The meteorological environment is divided into macro-climatic regions with different moisture and temperature conditions. The moisture condition affects the weathering of rock and the durability of weathered material. The moisture conditions also affect the stability of unbound layers, depending on the drainage conditions, the surfacing layer integrity and the moisture content. On the other hand, temperature conditions largely affect the design of surfacing layers, particularly hot mix asphalt. Pavement designers should always consider climatic conditions and avoid using materials that are excessively water-susceptible or temperature-sensitive in adverse conditions.

### (iii) Geotechnical characteristics

The in-situ ground condition of a site can sometimes necessitate the use of specialised construction methods or materials, or it can mean that certain areas of the site might not be suitable for construction. A proper preliminary soil survey should be conducted as the characteristics of the underlying subgrade will have implications for the structural design of the road. The specific considerations regarding the subgrade are discussed in **Section I.4.2.5**.

Aspects such as the material depth and the classification of the subgrade material are addressed. However, the following questions need to be answered during the initial analyses of the local conditions to inform the layout and network configuration of the proposed development as well as the subsequent geometric and structural design phases:

- What are the soil characteristics and quality? Classification of the subgrade material should be done.
- Are there any aggressive chemicals or minerals present?
- Is the site part of or close to a dolomitic area?
- Was the site used for mining and exploration in the past?
- Are there large rock outcrops on the site?
- Are there gullies or other ditches on the site?
- Is ground water present on the site?
- What is the height of the water table?
- Did dumping – legal or illegal – ever occur on the site?
- Is the site subject to seasonal flooding?

#### **(iv) Landscape and ecology**

The physical features of the landscape could have an impact on the layout of streets and the choice of pavement material. If the development is located in or near an ecologically sensitive area, there may be restrictions that may influence the layout of streets. Ensure that information is collected regarding the following:

- The position of any telephone poles, overhead power cables, rock outcrops, water features, dongas, etc. that could restrict building work or may require approvals from various government departments.
- Wetlands, surface water bodies or other ecologically sensitive areas on or near the site.
- Endangered or protected animal or plant species on or near the site.
- Existing vegetation, especially trees, and whether they are deciduous or evergreen, indigenous or alien.
- Natural features that may have cultural significance.

#### **(v) Adjacent land uses and edge conditions**

Adjoining properties have an impact on each other. Therefore, it is important to be aware of the land uses adjacent to the development site, as well as the edge conditions that affect the site. Some of the questions that need to be answered include the following:

- What are the adjacent land uses and how could that potentially influence decisions regarding transportation infrastructure to be provided as part of the proposed development? In particular, surrounding land uses are relevant for public transport planning.
- What are the local destinations (such as shops, schools, bus stops) that occupants of the new project will be wanting to access?
- How can the new development best be linked to these to encourage walking and cycling?

#### **(vi) Access to the site**

Any development has to be connected to the surrounding area and to the settlement as a whole. The layout of streets and the provision of transportation facilities are influenced by the location of access points and existing footpaths and routes. The following questions need to be answered:

- What are the existing and potential vehicular, cycle and pedestrian access points to the site?
- Are there existing footpaths / routes across the site? Where are these routes originating from and where are they going?
- Can the existing footpaths / routes be accommodated in the new development?
- Where are public transport facilities in the surrounding areas located in relation to the site? These may include commuter railway stations and services and other public transport facilities such as bus and mini-bus taxi terminals and stops.
- Are there existing public transport routes through or near the site? Where do these routes intersect or join with the pedestrian desire lines and the shortcuts that people take?

### 1.3.2.2 Available infrastructure and services

Developments create additional demand for services and may therefore have an impact on existing transportation infrastructure and systems. It may be necessary to document and assess the existing transportation infrastructure and public transport networks and services, including NMT facilities. This information can be used as the starting point for the planning and design of new networks and facilities, or the upgrading of existing infrastructure and services.

The location of existing public transport infrastructure such as stops, terminals and ranks should be documented. Public transport operations and routes should also be identified. For example, information regarding rail services, train station locations and feeder services, bus and minibus taxi services and main routes, BRT routes and stations should be collected. Existing NMT facilities must also be identified and assessed. These may be formal and/or informal, for example to and from existing public transport facilities, at schools, hospitals and other social and commercial amenities.

### 1.3.2.3 Existing socio-economic features

The planning and design of a development have to be guided by the potential needs of the residents of both the new development and existing neighbourhoods. If the community that will move into the proposed development is known, it is critical to understand their needs and involve them in the decision-making process from the outset (see **Section E**). It is also important to acquire information regarding the socio-economic features of the neighbouring communities. This will provide some indication of the transportation infrastructure and services that have to be provided. The following questions should be answered with respect to the existing community (if known) and the adjacent neighbourhoods, especially those that are functionally linked to the development:

- How many people live there?
- What is the average size of households in the area?
- What is the age profile of the residents?
- What is the income profile of the residents?
- What is the employment profile of the residents?
- What types of housing are people living in?
- Do residents have access to private cars?

### 1.3.3 Transportation infrastructure and road pavement options

The design of transportation infrastructure and services should cater for the travelling needs of individuals and the need for products to be conveyed. Transport users generally make decisions about destination, mode of travel, departure time, desired arrival time and route. The decisions take place within constraints that include budgets and

the availability of supporting services and infrastructure in the network. It is important to provide prospective users of a transportation system with sufficient options to allow them to choose an option that would adequately satisfy most of their needs. However, when transportation planners and designers have to make decisions regarding the type, capacity, coverage and cost of transportation infrastructure, the needs of individuals have to be balanced with the needs of society. A critical consideration would be the potential impact of a chosen transportation option on the environment. In addition, the structural design of transportation infrastructure tends to be guided by restrictions imposed on it by geology, topography, design traffic, construction materials, and accessibility and mobility requirements.

The transportation infrastructure and road pavement options discussed below essentially involve the geometric design of streets, and the types of road surfaces and pavement materials available. However, before particular options can be selected, various factors need to be considered. Some of these factors are outlined below before the possible options are discussed.

### **1.3.3.1 Factors to consider when choosing transportation and road pavement options**

In addition to the aspects highlighted in **Section 1.3.1** and **Section 1.3.2**, various other factors need to be considered when decisions have to be made regarding transportation demand, needs and infrastructure options. Assessments may be required to gain an understanding of, for instance, the following:

- The estimated number and nature of trips that will be generated by the proposed neighbourhood
- The nature of existing traffic in the area surrounding the proposed neighbourhood
- Planned developments, land-use changes and transportation infrastructure and services in the vicinity of the proposed neighbourhood

Based on the information gathered, the anticipated trip demand can be assigned to the transportation network. These aspects are briefly discussed below.

#### **The estimated number and nature of trips generated by the proposed neighbourhood**

Three distinct trip generation estimations need to be made, namely vehicle-based trips, public transport trips, and non-motorised trips. Estimates are usually based on traffic expected during a chosen peak hour or peak time. Traditionally, the morning weekday peak hour is used since this is normally the time period during which the highest number of person trips are made, and hence needs to be accommodated by the infrastructure. However, other factors may also have to be considered. There may be conditions peculiar to the development site, which may result in other forms of peaks, for instance travel may change seasonally due to holiday-makers visiting the area or leaving the area, or if special events are held in or close to the neighbourhood.

The information required to estimate trip generation includes the following:

- The socio-demographic and economic characteristics of the neighbourhood. This information often provides an indication of the number, pattern and modes used for trip making.
- The number of households, their location in the neighbourhood, and the type of housing that is to be supplied will have an impact on the transport demand and influence the modes used.
- Traffic generators including education facilities, hospitals and clinics, shopping/retail areas, transport terminals (road-based, rail and airports) generate and attract high concentrations of trips and should be treated individually.
- Land use types such as commercial, office or retail facilities may also generate particular trip patterns.



- Specific developments that could reduce motor vehicle trip making, such as transport-oriented developments.

A distinction should be made between trips that will have origins and destinations within the neighbourhood (e.g. trips made between home and school), trips that will be made from the neighbourhood to other destinations in the settlement (e.g. trips from home to work), and trips that may pass through the neighbourhood. In some cases it may also be important to gain an understanding of the distribution of trips according to purpose and the mode of transport (i.e. NMT and motorised trips, as well as the split between public and private transport). This will assist in planning services and infrastructure that will meet the transportation needs of those living in and around the proposed neighbourhood, particularly with respect to NMT.

### **The nature of existing traffic in the area surrounding the proposed neighbourhood**

The estimated number of trips that the proposed neighbourhood will add to current motor vehicle traffic should be considered in conjunction with the existing traffic situation ('background traffic') and transportation demand. The 'background traffic' refers to traffic demand that would have materialised irrespective of the development project under consideration. The annual rate of growth of this demand should be taken into consideration.

In some cases a detailed quantification of the existing transportation demand may be required (including vehicular traffic, NMT and public transport). Some of the data required may be available from local, provincial and national transport authorities and transport agencies. However, it may be necessary to conduct transport surveys to supplement the demand data available from secondary transport data sources. The need for surveys, and the types of surveys required, would be determined by the availability of secondary data sources, the context and size of the proposed development, and whether or not transport simulation modelling will be required. Different types of traffic surveys can be employed, including traffic count surveys (usually conducted at intersections and on road links), public transport passenger and NMT surveys (to estimate the demand on current transport systems and/or at public transport terminals, numbers of passengers accessing public transport facilities by foot, etc.) and origin - destination traffic and passenger surveys (to determine the origins and destinations of vehicles, and sometimes passengers).

### **Planned developments, land use changes and transportation infrastructure and services**

The potential impact on traffic demand and transportation infrastructure of other planned developments in the vicinity of the proposed neighbourhood should be carefully considered. The transportation infrastructure needs of these developments will affect the proposed development. Information should also be obtained regarding potential changes in land use and any latent land use rights for development (rights that exist but have not been exercised).

It is important to know what transportation infrastructure is planned for the areas adjacent to and surrounding the proposed development. Liaise with the municipal, provincial and national transport authorities and transport agencies to understand planned new roads, public transport services and facilities and non-motorised transport facilities within the area. The proposed timing and phasing of these improvements should also be considered. They would normally go ahead whether the new neighbourhood is developed or not, but the new project may change the time lines and priorities assigned to these improvements.

### **Assign the future trip demand to the network**

Based on all the information gathered, the future trip demand needs to be assigned to the various links and intersections making up the networks. This would allow for the demand flows on the links and at intersections to be estimated, and the required capacity of the links and intersections to be modelled. The trip assignment process is

most commonly undertaken using simulation software that provides estimates of vehicle queues and delays at the intersection during the modelled period.

The resulting vehicular demand and capacity relationships across the network will determine the levels of service of the future network. Road-based vehicle levels of service in urban areas are most commonly influenced by the intersection layouts and controls, and the level of service is defined by the average delay experienced by a driver on an approach to the intersection. If the level of service is not initially satisfactory, the transport planner must introduce roadway and/or intersection improvements to alter the demand-supply relationship and hence establish acceptable levels of service. The analysis will also determine the type of intersection control that is required, i.e. stop, traffic circle or signals. In all cases, the provision for NMT at intersections is critical.

The roadway and intersection cross-sections and land requirements are determined as part of this process. The cross-sections must also cater for NMT and public transport vehicle infrastructure. If on-street parking is to be provided in certain areas, this must also be included in the cross-section. NMT and motorised vehicle conflicts should be avoided as far as possible when designing the intersections and NMT roadway crossing points.

Levels of service for NMT and public transport facilities are commonly determined by traveller densities in confined spaces such as stops and terminals, and by passenger flows in restricted spaces such as walkways and bridge crossings. Types of control at the NMT and motorised vehicle traffic conflict points must be carefully considered to ensure safety and convenience.

The arrangement of NMT and traffic at generators such as schools and hospitals must receive specific attention. At schools, the conflicts between vehicles and pedestrians and cyclists must be identified and carefully planned to ensure the maximum levels of safety. At other facilities such as hospitals and large retail facilities, individual vehicle access, egress, NMT and parking studies may be required.



#### Transportation simulation software

Transportation simulation software is used as a tool to assist transport planners in simulating the transport demand and supply relationship to determine suitable levels of service in the peak periods. Deciding on the most suitable software depends on the nature of the proposed development, the simulation needs of the transport system and the needs of the transport planner. Several software platforms are available to transport planners, and most reputable platforms are suitable for use. However, there are important issues that planners should consider when deciding whether to use a software platform, and if so, what type of software is most suitable. Transportation simulation can be done at essentially three levels:

- **Macro-level models:** These applications are for large area networks, typically regions or metropolitan areas. They are complex models that require substantial data sets for their development and are developed by metropolitan and provincial transport authorities. The transport planner may be dependent on such a model to obtain sub-area traffic and passenger demands.
- **Meso-level models:** These models are network-based and used to simulate smaller areas. They are commonly used for urban settlement trip simulation, and can simulate detailed intersection operations.
- **Micro-level models:** These models are most commonly used to simulate traffic intersections. They can be network-based or simulate isolated intersections. Transport planners are advised against using isolated intersection simulation models in urban areas with complex road networks.

### 1.3.3.2 Geometric design options

The purpose of geometric design is to shape the visible, physical components of streets and roads to enable the convenient, economical and safe movement of goods and people, regardless of their mode of transport, and in such a way that the negative impact on the environment and surrounding communities are minimised. The geometric design of streets and roads should support the objectives described in [Section 1.2.2](#) and contribute to the creation of neighbourhoods that accommodate all people, including those with disabilities.

The design of streets and roads influences, and is influenced by, the surrounding environment, and it is directly linked to the character of a neighbourhood. It is therefore important to also consult [Section F](#), as the information about geometric design provided here is complemented by the information on neighbourhood layout and structure provided in [Section F](#).

Geometric design involves the three-dimensional design of the road or street, and it is guided by various factors, including the characteristics of the natural environment (e.g. topography, vegetation, soil conditions) and built environment factors such as the nature of the environment alongside the street or road (e.g. houses, shops, street cafes, open space). Critically, not only should the needs of those making use of motor vehicles be considered, but also of those making use of non-motorised transport and of the sidewalks (pedestrians, cyclists, those with disabilities etc.). The key is to have a thorough understanding of the context within which the street or road will be embedded. Furthermore, it is important to adopt a holistic approach when making decisions regarding the geometric design of streets and roads. A range of disciplines may have a role to play, including engineers, planners, urban designers, landscape architects, architects, environmental scientists and hydrologists.

In essence, the geometric design of streets and roads involves the following three key aspects:

- Alignment (horizontal and vertical)
- Cross-sections
- Intersections

These aspects are briefly outlined below. Each aspect involves a range of interlinked components that are described further in [Section 1.4.1](#).

#### (i) Alignment

The horizontal and vertical alignment of streets and roads is closely linked to the layout and structuring of a neighbourhood as discussed in [Section F](#), and the information provided in [Section F.4.1.4](#) should specifically be referred to. More information is also provided in [Section 1.4.1.5](#).

#### Horizontal alignment

The horizontal alignment of a road or street is essentially the route that it follows if viewed on a map. From a geometric design perspective, it involves the design of the curves and straight sections (tangents), guided by certain calculations, to ensure the safety and comfort of the users of the street or road. The process to determine the horizontal alignment of a street or road is iterative in nature since various factors need to be considered, including the local topographical and other characteristics of the physical environment, as well as the layout and structuring options outlined in [Section F.3.3](#) and design considerations discussed in [Section F.4](#).

### Vertical alignment

Streets and roads include sections that are sloping up or down, and sections that are commonly referred to as flat. This line that a street or road follows up and down a vertical plane is referred to as vertical alignment. As with horizontal alignment, factors that need to be considered include the topographical and other characteristics of the physical environment, as well as the layout and structuring options outlined in [Section F.3.3](#) and design considerations discussed in [Section F.4](#).

### (ii) Cross-sections

The cross-section of a street or road has to accommodate moving and parked vehicles, non-motorised vehicles such as bicycles, pedestrians, wheelchairs, engineering infrastructure and utilities such as stormwater drainage, water, electricity, communications and sewer trenches (also see [Section F.4.1.5](#)). In some cases, it is also required to provide space for more than just movement-related activities such as formal and informal trading, socialising and recreational activities for children. Neighbourhood streets are often regarded as public open space and may have to fulfil a range of functions (see [Section G.3.3.2](#)).

The cross-section (also referred to as the road reserve) may comprise all or some of the following components:

- Traffic lanes for motorised vehicles (including dedicated lanes for high occupancy vehicles such as buses)
- Cycle lanes (they could be incorporated on the outside of traffic lanes, or they could be located on the verge, either as dedicated cycle lanes or combined with pedestrian walkways)
- Parking lanes (between the outside traffic lane and the verge, or embayed in the verge area)
- Verges (the area between the edge of the outside traffic or parking lanes and the road reserve boundary)
- Sidewalks (the part of the verge that accommodates pedestrian traffic, usually paved)
- Median islands (the area between the inner edges of the inside traffic lanes of a divided street or road)

The aspects to consider when designing cross sections are discussed in [Section I.4.1](#).

### (iii) Intersections

Roads and streets form a network, and it is inevitable that different sections of the network will meet (connect or cross) at certain points to create intersections. The movement of motorised and non-motorised transportation (including pedestrians) is restricted at intersections, and this could lead to congestion and accidents. It is therefore essential to ensure that intersections are able to deal effectively, efficiently and safely with all types of traffic. Intersections can take on various forms, including three-legged (commonly known as T-junctions), four-legged and multi-legged intersections. Different types of intersection control can be employed, for instance signalisation, multi-way stop or yield, mini roundabouts, traffic circles.

Pedestrian crossings are critical parts of intersections. They should make it possible for all people, regardless of age, to cross a street safely and conveniently, including people with physical, dexterity and sensory impairments, wheelchair users, people pushing prams, etc.

### 1.3.3.3 Road pavement options

When selecting a road pavement option, consider whether it meets the following requirements:

- a reasonably smooth riding surface
- adequate skid resistance (surface friction)
- favourable light-reflecting characteristics
- low noise pollution
- good waterproofing qualities
- protection of the natural soil subgrade

Decisions need to be made regarding the type of pavement as well as the material to be used. More information is provided below.

#### (i) Road pavement types

Road pavements can be classified as surfaced and unsurfaced. In turn, surfaced pavements can be categorised as flexible, semi-rigid and rigid, while gravel roads are regarded as having an unsurfaced pavement.<sup>4</sup> These types are briefly discussed below.

The classification does not only refer to the surface material, but encompasses all layers of the pavement structure (Figure 1.2). The pavement structure refers to the combination of different layers (including the natural soil subgrade) that carries traffic loads. The layers have different functions, which determine the structural capacity and performance of the pavement. This performance is also affected by the climate, the traffic loading and the distress characteristics that occur in the pavement over time.

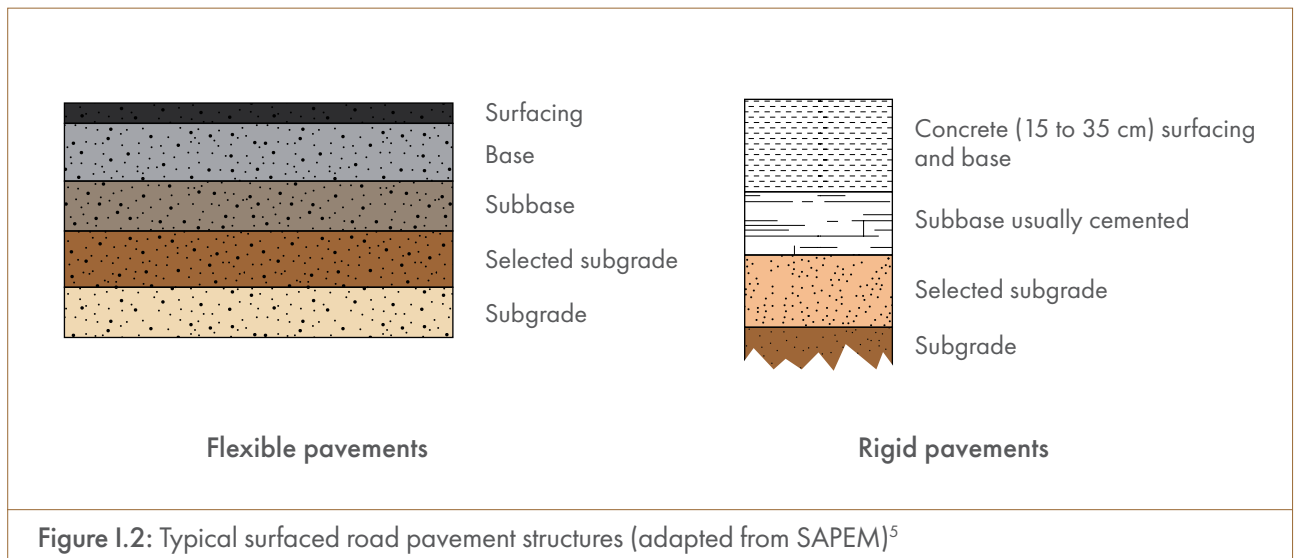


Figure 1.2: Typical surfaced road pavement structures (adapted from SAPEM)<sup>5</sup>



### Pavement structure

SAPEM describes the purpose of the various layers in the pavement as follows<sup>6</sup>:

- **Surfacing:** This is a functional wearing course that provides waterproofing, skid resistance, noise-damping, durability against the elements, visibility and drainage. For surfaced roads, the upper layer is bound, consisting of spray seals.
- **Base:** This is a load spreading layer and is the most important structural component of the pavement. The layer must provide the required support for the surfacing and distribute the very high tyre pressures and wheel loads uniformly over the underlying layers and subgrade. The base comprises bound material e.g. asphalt, concrete or stabilised, or it can be unbound e.g. crushed stone or gravel base.
- **Subbase:** This layer provides support for the base as well as a platform upon which to construct a structural base layer of high integrity. It also protects the underlying selected subgrade layer by further spreading the load.
- **Selected subgrade:** These layers are primarily capping for the subgrade to provide a workable platform on which to construct the imported pavement layers. At the same time, these layers provide depth of cover over the subgrade to reduce the stresses in the subgrade to acceptable levels.
- **Subgrade:** This is the existing material upon which the pavement must be constructed. It can be modified with stabilisers to reduce plasticity, ripped and recompacted to achieve uniform support, or undercut and replaced, depending on its quality.

### Flexible pavements

Flexible pavements are usually designed in such a way that the material quality gradually, and smoothly, increases from the in-situ subgrade up to the structural layers and surfacing to form a well-balanced pavement structure. Alternatively, a granular base may be placed on a stronger, lightly cemented subbase to form an inverted pavement structure. Differentiation is also made between deep and shallow pavements:

- In shallow pavements, the strength of the pavement is concentrated in the uppermost layers.
- In deep pavements, the strength is distributed throughout the depth of the pavement.

Four types of flexible pavements are commonly used in South Africa, depending on the material used on the base layer. The four flexible pavement types include unbound granular, hot mix asphalt, bitumen stabilised and/or cemented base layer.

### Semi-rigid pavements

Semi-rigid pavements consist of constructed concrete block paving or segmented concrete paving, in other words small individual shaped blocks laid on a sand bedding layer. Sand is placed in the joints between the blocks to fill the gaps and to enhance interlocking between the blocks. The concrete block system provides a durable wearing course, supported by subbase and selected layers, of which the thickness depends on the applied loading and subgrade strength. The concrete blocks carry much of the applied loading, but some load is distributed to the underlying layers.

## Rigid pavements

Concrete roads, also referred to as rigid pavements, are particularly strong and have a very high modulus of elasticity. This results in great load spreading in the top layer and hence low stresses in the underlying substructure. Concrete pavements can be constructed on poor subgrades, and generally have fewer pavement layers than flexible pavements.

## Gravel roads

Gravel or unpaved roads need a designed layer of imported material to carry specified loads in all weather conditions. The wearing course should also protect the subgrade below. The material requirements for these types of roads are less stringent in terms of strength, but have to be erosion-resistant. Typical challenges associated with gravel roads include dust, potholes, ruts, cracks, erosion and slipperiness. Gravel roads are not discussed in detail in this Guide, but more information is available in TRH20 - *Unsealed Roads: Design, Construction and Maintenance*<sup>7</sup> and *Towards Appropriate Standards for rural roads: Discussion document*.<sup>8</sup>

### (ii) Road pavement materials

The selection of materials for pavement design is based on a combination of availability, economic factors and the documented track record of the material. These factors have to be evaluated during the design in order to select the materials best suited to the conditions. Standard material specifications are defined in guideline documents such as the following:

- TRH4: Structural Design of Flexible Pavements for Inter-urban and Rural Roads
- UTG3: Structural Design of Urban Roads
- TRH14: Guidelines for road construction materials
- The South African Pavement Engineering Manual (SAPEM)
- The SABITA manuals

Categorisation of pavement materials is done by considering issues such as the fundamental behaviour of the material as well as its strength characteristics. Available road material options are discussed below.

### Granular materials

Unbound granular materials include graded crushed stone, natural and crushed gravels, sand and soils. Granular materials are typically used in the construction of the base, subbase and selected subgrade pavement layers. Certain types of gravel are also used for the wearing course of unpaved streets. In the TRH 14 classification system, the untreated or granular materials are classified as graded (engineered) crushed stone (G1 to G3), natural gravel (G4 to G6), gravel-soil (G7 to G10), macadam base layers and dump rock (DR). The selection of a type of gravel is informed by issues ranging from traffic load, availability of material, climate, to labour intensity of construction.

### Cemented materials

Available local natural gravel materials are often found to be of inadequate quality to provide the required pavement structural strength. Cemented materials are formed when the materials with inadequate quality are treated or stabilised to improve their properties for use in selected subbase or base layers. The material can be treated using conventional stabilisers such as cement, lime, slagment, lime/fly-ash mixtures or various combinations of pozzolanic binders, depending on the properties of the natural materials.

**Bitumen stabilised materials**

Bitumen stabilised materials (BSMs) are pavement materials that are treated with either bitumen emulsion or foamed bitumen to improve their strength, as well as to reduce the moisture susceptibility of the material. The materials to be treated may be granular materials, previously cement-treated materials or reclaimed asphalt (RA) layers. The bitumen stabilised material may be used on new construction projects to treat the locally available material, and to enable the use of this material in the pavement base layer or on rehabilitation projects by treating the existing base material.

**Hot mix asphalt materials**

Hot mix asphalt (HMA) material may be used for the construction of surfacing and base pavement layers. HMA is composed of virgin aggregates or reclaimed asphalt (RA), filler and bituminous binders. The use of RA in HMA is considered to be economical and have environmental benefits, as it enables a reduction in consumption of non-renewable resources like petroleum products (fuel and bitumen) and aggregates, as well as in the use of landfill space for discarding asphalt removed from existing roads.

**Spray seals and slurry seals or micro-surfacing**

A spray seal comprises of a coat of bituminous binder sprayed onto the road surface, followed by a layer of aggregate. The layer is then rolled to ensure good adhesion between the aggregate and the binder film. The primary function of a spray seal or slurry seal layer is to provide a waterproof cover to the underlying pavement structure, provide a safe all-weather, dust-free riding surface with adequate skid resistance and to protect the underlying layer from the abrasive forces of traffic and the environment.

**Primes, tack coats and pre-coating fluids**

Primes, tack coats and stone pre-coating fluids are essential materials in the construction and maintenance of roads. A prime consists of a bituminous binder and is used as a preliminary treatment on a granular layer prior to application of an asphalt layer, to promote adhesion between the two layers. A tack coat is also a bituminous product that is applied either on top of a primed granular base or between layers of asphalt to promote adhesion and enhance adhesion along transverse and longitudinal joints in asphalt layers. Pre-coating fluid is low viscosity bitumen and is used to pre-coat surfacing aggregates to improve the adhesion of the aggregate to the bituminous binder, as well as to reduce the possibility of early chip loss and stripping.

**Portland cement concrete**

The use of concrete as a surface layer is not very common in South Africa, but it offers significant compression and flexural strength, resulting in a very durable structural surface layer that needs very little maintenance during its design life. Concrete is completely resistant to petrol and diesel spillages, which makes this surface ideal for bus depots, fuelling stations, parking lots and overnight rest areas where oil and fuel leaks/spillages can be problematic. The most popular types of rigid pavements used in South Africa include the following:

- Conventional concrete pavements: Plain jointed concrete pavement with no steel (JCP); Dowels and tie bars (steel rods placed at joints), transversely and longitudinally; and Continuously reinforced concrete pavements (CRCP)
- Precast concrete slab pavements



- Roller-compacted pavements (RCC)
- Ultra-thin concrete pavements (UTCP): For low-volume roads (typical less than 2 000 vehicles per day) and for high-volume roads
- Pervious or porous concrete pavement (PCP)

### **Paving blocks**

Concrete block paving, also referred to as segmented concrete paving, comprises singular shaped blocks interlocking with each other to create a durable wearing course, supported by subbase and selected layers. Precast paving blocks have been successfully used in South Africa for non-trafficked areas, such as walkways, as well as heavily trafficked streets.

### **Various proprietary products**

Proprietary construction products or systems are manufactured and distributed under exclusive rights, but these products are not usually covered by the national standard. However, they may be standard products in the sense that they meet the requirements of local or foreign standards, or they may be non-standard or innovative, in that there are currently no applicable standards.

## 1.4 Design considerations

The layout of the movement network contributes significantly to functionality of a neighbourhood and to its attractiveness to residents. Streets also form conduits for essential services such as water supply, sewerage, power and cabling. It is therefore essential that all relevant planners and designers work closely together, especially the transport planner, the town planner, the stormwater engineer, the geometric designer and the road pavement design engineer. It is essential that the information on stormwater management provided in **Section L** be used to inform decisions made regarding transportation infrastructure design.

Two key aspects related to transportation infrastructure and services are discussed below, namely geometric design and road pavement design.

### 1.4.1 Geometric design

Geometric design aims to optimise efficiency and safety while minimising cost and environmental damage. As mentioned in **Section 1.3.3.2**, geometric design essentially deals with horizontal and vertical alignment and the design of cross-sections and intersections. The information provided below focuses on the key principles that should be considered with respect to each of these three aspects. Furthermore, these aspects are informed by a number of factors (or design parameters), in particular the design vehicle, speed parameters, traffic volumes, densities and composition, and sight distances, as outlined below. These parameters enable a consistent approach to geometric design and align the design of the street with the expectations of street users. If the approach to geometric design is consistent, the user will not be caught off guard by an unexpected feature of the street, resulting in more predictable user behaviour and, ultimately, improved safety.



Geometric design is strongly influenced by engineering principles as well as contextual factors, and requires specialist knowledge and experience. For more detailed information, it is recommended that suitably qualified professionals refer to the *Geometric Design of Roads Handbook*<sup>9</sup> written by Keith M. Wolhuter.

#### 1.4.1.1 The design vehicle

Road and street networks need to be designed to accommodate a range of motorised and non-motorised vehicles (including pedestrians). The different physical dimensions and operational characteristics of these vehicles have to be taken into consideration when designing a street. However, it would not be possible to use all the features of all the possible vehicles that may make use of all streets, and the design vehicle represents a combination of the critical features of all the vehicles of a particular type or class. A number of different types of design vehicles can be used to guide the design of a particular street, for instance to influence street dimensions such as the width of vehicle lanes and pedestrian sidewalks, curves and the radii of bends at intersections.

Design vehicles can broadly be grouped into two categories, namely motorised vehicles and non-motorised vehicles.

### (i) Motorised vehicles

The most common types of motorised vehicles that use neighbourhood streets are passenger cars, buses and trucks. These include minibus taxis, recreational utility vehicles and light delivery trucks (vans and bakkies). Different design vehicles are usually defined to represent different types of vehicles (e.g. passenger cars and bigger vehicles such as buses). The critical features that are taken into consideration when defining the design vehicle include dimensions (e.g. length, width, height, ground clearance, wheel base, front overhang and rear overhang), operational factors (e.g. power-to-weight ratio, braking capability and deceleration rates, minimum turning circle radius and swept path).

The features of the design vehicles are used to inform various aspects of geometric design. For instance, the power-to-weight ratio, particularly of trucks, is used to derive the truck speed on gradients. Another example relates to turning circles, which indicates the manoeuvrability of a vehicle. A smaller turning radius will improve manoeuvrability, while a large radius may make it difficult for a large vehicle to negotiate a sharp turn. The turning radius is used when designing intersections and on-street parking.



The operational characteristics of motorised vehicles are not only influenced by the vehicle, but also by the driver. There are many driver characteristics that could or should (depending on availability of data) be considered when doing the geometric design of roads, including the driver's age, decision-making methods, information processing and psychological status.

Two motorised vehicles are recommended for use in the design of neighbourhood roads. The passenger car should be used for speed-related standards and the bus for standards relating to manoeuvrability, typically at intersections. The bus also dictates the maximum permissible gradient.

### (ii) Non-motorised vehicles

The most common forms of non-motorised transport (NMT) are walking and cycling. The pedestrian and cyclist have certain physical design dimensions and operational characteristics that have to be considered in the design of streets. Other forms of NMT include people pushing prams or trolleys, people using wheelchairs, push carts and animal-drawn vehicles. More information regarding the various types of NMT users is available in the *NMT Facility Guidelines*<sup>10</sup>.

Information related to NMT used to define design vehicles involves, for instance, travelling speeds. Walking speed varies depending on a number of factors such as the number of pedestrians in a given space, the surface covering, the reason for walking (e.g. to and from work or public transport, leisure, window shopping), the age of the pedestrian and whether the person has a disability or not. The walking speed used to guide geometric design decisions should be adjusted according to the expected conditions. In general, a lower walking average speed should be applied when designing streets and pathways in the vicinity of old-age homes, hospitals and schools. Walking speed is useful for calculations related to, for instance, the design of pedestrian crossings.

In addition to travelling speed, dimensions are also used to inform geometric design decisions. For instance, the space needed per person at a pedestrian crossing would be less than the space needed by pedestrians on the move. Also, cyclists, people using wheelchairs and pedestrians with luggage will require more space than regular

pedestrians. This information will inform design decisions related to, for instance, the width of walkways and cycle paths.

Other forms of NMT may also have to be considered. For instance, in certain neighbourhoods it may be necessary to design streets to accommodate animal-drawn carts.

#### **1.4.1.2 Speed parameters**

There is an interrelated relationship between the design of a street and the speed at which motorists will travel along that particular street. On the one hand, the design of a street is informed by the anticipated speed at which it would be used. On the other hand, the speed at which the street will eventually be used will, to a large extent, depend on the geometric design features of the street. To assist with geometric design decisions, a design speed and an operating speed are used.

The design speed can be regarded as the maximum safe speed that can be maintained on a street when traffic conditions are so favourable that the speed selected by a driver is determined by the characteristics of the street. In reality, this speed would of course also be influenced by other factors such as the driver's proficiency and ability to react (reaction time), the condition of the vehicle (particularly its brakes and tyres), the weather conditions and the time of day (since it may affect visibility).

The design speed is a speed selected for the purposes of designing those features of a street that would affect the safe operation of vehicles, for instance horizontal and vertical curvature, sight distance and superelevation. Design speed is linked to the functional classification of the street, the context (e.g. presence of pedestrians, adjacent land use and topography), as well as the anticipated operating speed.

The operating speed relates to the actual speed at which vehicles travel along a particular street. Often this is higher than the design speed. The geometric design of a street could influence the speed at which vehicles are comfortably able to travel. In some cases, design interventions could be implemented to reduce operating speeds, for instance on streets in the vicinity of schools, old age homes, public transport stops, and areas where there is high levels of pedestrian activity.

#### **1.4.1.3 Traffic volumes, densities and composition**

The nature of the traffic that a particular street is expected to carry in future is measured as the estimated number of vehicles per hour (traffic volume) and vehicles per kilometre (vehicle density). This information needs to be provided for different types of motorised and non-motorised transport (composition). It provides an indication of the traffic conditions that a street should be designed for. It could, for instance, influence the design of the cross-section of a street, particularly the number of lanes required in each direction, and it could also affect the location and design of intersections.

#### **1.4.1.4 Sight distance**

Sight distance refers to the distance between a road user's eyes and a specific object or road feature that has to be seen by the user. Different sight distances are applicable depending on the aspect of the street that has to be designed. The intention is to allow a user of a motorised or non-motorised vehicle to observe a potential hazard in time to react effectively and safely. Different types of sight distances are used in calculations related to various aspects of geometric design.

One type of sight distance is referred to as stopping sight distance. This is the distance that is required for a driver to safely bring a vehicle to a standstill after observing a potential hazard. Stopping distance includes the distance covered during the time that the driver takes to react and the distance that it takes for the vehicle to come to a complete stop. Various factors influence stopping sight distance, including vehicle speed, driver reaction time, road conditions and skid resistance.

Other types of sight distance include barrier sight distance, decision sight distance, passing sight distance and intersection sight distance. Intersection sight distance also involves sight distance specifically applicable to pedestrians. This is used to design street crossings that allow pedestrians to safely cross an intersection.

#### 1.4.1.5 Horizontal alignment

Horizontal alignment (as described in [Section 1.3.3.2](#)) affects, and is affected by, the factors mentioned in Sections 1.4.1.1 to 1.4.1.4. In addition, horizontal alignment is also influenced by vertical alignment, and vice versa. For instance, the street layout and horizontal alignment of a neighbourhood may be determined to some degree by the vertical characteristics of the site, especially if the terrain is hilly.

General principles to be observed in the determination of the horizontal alignment of a road or street are the following:

- Short lengths of tangent (straight) should be used between reverse curves so vehicles traversing a curve in one direction do not have to immediately traverse one in the reverse direction.
- Broken back curves (where two curves in the same direction are separated by a short tangent) should preferably not be used, as drivers generally do not expect this.
- Large- and small-radius curves should not be mixed. Successive curves to the left and the right should generally have similar radii.
- For small-deflection angles, curves should be sufficiently long to avoid the impression of a kink.
- Alignment should be sensitive to the topography to minimise the need for cuts and fills and the restriction that these place on access to plots from the street. Streets at right angles to the contours can create problems in terms of construction, maintenance, drainage, scour (in the case of gravelled surfaces) and also constitute a traffic hazard. During heavy rainstorms, water flowing down a steep street can flow across the intersecting street.

Curves in the road are often accompanied by superelevation, which is the upward slope of the road from its inner to outer edges. This helps to counteract the centrifugal force exerted on a vehicle negotiating a curve. In urban areas, superelevation is not always required or possible. Care should be taken not to introduce superelevation, which would make it difficult to access properties alongside the street due to the one edge of the street being elevated above natural ground level.

#### 1.4.1.6 Vertical alignment

Similar to horizontal alignment, vertical alignment (as described in [Section 1.3.3.2](#)) affects, and is affected by, the factors mentioned in Sections 1.4.1.1 to 1.4.1.4. As previously mentioned, vertical alignment is also influenced by horizontal alignment, and vice versa.

Vertical alignment is the combination of parabolic vertical curves and straight sections joining them. Straight sections are referred to as grades, and the value of their slope (steepness) is the gradient, usually expressed in percentage form, e.g. a 5% grade means a climb through 5 m over a horizontal distance of 100 m.

A smooth grade line with gradual changes appropriate to the class of road and the character of the topography is preferable to an alignment with numerous short lengths of grade and vertical curves. The “roller coaster” or “hidden dip” type of profile should be avoided. For aesthetic reasons, a broken back alignment is not desirable in sags where a full view of the profile is possible. On crests, the broken back curve adversely affects passing opportunity. The minimum rate of curvature is usually determined by sight distance, the level of ease with which it can be traversed, as well as aesthetic considerations.

On neighbourhood streets, gradient may have a significant effect on the cost of the development. Where possible, road alignment should be designed to minimise the extent and cost of earthworks and to avoid problems with access and house design. It therefore has to be accepted that short sections of steep gradients may be necessary in some township developments.

The following should be taken into consideration:

- According to the *National Technical Requirement 1: Pedestrian Crossings* (NTR 1)<sup>11</sup>, gradients along the path of pedestrian and NMT travel shall not be steeper than a ratio of 1:12 (8.33%) and is preferred to be a ratio of at least 1:15 (6.66%).
- Gradients should be selected in consultation with the stormwater design engineer, as steep gradients on short access loops and cul-de-sacs could result in properties being flooded and surface runoff washing across intersecting streets.
- Gravel surfaces are subject to scour at water flow speeds of the order of 0.6 to 1.0 m/s. Under conditions of overland flow, this speed is achieved at slopes of the order of 7% to 8%. The slope in question is the resultant of the vectors of longitudinal slope and crossfall.

#### 1.4.1.7 Cross-section design

As discussed in [Section F.4.1.5](#), the cross-section of a street provides space for moving and parked vehicles, non-motorised vehicles such as bicycles, pedestrians, engineering infrastructure and utilities such as stormwater drainage, water, electricity, communications and sewer trenches. In addition, it may also have to accommodate activities other than those related to movement. Residential streets, for example, offer a neutral terrain on which neighbours can meet informally. They can also serve as playgrounds for children, especially in developments where plot sizes are too small for this purpose. Refer to [Section G.3.3.2](#) for a discussion on how streets are used as public open spaces in a neighbourhood.

Designing the cross-section of a street involves, firstly, selecting the relevant components to be included, and secondly determining their dimensions based on an understanding of the context and factors such as future traffic volumes, densities and composition. The cross-section may comprise all or some of the components summarised below.

##### Lanes for motorised vehicles

The number and width of traffic lanes provided would depend on a number of factors, including the location, purpose and classification of the street or road. The selection of lane width has traditionally been based on traffic volume and motorised vehicle type and speed. However, issues such as the availability of land, the impact of adjacent land uses and the specific needs of local communities also have an impact on the width of lanes. A distinction is often made between basic lanes and auxiliary lanes. The former are usually extended over long distances of the road, while the latter are only added to the cross-section to serve a short-term need.



### Camber and crossfall

Camber implies two slopes away from a central high point, as in a two-lane two-way road, where the cross-section slopes down from the centre line to the shoulders. Crossfall is a single slope from shoulder to shoulder. The slope, whether camber or crossfall, is provided to facilitate drainage of the road surface.

In the case of very narrow reserves, such as in the case of lanes or alleys where spatial restrictions may preclude the provision of drainage outside the width of the travelled way, a negative or reverse camber, i.e. sloping towards a central low point, could be considered. In this case, the centre line of the street is the low point to create a flat V configuration. The entire surfaced width then serves as a drainage area.

In exceptional cases, local residential streets may have only one lane, with provision for passing made at intervals. Bus Rapid Transit (BRT) systems in South Africa make use of exclusive bus lanes. BRT buses operate for (at least) a significant part of their journey within a fully dedicated right of way, in order to avoid traffic congestion.

### Verges

The verge is defined as the area between the roadway edge and the road reserve boundary. The verge width is the sum of the various elements it is required to contain. As discussed in **Section F.4.1.5**, there is a range of functions and activities that have to be accommodated. Some municipalities have developed their own specifications and guidelines and information is also provided in *TRH26: South African Classification and Access Management Manual* and in *TRH 27: South African Manual for permitting services in the Road Reserve*. The different elements that might be included in the verge include sidewalks, cycle lanes, parking and loading space, streetlights and street furniture, street trees and landscaping, public transport bays and services reticulation such as trenches for sewers, water pipes, stormwater pipes, electricity cables and telecommunication cables as well as stormwater channels (see **Section F.4.1.5**).

### Cycle lanes

If at all possible, cycle lanes should be located in the verge area as the speed differential between bicycles and pedestrians is likely to be less than that between bicycles and motorised vehicles. Where this is not possible, a cycle lane can be added outside those intended for motorised vehicles. Such lanes should be of the order of 1.5 m wide and clearly demarcated as cycle lanes. If these lanes are wider than 2 m, passenger cars are likely to use them, possibly even for overtaking on the left, which is a manoeuvre to be actively discouraged.

### Sidewalks

Ideally, all neighbourhood streets should have sidewalks on both sides. A sidewalk comprises the entire width between the kerb and the road reserve boundary. According to *NTR 1*, sidewalks should be at least 1.2 m wide when used for pedestrians only. This space should be clear and unobstructed. In shared space configurations, where cyclists and other NMT users are to be accommodated on the sidewalk, the clear and unobstructed space should be at least 3 m wide.

*NTR 1* provides details on the design and measurements for drop kerb ramps or kerb cut options (also called a dropped intersection) to get pedestrians to the road level before crossing the road. The decision as to whether a dropped kerb or a dropped intersection is an option will depend on the width of the sidewalk. The total space required for the installation of the ramped surfaces has to be accommodated in the width of the sidewalk.

Shelter and a pleasant walking environment is an important part of promoting NMT and can be served through the planting of trees in the space for signage and utilities, which is located within the first 0.5 m from the kerb edge. All street furniture is to be located in the designated service areas, to prevent cluttered pedestrian access areas.

### Median islands

The median island is the total area between the inner edges of the inside traffic lanes of a divided road, and includes the inner shoulders and central island. For higher-order roads, the purpose of the median is to separate opposing streams of traffic and hence reduce the possibility of vehicles crossing into the path of opposing traffic. Within the neighbourhood context, the number of lanes determines the road-crossing distance for pedestrians and will determine when a median will be required to provide an area of refuge for pedestrian safety.



### Street lighting

One of the purposes of street lighting is to enable vehicles and people to move safely and comfortably in public open space. The design of street lighting luminaries is addressed in the CIE 140 standard for road lighting calculation.<sup>12</sup> The standard deals with the calculation of luminance and illuminance, and introduces conventions for the location of calculation grid points and observer positions. It also covers the computer programs that can be used for calculations. Other important standards that are applicable for street lighting design are *SANS 10098 – 1*<sup>13</sup> and *SANS 10098 – 2*<sup>14</sup> which are substantially applied by municipalities and utilities in the design of their street lights.

Street lighting is categorised as follows: Group A covers the lighting of important routes; Group B deals with the lighting of residential streets and Group C refers to special lighting requirements. There are different methods of design that can be used for each of the different groups. These methods are described in *SANS 10098 – 1*. The first method involves certified luminance performance tables, while the second method makes provision for the use of computer calculations.

New street lighting technologies are constantly being developed, and energy-efficient technologies are becoming increasingly popular. An overview of lighting technologies is presented in the *Efficient public lighting guide*.<sup>15</sup> Maintenance is an important aspect to consider when designing street lighting. Information regarding maintenance is provided in *ARP 035:2014*.<sup>16</sup>

#### 1.4.1.8 Intersections

Intersections are required to accommodate the movement of both motorised and non-motorised transport. For both groupings intersections have a lower capacity than the links on either side of them. The efficiency of the intersections therefore has a significant impact on the efficiency of the network as a whole when measured according to factors such as energy consumption, time, safety and convenience.



A large proportion of accidents occurring on the road network takes place at intersections. For reasons both of efficiency and safety it is therefore necessary to pay careful attention to the design of intersections. Aspects of design that have to be considered include the location and spacing of intersections, and the form of the intersection linked to the type of intersection control. These aspects are briefly outlined below.

### Location and spacing of intersections

The location and spacing of successive intersections is essentially a function of the layout planning of the area being served (see **Section F**). Various factors related to neighbourhood layout and structure (as discussed in **Section F.4**) need to be taken into consideration, including street hierarchy, street block length, the nature of the streets and the needs of pedestrians and other NMT users.

Intersection sight distance is critical for all users of the intersection to be able to enter and exit the intersection safely. Users should have unobstructed views of the entire intersection and any potentially conflicting vehicles before entering. The location of an intersection on a horizontal curve can create sight problems for the drivers on both legs of the intersecting road and should be avoided where possible. The risk involved in sharp braking during an emergency should also be borne in mind when locating an intersection on a curve.

It is suggested, as a safety measure, that intersections should not be located on relatively steep grades. Drivers have difficulty in judging the additional distance required for stopping on downgrades, and buses and freight vehicles have difficulty in stopping and pulling away on steep slopes.

One of the consequences of a collision between two vehicles at an intersection is that either or both may leave the road. It is therefore advisable to avoid locating an intersection other than at approximately ground level. Lateral obstructions of sight distance should also be considered when the location of an intersection is being determined.

The location of an intersection may have to be modified as a result of an excessive angle of skew between the intersecting roads, i.e. the change of direction to be negotiated by a vehicle turning left off the through-road. Preferably, roads should meet at, or nearly at, right angles.

On higher-order roads, the ideal distance between successive intersections should be such that traffic flows along them should be at so-called "green wave conditions", which means that traffic signals change to their green phase as approaching groups of vehicles reach them. Minimum distances between intersections are primarily concerned with the interaction between these intersections. A driver cannot reasonably be expected to utilise the decision sight distance to an intersection effectively if an intervening intersection requires his or her attention.

On residential streets, the spacing of intersections is at shorter intervals and primarily determined by the layout of the streets providing access to the various plots. The spacing of intersections should be such that they are not so close that waiting traffic at one intersection could generate a queue extending beyond the next upstream intersection. Very closely spaced intersections would also result in a disproportionate percentage of space being dedicated to the road network.

### The form of intersection and type of control

When decisions have to be made about the form of an intersection and the type of traffic control measures to employ, each intersection should be considered on its own merits. Volumes of vehicular traffic being served by the intersection are but one aspect to consider. Safety is enhanced by inter alia reducing the number of conflict points

at which accidents can occur. The number of conflict points increases significantly with the number of legs added to the intersection. In addition to the decrease in safety with an increasing number of approaches to an intersection, there is also a decline in operational efficiency, i.e. an increase in delay.

Four- and three-legged intersections are most common. Multi-leg intersections, i.e. intersections with more than four legs, should be avoided as far as possible. Other forms of intersections and types of control that can be employed include mini-roundabouts, traffic circles and gyratories.

The primary difference between these three forms of control is the diameter of the central island. The gyratory can have a central island with a diameter of 50 m or more, whereas the traffic circle would typically have a central island with a diameter of the order of 10 m and the mini-roundabout a central island that could range from a painted dot to about 4 m diameter. These three forms may have different interpretations depending on the local circumstances. They have advantages as well as disadvantages, and each location should be carefully assessed before deciding on one of these options.

Mini-roundabouts are often challenging for pedestrians and cyclists to negotiate. The need for vehicles to stop at the intersection is reduced, and traffic flow may not be easy to anticipate. Crossing opportunities for cyclists and pedestrians are reduced and the task of judging acceptable gaps could be difficult. The circulatory flow and reduced carriageway width offer less protected space for cyclists. In addition, the distinction between behaviour at a traffic circle and that required at a mini-roundabout is not clear to many drivers.

Signalised intersections usually apply to higher-order roads and are an expensive form of control. The aim of a signalised intersection is not, in the first instance, to reduce speed/calm traffic. By imposing a delay on the through flow, the intersecting flow will be allowed to either cross or join it.

A multi-way stop or yield intersection implies that every approach to the intersection is subject to stop or yield control. Some municipalities in South Africa have also instituted a variation on this form of control by applying stop control not to all but to the majority of approach legs, e.g. two out of three or three out of four. The operation of intersections subject to this form of control grants priority to vehicles based on the principle of "first come, first served". This form of control is appropriate to the situation where no clear distinction can be drawn between the intersecting roads in terms of relative importance and where traffic flows on each are more or less equal. It is often regarded as an interim measure prior to the installation of traffic signals.

Priority control implies that one of the intersecting roads always takes precedence over the other with control taking the form of either 'stop' or 'yield' control. This form of control applies to the situation where it is clear which is the more important of the two intersecting roads. Priority control can also be alternated between successive intersections, for example in a residential area where the layout is more or less a grid pattern and the intersecting streets are of equal importance. In this case, the switching of priority would partially serve as a traffic-calming measure. In general, this is the most commonly used form of intersection traffic control.

## 1.4.2 Road pavement design

This section focuses on the structural design of urban road pavements, including neighbourhood streets, sidewalks and cycle lanes. The aim of structural design is to produce a structurally balanced pavement structure which, at minimum present worth of cost (PWOC) (see [Section 1.4.2.8](#)), will carry the traffic for the structural design period in the prevailing environment, at an acceptable level of service (LoS) (see [Section 1.4.2.1](#)) without major structural distress.

The stepwise pavement design process is detailed in the flowchart in Figure 1.3. The various steps are used to structure the road pavement design guidance provided in the remainder of this section (1.4.2).

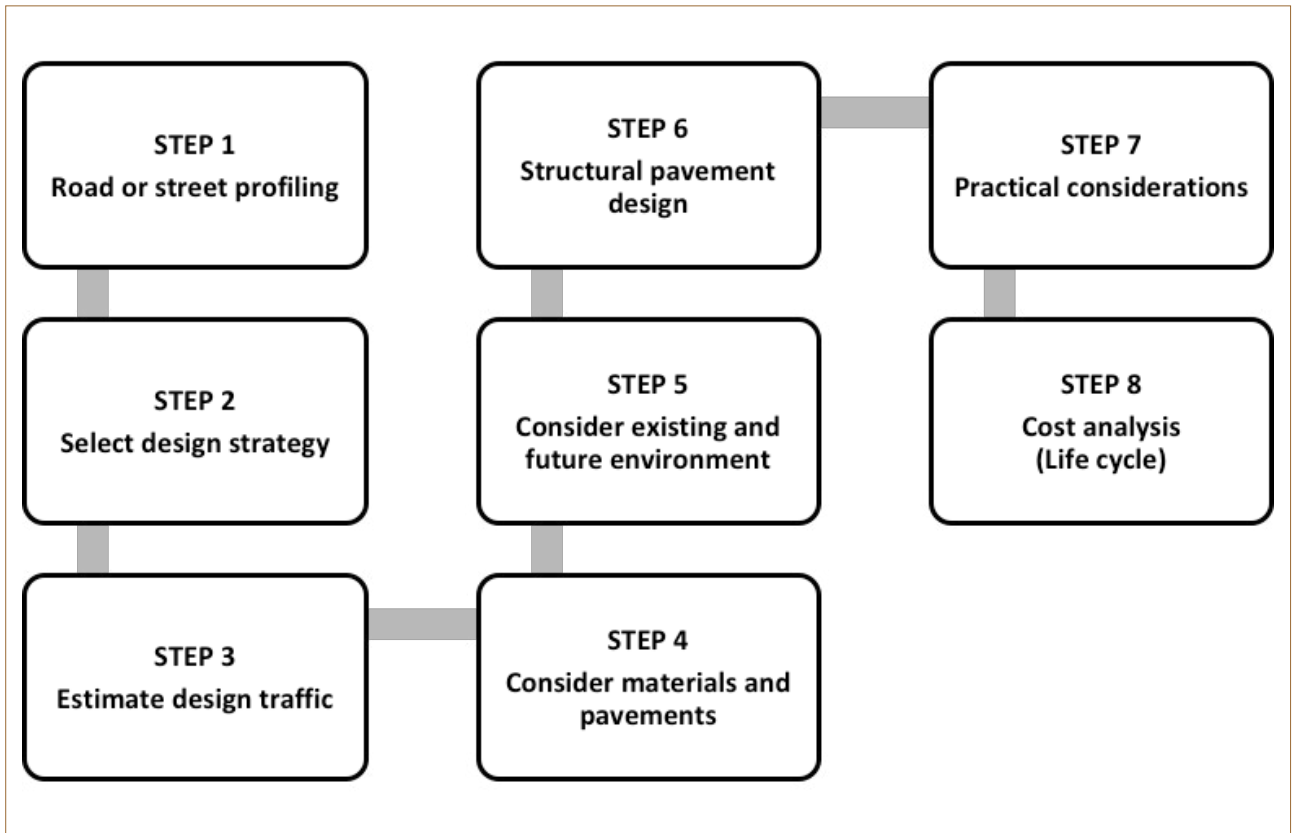


Figure 1.3: Conceptual road pavement design flowchart

### 1.4.2.1 Street profiling

Compiling a street ‘profile’ is a critical aspect of the pavement design process. A number of characteristics define the profile of a street, including the street category, the description and function of the street, the level of service of the street, vehicle and pedestrian traffic, pavement design bearing capacity and whether the street is paved or unpaved.

The six-tiered urban functional road or street classification of TRH26 is discussed in [Section 1.2.3.1](#). For the purpose of pavement structural design, it is important to note that the TRH26 manual differentiates between roads in rural areas and roads in urban areas. In the manual an urban area is defined as an area that has been subdivided into plots, whether formal or informal. It includes formally declared townships as well as informal settlements. This Guide focuses on neighbourhood streets, which are defined in TRH26 as urban.

According to *TRH4: Structural Design of Flexible Pavements for Inter-urban and Rural Roads* and *TRH22: Pavement Management Systems*, roads can also be divided into four broad risk-based categories based on design reliability. This is done for pavement management purposes (see Table 1.2).

**Table I.2:** Generic risk-based structural road categorisation (modified from TRH4, 1994 and TRH22, 1994)

Road structural category*	Approximate design reliability (%)	Description
A	95	Inter-urban freeways, major inter-urban rural roads
B	90	Inter-urban collectors, major rural roads, major industrial
C	80	Lightly trafficked rural roads, strategic roads
D, E**	50	Special pavements, access roads, walkways, cycle lanes, walkways, sidewalks, NMT, etc.

\* Diminishing approximate design reliability, "Category A" highest, i.e. lowest risk for failure. Risk of failure (%) = (100 minus Design Reliability, in %).

\*\* E added for walkways, cycle lanes and NMT modes such as carts, etc.

For the purpose of pavement structural design, this Guide combines the classifications of TRH26 and TRH4 to identify five different street classes/categories, namely U2-B, U3-B, U4-C, U5-D and U6-E. These categories range from arterial streets with high volumes of traffic (low risk of failure), to lightly trafficked residential streets and walkways (higher risk of failure). Although this Guide is focused on the design of neighbourhood streets, information on the structural design of certain higher-class roads (U2-B and U3-B) is also included.

The detailed pavement and traffic engineering definitions of the five combined road/street classes and categories for structural pavement design purposes are summarised in Table I.3.

**Table I.3:** Definition of the combined road classes and categories for structural pavement design purposes

Combined Road Class Category	U2-B	U3-B	U4-C	U5-D, U6-E
Description	Major arterial	Minor arterial	Collector street	Local Street Walkway*
Basic function	Mobility		Access/Activity	
Level of Service (LoS):	High:	High to Moderate:	Moderate:	Moderate to Low:
Scale: 5 to 1	4	4 to 3	3	3 to 1
Approximate design reliability (%)	90	90	80	50
Length of road exceeding terminal condition at the end of design life (%)	10	10	20	50
Equivalent 80 kN single axle loading (million E80/lane), including construction traffic	0.3 to 10 depending on design strategy	0.3 to 10 depending on design strategy	< 3 depending on design strategy	< 1 depending on design strategy
Typical Traffic Loading Class (TLC) in terms of Equivalent Standard (ES) 80 kN axle loads	ES1 – ES10	ES1 – ES10	ES0.03 – ES3	ES0.003 – ES1
Daily Traffic: Equivalent vehicle units (EVU) (1.25 veh=1 EVU)	600 to 10 000	600 to 10 000	< 600	< 500

**Table 1.3:** Definition of the combined road classes and categories for structural pavement design purposes

Combined Road Class Category		U2-B	U3-B	U4-C	U5-D, U6-E
Description		Major arterial	Minor arterial	Collector street	Local Street Walkway*
Riding quality: International Roughness Index (IRI) (m/km)	Constructed	2.9 to 1.6	2.9 to 1.6	3.5 to 2.4	4.2 to 2.4
	Terminal	4.2	4.2	4.5	5.1
Flexible pavements rut level (mm)	Warning	10	10	10	10
	Terminal	20	20	20	20
<b>Area of shattered concrete or rigid pavements (%)**</b>					
CRCP and UTRCP	Warning	0.3	0.3	0.48	0.5
	Terminal	0.7	0.7	0.8	1.0
JCP and DJCP	Warning	3	3	4	5
	Terminal	6	6	8	10
Typical standard for surfacing		Paved/ unpaved	Paved/ unpaved	Unpaved, or paved for reasons other than traffic (e.g. drainage)	Unpaved, or paved for reasons other than traffic (e.g. drainage)
Pedestrian traffic		Low	Low	High	High

\* Include non-motorised transport (NMT)

\*\* CRCP: Continuous Reinforced Concrete Pavement, UTRCP: Ultra-Thin Reinforced Concrete Pavement, JCP: Jointed Concrete Pavement, DJCP: Doweled Jointed Concrete Pavement

Another factor to consider is the level of service (LoS). The LoS that a user expects from a street is related to the function of the street, whether it is paved or unpaved, and partly to the volume of traffic carried. For example, the user will expect a better riding quality on a dual-carriageway arterial road than on a minor residential street. Irrespective of this, the user will generally expect the highest possible standard. Different streets within a neighbourhood function at different LoS. The LoS values can be determined by the functional use of the street and the drainage provision on a five-point scale, with 5 as highest LoS. In Table 1.4 the description of each type of street and its drainage is given, with the associated LoS values. In the matrix the combined LoS value is given. The final LoS value is determined mostly by the LoS of the water drainage.

**Table I.4: Levels of Service (LoS) of streets or drainage and combined facilities**

Combined Road Class Category	Street LoS*	Drainage LoS:	4 & 5	3	2	1
		Description	Pipe system, kerbs, gutter and surfaced (paved) street	Lined channel on shoulder or on street	Unlined channel on shoulder or on street	Unsurfaced street with provision of drainage with sheet flow
U2-B, U3-B	5	District and/or local distributors (bus routes) with a designed structure and surfacing	5	4	3	
	3	Gravel		3	2	
U4-C	5	Residential access collectors with a designed light structure and surfacing	5	4	3	2
	3	Gravel		3	2	1
	1	In situ		3	2	1
U5-D, U6-E	5	Access and basic access streets with surfacing on light structure	5	4	3	2
	3	Gravel		3	2	1
	1	In situ		3	2	1

\* LoS on a five-point scale, with 5 as the highest quality.

**Table I.5: Categorisation of urban street and route standards**

Paved collector/distributor streets (bus routes, may include Bus Rapid Transit (BRT))	Unpaved collector/distributor streets (bus routes)	Access streets (> 75 vehicles per day)		Basic access streets (< 75 vehicles per day; < 5 heavy vehicles per day)		
		Paved access streets	Unpaved access streets	Paved basic access streets	Unpaved basic access streets	
					Gravel basic access streets	Earth basic access streets

The main categories as highlighted in Table I.5 are discussed below.

#### 1.4.2.1.1 Arterial streets

Arterial streets are the major routes providing mobility between and within residential, recreational, commercial and industrial areas. The traffic volumes on these streets will be high and the streets will generally carry significant numbers of buses and other heavy vehicles such as construction vehicles. The heavy vehicle traffic carried by paved

arterial streets will generally justify their being built to a traditional paved standard for bearing capacity, if funds are available.

Although unpaved arterial roads and streets exist in some areas, the cost of maintaining such infrastructure can be excessive. If not maintained frequently, such roads may not retain a riding quality of an acceptable level and it may result in safety hazards and dust pollution. The user costs, in comparison with a paved street, are extremely high. All attempts should be made to provide arterials carrying bus and heavy goods vehicles of a suitable, relatively low-risk, paved standard, whilst arterials carrying mostly light goods vehicles can afford slightly higher-risk pavements. Although undesirable, financial constraints may prevent an authority from being able to pave all arterial streets in a road network. The optimum use of available materials is thus necessary to reduce the undesirable effects as far as possible.

#### **1.4.2.1.2 Access streets**

Access streets include all residential streets below the level of urban bus routes. Their primary function is access to residential erven and they will thus carry few heavy vehicles. Depending on the level of development and car ownership in the area, traffic may be so light that the primary structural design objectives may relate more to minimising damage from water erosion than to supporting traffic loading. Access streets may be further divided into access streets with traffic levels of more than 75 vehicles per day (vpd) and those with less than 75 vehicles per day, of which less than approximately 5 are heavy vehicles. Access streets carrying more than 75 vehicles per day require a more robust structural design than those carrying lighter traffic volumes (basic access streets).

It may be economically justifiable to pave access streets with traffic levels of more than 75 vehicles per day. The aspirations of residents and street users may also influence this decision.

#### **1.4.2.1.3 Basic access streets**

Basic access streets are defined as access streets in the early stages of development, and are designed and constructed subject to constraints imposed by the administrative authority owing to limited budgets or other circumstances. The objective is to maximise the longer-term performance of such streets within these constraints.

Access streets with relatively light traffic can justifiably be left unpaved. If the street is to have an unsealed pavement it is essential that the best quality material available locally is used (blending and/or processing should be considered where necessary to improve the materials), and some method of dust palliation could be considered.

Although unpaved basic access streets are undesirable from the point of view of dust generation, the creation of mud when wet, the need for constant maintenance, and financial constraints may preclude the use of higher-quality streets for the very low traffic loading typical of these streets. The optimum use of available materials is thus necessary to reduce the undesirable effects as far as possible.

Earth basic access streets are considered a viable option only if the in-situ material is of a quality that will support vehicles even in a soaked condition. One of the major problems with earth streets is that they initially form tracks, and, if bladed, a street that is lower than the surrounding terrain results, with significant drainage and erosion problems.

#### 1.4.2.1.4 Tertiary ways

Unpaved basic access streets may evolve from informal access routes, which are referred to as tertiary ways. In developing areas, an infrastructure of narrow ways that carry no or few vehicles exists. These non-trafficked tertiary ways are mostly informal and un-serviced, but in older developing areas they are formalised (upgraded) by the provision of surfacings, drainage or even services like water and electricity.

In an informal residential development no layout planning for tertiary ways is done. The existence of these ways is dictated by pedestrians' needs to follow the shortest possible route. It is advisable to design for tertiary ways during layout planning as this forms the basic link between dwellings.

#### 1.4.2.2 Design strategy

The design strategy could influence the total cost of a pavement structure. The strategy includes the selection of analysis and structural design periods and the important consideration of life cycle analysis. Normally, a design life cycle strategy is applicable only to paved Category U2-B and U3-B roads/streets.

##### 1.4.2.2.1 Analysis and structural design periods

The analysis period is a convenient planning period during which complete reconstruction of the pavement is undesirable. The structural design period, on the other hand, is defined as the period for which it is predicted with a high degree of confidence that no structural rehabilitation or significant maintenance will be required.

In situations where geometric design is expected to be appropriate for longer periods, the analysis period can be as long as 30 years. A shorter analysis period such as 10 years is recommended for uncertain geometric design life, or when substantial changes in the traffic situation are expected. When deciding on a structural design period, various factors should be considered for each category, as summarised below.

##### (i) Category U2-B and U3-B

A longer structural design period is generally recommended. However, the following factors may encourage a shorter design period:

- A changing traffic situation, which may cause the geometric design to become outdated
- Shortages of funds for the initial construction cost
- A lack of confidence in design assumptions, especially the design traffic

If a shortened structural design period is selected for categories U2-B and U3-B, the design should be able to accommodate a staged construction approach (see [Section 1.4.2.9.1](#)).

##### (ii) Category U4-C

If it is expected that structural rehabilitation will be difficult, a long period may be appropriate. For residential streets, a fixed structural design period of 20 years is recommended. Financial constraints may dictate a shorter structural design period of 10 years.



(iii) Category U5-D

Since the traffic volume is limited for this category of streets, a structural design period may not be required. However, the traffic growth can be rapid and unpredictable. A short structural design period enables changes in the initial life cycle strategy to adapt to changing circumstances, without any major financial implication.

(iv) Category U6-E

As these roads are for pedestrian use only, a structural design period may not be applicable.

Table 1.6 provides a summary of structural design periods for different street categories.

Functional Class/Category	Structural design period* (years)	
	Range	Recommended
U2-B and U3-B	10-25	20
U4-C	10-30	20

\* The analysis period for category U2-B roads/streets is normally 30 years.

1.4.2.2.2 Pavement life cycle strategies

Various alternative designs are initially considered depending on the availability of materials, the structural capacity demand of the actual traffic spectrum and the service level of the facility. The final selection of a particular design depends on an economic analysis, and requires an understanding of the behaviour of different pavement types, and the type and timing of maintenance and rehabilitation during the life cycle as illustrated in Figure 1.4. The three scenarios show the generalised trends of riding quality decreasing with time for three different pavement structures as follows:

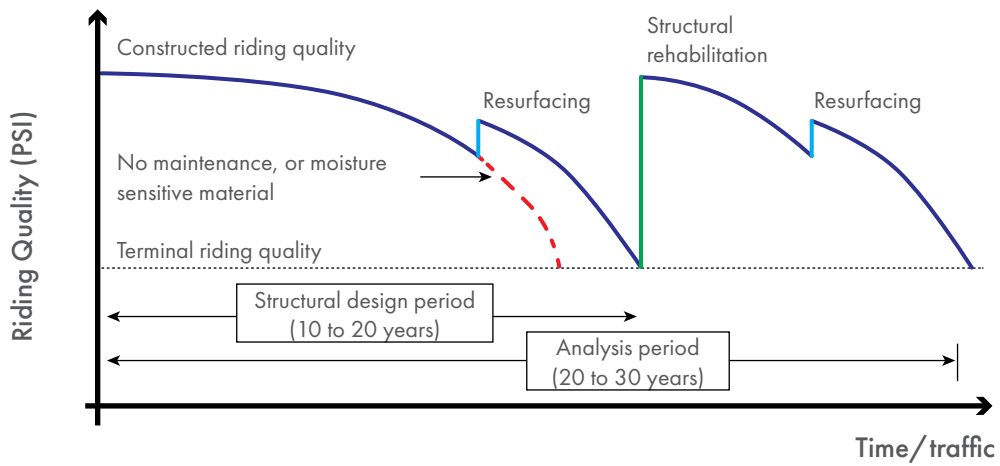
**Design a:** Flexible pavement with lower initial construction costs, which requires resurfacing to maintain the condition of the surface, followed by some structural rehabilitation such as an overlay, and later another resurfacing.

**Design b:** Flexible pavement with reduced future construction costs, which is structurally adequate for the whole of the analysis period and requires only three resurfacing actions.

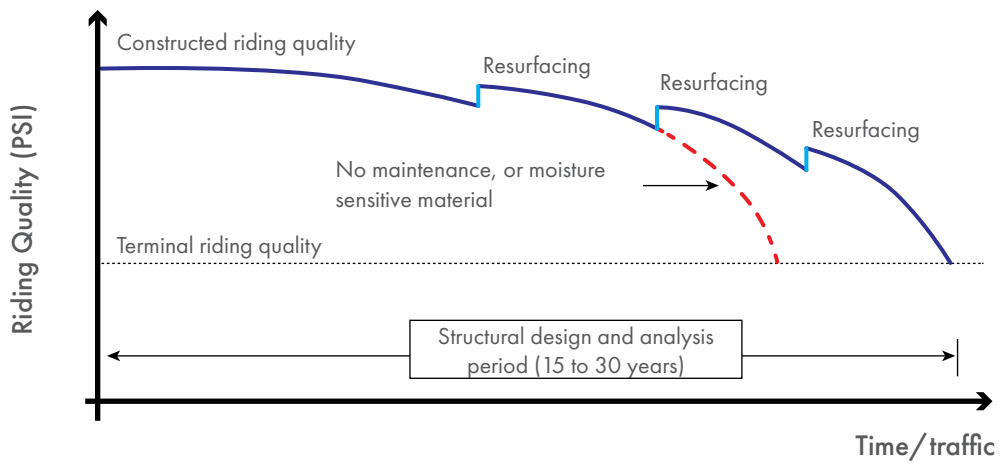
**Design c:** Concrete pavement with reduced future construction costs, which is structurally adequate for the whole of the analysis period and does not require resurfacing.



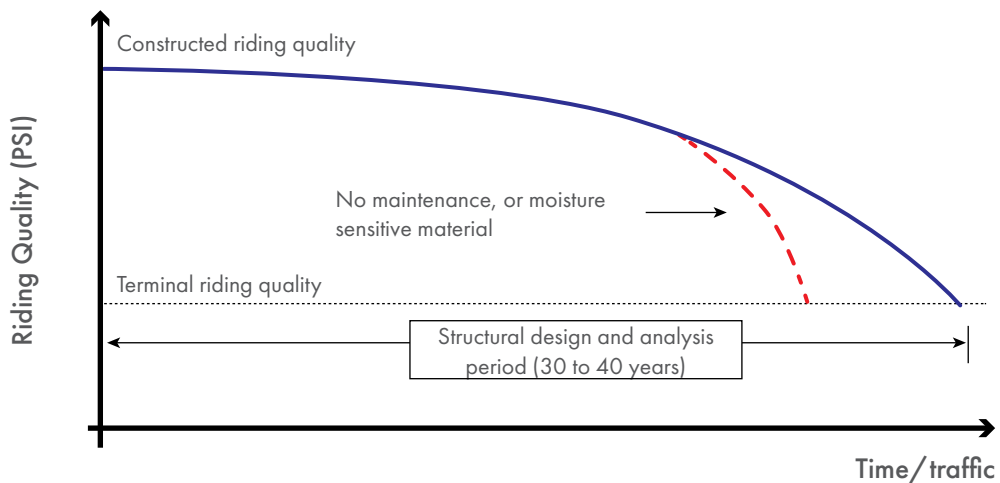
The timing and nature of the maintenance measures can only be estimated when the design strategy is developed. The maintenance programme should be informed by the actual factors once construction has been completed.



(a) Reduced Initial Construction Costs for Flexible Pavements



(b) Reduced Future Construction Costs for Flexible Pavements



(c) Reduced Future Construction Costs for Concrete Pavements

Adapted from SAPEM<sup>17</sup>

Figure 1.4: Illustration of design periods and alternative design strategies

### 1.4.2.3 Design traffic estimates

On determining a design strategy, an estimate should be made of the traffic load to be accommodated in the design. The composition of vehicle traffic on streets varies considerably, ranging from light passenger vehicles to buses and heavy vehicles transporting commercial goods. The composition of the traffic on one street will differ from that on another because of the differences in street functional class or category. The unique traffic spectrum on a particular street will be the design traffic for that street.

The pavement design process focuses on the response of pavements to loading, specifically the volume and loading of heavy vehicles. The extremely variable nature of traffic makes the quantification of traffic loading for a particular road/street complicated. Traffic loading for a particular road/street is influenced by various factors, including shifts in the preferred mode of transport, economic growth, sporadic construction activity, changes to legal axle load limits, changes in the mechanical design and load-carrying capacity of vehicles, the wander of heavy vehicles across the width of the lane (e.g. vehicles used in Bus Rapid Transit (BRT) systems have a much more concentrated wander, and hence causes a greater degree of damage to the pavement), the speed at which heavy vehicles move. The following documents deal with the collection of traffic data and design traffic estimation:

- TRH16 (1991) Traffic Loading for Pavement and Rehabilitation Design
- TMH8 (2014) Traffic and Axle Load Monitoring Procedures
- TMH3 (2015) Specifications for the Provision of Traffic and Weigh-in-Motion Monitoring Service
- TMH14 (2015) South African Standard Automatic Traffic Data Collection Format

#### 1.4.2.3.1 Concepts for design traffic estimation

##### (i) Legal axle loads

The key factors that play a role in the determination of a legal axle load are vehicle manufacturer's specification, tyre load rating and permitted axle loadings. In South Africa, the static axle mass for different axle groups are set out in TRH16<sup>18</sup> and are based on Regulations 234 to 240 of the Road Traffic Act of 1996.

##### (ii) Equivalent standard axle loads

The concept of equivalent standard axle load was developed from data that was collected as part of the AASHO Road Test. It is based on the principle that any load may be converted to an equivalent number of standard axle loads, based on the damage done by the load in relation to the damage done by the standard load.

Load sensitivity is generally expressed by the power damage law, often called the 4<sup>th</sup> power law. The standard axle load for South Africa is a dual-wheel, single-axle load of 80 kN. The Load Equivalency Factor (LEF) of any other load  $P$  is calculated using Equation 1.1, which is known as the 4<sup>th</sup> power law if  $n = 4$ .

$$LEF = (P/80)^n \quad \text{Eq 1.1}$$

Where:

$LEF$  = Load Equivalency Factor (E80)

$P$  = axle load in kN

$n$  = relative damage exponent (usually 4) (see Table 1.7)

The damage exponent  $n$  was originally determined as 4.2 from the AASHO Road Test. However, a value of 4 is often used. Pavements that are sensitive to loading, such as those that are shallow-structured with cemented bases, may have  $n$ -values of more than 4, whereas less sensitive deep-structured pavements may have  $n$ -values typically less than 4. Heavy Vehicle Simulator (HVS) testing in South Africa has shown that depending on the pavement type, pavement balance and distress mechanism,  $n$  may vary from 2 to 6, as shown in Table I.7.

Base/Subbase combination		Range of values (Recommended value)
Granular/granular		3 - 6 (4)
Granular/cemented		2 - 4 (3)
Cemented/granular	Pre-cracked	4 - 10 (5)
	Post-cracked	3 - 6 (5)
Cemented/cemented	Pre-cracked	3 - 6 (4 - 5)
	Post-cracked	2 - 5 (4 - 5)
Bitumen Stabilised Material (BSM)/granular		2 - 6 (4)
Hot mix asphalt/cemented		2 - 5 (4)
Concrete		(4.5)

### (iii) E80s per heavy vehicles (E80/HV)

An E80/HV is a factor that converts different truck loads to an equivalent number of standard axles. The E80/HV for each vehicle type is, however, not that useful, considering the many different vehicle types on any one route. Therefore, the average E80/HV for a network or section of road is generally used. It should be noted that changes to the legal axle load and the level of enforcement generally affect the E80/HV for a network.

### (iv) Daily traffic parameters

Traffic volumes are usually expressed in terms of average daily traffic (ADT) measured in vehicles per day, with the ADT referring to an extended period. Reference is made to Annual Average Daily Traffic (AADT) only if traffic counts are available for a calendar year. When designing road pavements, the traffic averages of heavy vehicles need to be determined in order to calculate axle load. Average Daily E80 (ADE) refers to the average daily E80 per lane per day over the period during which the axle load survey was conducted. Annual Average Daily E80 (AADE) is the total E80 per lane allied during one year divided by 365 days. The AADE cannot be determined from a single survey conducted over a short period of time because of cyclic and random variations in traffic loading that occur during the calendar year. Since axle load surveys are normally conducted over short periods ranging from several days to two weeks, adjustment factors derived from permanent classification count stations are often applied to convert the measured average daily E80 to estimated AADE values.

#### 1.4.2.3.2 Traffic loading classes for structural pavement design

Table I.8 summarises different traffic loading classes, defined in terms of the cumulative equivalent traffic or pavement bearing capacity in the design lane over the structural design period. This definition is used because of the large variation associated with real pavement performance and the associated difficulty in predicting pavement life. Although the traffic classification is useful for communication purposes, the actual equivalent traffic may be required for specific purposes.

**Table 1.8:** Classification of road pavements and traffic loading class for structural design purposes (TRH4)

Pavement Traffic Loading Class (TLC) i.t.o. number of Equivalent Standard (ES) 80 kN axle loads	Bearing capacity (million 80 kN axles/lane)	Typical traffic volumes and type of traffic	
		Approximate vehicles per day per lane (vpdpl)	Description
ES0.003	< 0.003	< 3	Very lightly trafficked roads/streets with very few heavy vehicles. Includes roads/streets transitioning from gravel to paved roads and may incorporate semi-permanent and/or all-weather surfacing layers.
ES0.01	0.003 - 0.01	3 - 10	
ES0.03	0.01 - 0.03	10 - 20	
ES0.1	0.03 - 0.1	20 - 75	
ES0.3	0.1 - 0.3	75 - 220	
ES1	0.3 - 1	220 - 700	Lightly trafficked roads/streets carrying mainly cars, light delivery and agricultural vehicles with very few heavy vehicles.
ES3	1 - 3	> 700	Medium volume, few heavy vehicles.
ES10	3 - 10	> 700	High volume and/or many heavy vehicles.
ES30	10 - 30	> 2 200	Very high volume of traffic and/or a high proportion of fully laden heavy vehicles
ES100	30 - 100	> 6 500	

It is important to note that road pavement design methods are moving away from using load equivalency and standard axle loads by incorporating the axle load histogram in the design analysis, using an incremental damage approach. The simplest form of this utilises Miner's Law with the current failure criteria. The revised South African Road Design System (SARDS)<sup>19</sup> will incorporate the full traffic spectrum, in which case the E80 may not be used any longer for pavement design.

#### 1.4.2.3.3 Traffic measurement and vehicle classification

##### (i) Traffic measurement

Traffic counts and classification are done manually or are automated using traffic counting stations installed on the road. Traffic counting is performed on a special or project basis (short-term), or on a temporary (medium-term) to permanent (long-term) basis by road authorities, as part of their road management system data collection strategy. While permanent stations provide a continuous traffic record from one year to the next, temporary stations are used on a sampling or periodic basis to collect data over a specified time period.

##### (ii) Vehicle classification

The appropriate vehicle classification system depends on the traffic data required and the capabilities of the traffic monitoring equipment. Heavy axle loads, associated with heavy vehicles, do most of the damage on pavements.

**Design considerations**

For pavement design, traffic should therefore be split between light and heavy vehicles. Based on the length of the vehicle (extended vehicle classification system), heavy vehicles can be classified into three groups that are commonly used for the estimation of pavement design traffic:

- Short heavy vehicle (S): length < 10.8 m
- Medium heavy vehicle (M): length between 10.8 and 16.8 m
- Long heavy vehicle (L): length > 16.8 m

**1.4.2.3.4 Traffic investigation for pavement design**

An incorrect design traffic estimate results in the same design risk as a pavement structure of inadequate structural capacity. Traffic loading information for pavement design may be obtained from the following sources or methods: Tabulated average E80 values, published results of surveys, transportation planning models, and estimation procedures based on visual observations and project-specific traffic surveys. The level of effort and cost associated with these methods increases from the use of known results to the project specific surveys, but so does the value of the results obtained. The application of each of the above sources or methods is linked to the different categories of road/street, as recommended in Table I.9.

**Table I.9:** Recommended traffic investigation levels for road functional class/category

Road functional class/ category	Traffic parameter			
	Base year HV volume	HV volume growth rate	Base year E80/ HV	E80/HV growth
U2-B, U3-B	Traffic surveys <sup>1</sup>	Transportation models Published results	Traffic surveys	Published results
U4-C	Visual observation <sup>2</sup>	Published results	Visual observation	Published results
U5-D, U6-E	Published results <sup>3</sup>	Published results	Published results	Published results

<sup>1</sup> Project-specific traffic survey

<sup>2</sup> Project-specific visual observation and tabulated values

<sup>3</sup> Published results, or results from other projects with similar traffic characteristics

**1.4.2.3.5 Calculation of design E80**

The detailed computation of the design E80 or cumulative equivalent traffic over the structural design period involves the load equivalency of the road/street traffic, surveys of road traffic conditions, projecting the road traffic data over the structural design period and estimating the road lane distribution.

**(i) Load equivalency of traffic**

The Load Equivalent Factor (LEF) used to calculate the E80 relates the application of any given axle load to the equivalent damage caused relative to the standard axle, which is taken as 80 kN. The LEF is calculated using Equation I.1, as described in **Section I.4.2.3.1**. Table I.10 provides average equivalency factors based on Equation I.1, with  $n = 4$ .

**Table I.10:** Average Single 80 kN axle equivalency factors, derived from  $F_{ave} = (P/80)^n$ , with  $n = 4$

Single axle load, P* (kN)	Average 80 kN axle equivalency factor, F**	Single axle load, P (kN)	Average 80 kN axle equivalency factor, F <sub>ave</sub>
<15	0.005	115 - 124	5.021
15 - 24	0.005	125 - 134	6.916
25 - 34	0.021	135 - 144	9.303
35 - 44	0.064	145 - 154	12.262
45 - 54	0.154	155 - 164	15.876
55 - 64	0.317	165 - 174	20.237
65 - 74	0.584	175 - 184	25.441
75 - 84	0.994	185 - 194	31.590
85 - 94	1.590	195 - 204	38.791
95 - 104	2.422	>205	43.118
105 - 114	3.545		

\* Single axle load with dual wheels

\*\* Average is based on  $LEF = ((P_{lower\ limit}/80)^n + (P_{upper\ limit}/80)^n)/2$

The Average Daily Equivalent (ADE) traffic can be determined by multiplying the number of axle loads ( $t_j$ ) in each load group in the entire load spectrum by the relevant load equivalency factor ( $LEF_j$ ).

By summation, the average daily equivalent traffic is calculated using Equation I.2.

$$ADE = \sum t_j \cdot F_j \quad \text{Eq I.2}$$

A sensitivity analysis should be conducted on the spectrum of loads with n-values as indicated in Table I.7, especially when dealing with abnormal load spectra.

### (ii) Surveys of traffic conditions

The present average daily traffic is the amount of daily traffic in a single direction, averaged over the present year. This traffic can be estimated from traffic surveys carried out at some time before the initial year. Such a survey may include static weighing of a sample of vehicles, dynamic weighing of all axles for a sample period (e.g. weigh-in-motion (WIM) survey), or estimation procedures based on visual observation (Table I.11 can be used to assist in this.)

**Table I.11:** Recommended E80/axle loading for visual observation technique

Description of Heavy Vehicle Loading	Percentage of Vehicles		Axle Load Factors (E80/axle)
	Fully Laden (%)	Empty or Partially Laden (%)	
Predominantly lightly laden vehicles	< 35	> 45	0.3
Fully laden, partially laden and empty vehicles	40 - 45	34 - 45	0.5
Fully and partially laden vehicles	60 - 75	< 30	0.7
Predominantly fully laden vehicles	> 70		0.9

## (iii) Projection of the traffic data over the structural design period

## Projection to initial design year:

The present average daily equivalent traffic (daily E80s) can be projected to the initial design year by multiplying by a growth factor determined from the growth rate:

$$g_x = (1 + 0.01 \times i)^x \quad \text{Eq 1.3}$$

Where:

$g$  = growth factor

$i$  = growth rate (%)

$x$  = time between determination of axle load data and opening of streets in years

The traffic growth factor ( $g$ ) is given in Table I.12.

Time between determination of axle load data and opening of road, $x$ (years)	* $g$ for traffic increase, $i$ (% per annum)								
	2	3	4	5	6	7	8	9	10
1	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10
2	1.04	1.06	1.08	1.10	1.12	1.14	1.17	1.19	1.21
3	1.06	1.09	1.12	1.16	1.19	1.23	1.26	1.30	1.33
4	1.08	1.13	1.17	1.22	1.26	1.31	1.36	1.41	1.46
5	1.10	1.16	1.22	1.28	1.34	1.40	1.47	1.54	1.61
6	1.13	1.19	1.27	1.34	1.42	1.50	1.59	1.68	1.77
7	1.15	1.23	1.32	1.41	1.50	1.61	1.71	1.83	1.95
8	1.17	1.27	1.37	1.48	1.59	1.72	1.85	1.99	2.14
9	1.20	1.30	1.42	1.55	1.69	1.84	2.00	2.17	2.36
10	1.22	1.34	1.48	1.63	1.79	1.97	2.16	2.37	2.59

$$*g = (1 + 0.01 \times i)^x$$

## Computation of cumulative equivalent traffic:

The cumulative equivalent traffic (total E80s) over the structural design period may be calculated from the equivalent traffic in the initial design year and the growth rate for the design period. Where possible, the growth rate should be based on specific information. More than one growth rate may apply over the design period. There may also be a difference between the growth rates for total and equivalent traffic. These rates will normally vary between 2% and 10%, and a value of 6% is recommended.

The Annual Average Daily Equivalent (AADE) traffic in the initial year is given by

$$AADE_{initial} = ADE \times g_x \quad \text{Eq 1.4}$$



The cumulative equivalent traffic may be calculated from

$$N_e = AADE_{initial} \times f_y \quad \text{Eq 1.5}$$

Where

$$f_y = \text{cumulative growth factor, based on}$$

$$f_y = 365 (1 + 0.01 \times i)[(1 + 0.01 \times i)^y - 1]/(0.01 \times i) \quad \text{Eq 1.6}$$

(y = structural design prediction period)

The cumulative growth factor ( $f_y$ ) is given in Table I.13.

**Table I.13: Traffic growth factor ( $f_y$ ) for calculation of cumulative traffic over prediction period from initial (daily) traffic**

Prediction period, y (years)	Compound growth rate, i (% per annum) *									
	2	4	6	8	10	12	14	16	18	20
4	1 534	1 611	1 692	1 776	1 863	1 953	2 047	2 145	2 246	2 351
5	1 937	2 056	2 180	2 312	2 451	2 597	2 750	2 911	3 081	3 259
6	2 348	2 517	2 698	2 891	3 097	3 317	3 551	3 801	4 066	4 349
7	2 767	2 998	3 247	3 517	3 809	4 124	4 464	4 832	5 229	5 657
8	3 195	3 497	3 829	4 192	4 591	5 028	5 506	6 029	6 601	7 226
9	3 631	4 017	4 445	4 922	5 452	6 040	6 693	7 417	8 220	9 109
10	4 076	4 557	5 099	5 710	6 398	7 173	8 046	9 027	10 130	11 369
11	4 530	5 119	5 792	6 561	7 440	8 443	9 588	10 895	12 384	14 081
12	4 993	5 703	6 526	7 480	8 585	9 865	11 347	13 061	15 044	17 336
13	5 465	6 311	7 305	8 473	9 845	11 458	13 352	15 575	18 183	21 241
14	5 947	6 943	8 130	9 545	11 231	13 242	15 637	18 490	21 887	25 927
15	6 438	7 600	9 005	10 703	12 756	15 239	18 242	21 872	26 257	31 551
16	6 939	8 284	9 932	11 953	14 433	17 477	21 212	25 795	31 414	38 299
17	7 450	8 995	10 915	13 304	16 278	19 983	24 598	30 346	37 500	46 397
18	7 971	9 734	11 957	14 762	18 308	22 790	28 458	35 625	44 680	56 115
19	8 503	10 503	13 061	16 338	20 540	25 934	32 859	41 748	53 154	67 776
20	9 045	11 303	14 232	18 039	22 995	29 455	37 875	48 851	63 152	81 769
25	11 924	15 808	21 227	28 818	39 486	54 506	75 676	105 517	147 559	206 727
30	15 103	21 289	30 587	44 656	66 044	98 656	148 459	224 533	340 661	517 664
35	18 612	27 858	43 114	67 927	108 816	176 464	288 595	474 509	782 431	1 291 373
40	22 487	36 071	59 877	102 120	177 700	313 586	588 416	999 544	1 793 095	3 216 609

\* based on  $f_y = 365 (1 + 0.01 \times i)[(1 + 0.01 \times i)^y - 1]/(0.01 \times i)$

#### 1.4.2.3.6 Estimating the lane distribution of traffic

On multi-lane roads, the traffic will be distributed among the lanes. Note that the distribution of total traffic and equivalent traffic will not be the same. The distribution will also change along the length of street, depending on geometric factors such as climbing or turning lanes. Suggested design factors of equivalent traffic ( $B_e$ ) are given in Table I.14. As far as possible, these factors incorporate the change in lane distribution over the geometric life of a facility. The factors should be regarded as maxima and decreases may be justified.

The design cumulative equivalent traffic:

The design cumulative equivalent traffic per lane ( $N_e$ ) may be calculated by multiplying the equivalent traffic by a lane distribution factor ( $B_e$ ):

$$N_e = E80_{total} = (\sum t_j \times F_j) \times g_x \times f_y \times B_e \quad \text{Eq 1.7}$$

Where:

$\sum t_j \times F_j$  = equivalent daily traffic at time of survey

$g_x$  = growth factor to initial year ( $x$  = period from traffic survey to initial design year)

$f_y$  = cumulative growth factor over structural design period ( $y$  - structural design period)

$B_e$  = lane distribution factor for equivalent traffic (see Table I.14)

To check the geometric capacity of the street, the total Annual Average Daily E80 (AADE) traffic towards the end of the structural design period can be calculated from

$$AADE = ADE \times g_x \quad \text{Eq 1.8}$$

with  $g_x$  as previously defined.

When projecting traffic over the structural design period, the possibility should be kept in mind that capacity conditions may be reached, which would result in no further growth in traffic for that particular lane.

**Table I.14:** Design factors for the distribution of equivalent traffic ( $B_e$ ) among lanes and shoulders

Total number of lanes in both directions	E80 Lane distribution factor			
	Surfaced slow shoulder	Lane 1	Lane 2	Lane 3
2	1.00	1.00	-	-
4	0.95	0.95	0.3	-
3	0.7	0.70	0.6	0.25

Note: Lane 1 is the outer or slow lane

#### 1.4.2.3.7 Design traffic on unpaved roads

For the design of unpaved roads, only the average daily traffic is required, as performance is mostly a function of the total traffic, with the split between light and heavy vehicles being of little importance. This is the result of the traffic-induced deformation of properly designed unpaved streets being restricted to the upper portion of the gravel surfacing. Such problems can be rectified during routine surface maintenance involving grading and spot re-gravelling, or by re-gravelling of the road.

#### 1.4.2.4 Material and pavement selection

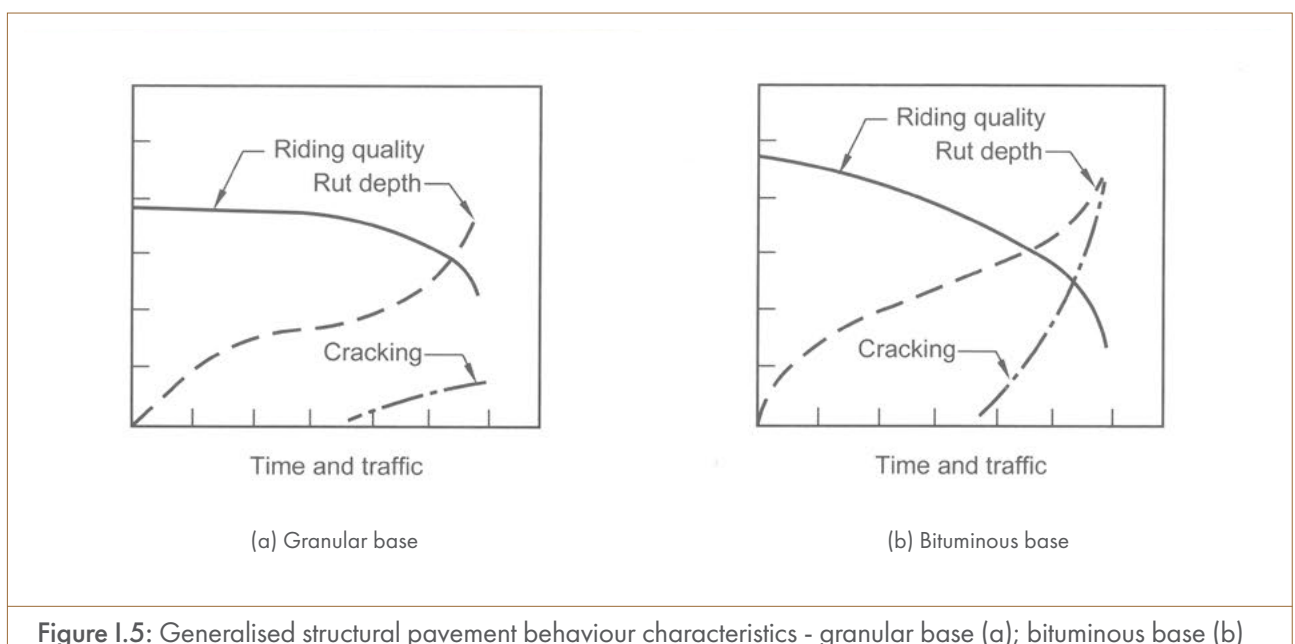
Pavement types and pavement material options are discussed in [Section 1.3.3](#). When selecting a pavement type, it is important to understand that the structural behaviour of pavement types differ, especially with respect to the behaviour under loading, the load sensitivity of different pavements, and the pavement behaviour over the long term. A brief description of the typical structural behaviour of different pavement types is given below to guide decision making.

1.4.2.4.1 Flexible pavements

The typical structural behaviours of the four types of flexible pavements commonly used in South Africa are discussed separately.

(i) Unbound granular base pavements

This type of pavement comprises a thin bituminous surfacing, a base of untreated gravel or crushed stone, a granular or cemented subbase and a subgrade of various soils or gravels. The mode of distress in a pavement with an untreated subbase is usually deformation, arising from shear or densification in the untreated materials. The deformation may manifest itself as rutting or as longitudinal roughness, eventually leading to cracking. This is illustrated in Figure 1.5(a).



In pavements with cemented subbases, the subbase improves the load-carrying capacity of the pavement, but at some stage the subbase will crack under traffic. The cracking may propagate until the layer eventually exhibits properties similar to those of a natural granular material. It is unlikely that cracking will reflect to the surface, and there is likely to be little rutting or longitudinal deformation until after the subbase has cracked extensively. However, if the subbase exhibits large shrinkage or thermal cracks, they may reflect to the surface.

The post-cracked phase of a cement-treated subbase under granular and bituminous bases adds substantially to the useful life of the pavement. Elastic deflection measurements at various depths within the pavement have indicated that the initial effective modulus of this material is relatively high (3 000 to 5 000 MPa) as shown in Figure 1.6(a). This relatively rigid subbase generally fatigues under traffic, or in some cases even under construction traffic, and assumes a lower effective modulus (800 to 1 000 MPa). This change in modulus does not normally result in a marked increase in permanent deformation, but the resilient deflection and radius of curvature (RoC) do change, as shown in Figure 1.6(b).

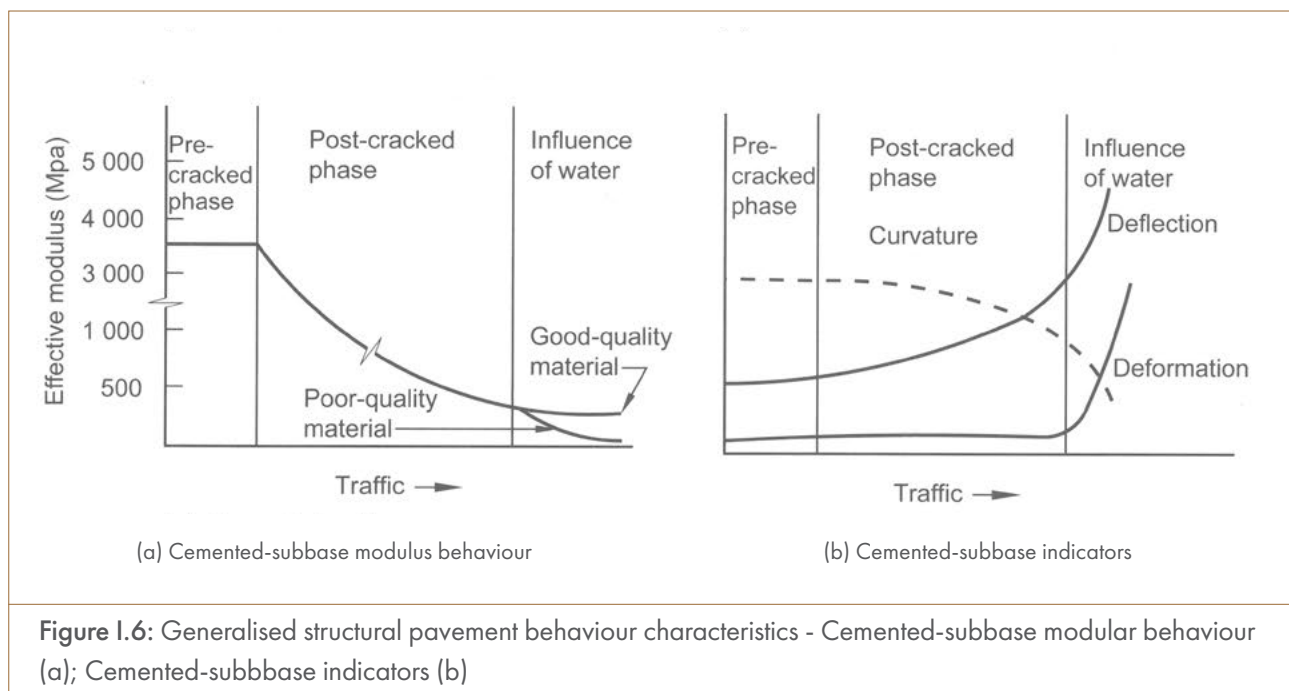
In the mechanistic design approach (see [Section 1.4.2.6.1](#)), these phases have been termed the pre-cracked and post-cracked phases. The design accommodates the changes in modulus of the subbase and, although the safety

factor in the base will be reduced, it will still be well within acceptable limits. The eventual modulus of the cemented subbases will depend on the quality of the material originally stabilised, the cement agent, the effectiveness of the mixing process, the absolute density achieved, the durability of the stabilisation and the degree of cracking. The ingress of moisture can affect the modulus in the post-cracked phase significantly. In some cases the layer may behave like a good-quality granular material with a modulus of 200 to 500 MPa, but in other cases the modulus may be between 50 and 200 MPa. This change is shown diagrammatically in Figure 1.6(a).

The result is that the modulus of the cemented subbase assumes very low values and this causes fatigue and high shear stresses in the base. Generally, surface cracking will occur and, with the ingress of water, there may be pumping from the subbase. Therefore, regular road inspection and maintenance should be executed.

For high-quality, heavily trafficked pavements, it is necessary to avoid materials that will eventually deteriorate to a very low effective layer modulus. Many of these lower-class materials have, however, proved to be adequate for lower classes of traffic.

The surfacing may also crack owing either to hardening of the binder as it ages or to load-associated fatigue cracking. The strength of granular materials is often susceptible to water, and excessive permanent deformation may occur when water enters through surface cracks. The water susceptibility of a material depends on factors such as grading, the plastic index (PI) of the fines, and density. Waterbound macadams are less susceptible to water than engineered crushed-stone base materials and are therefore preferred to be used in the wetter regions of the country.



**Figure 1.6:** Generalised structural pavement behaviour characteristics - Cemented-subbase modular behaviour (a); Cemented-subbase indicators (b)

## (ii) Hot mix asphalt base pavements

In hot mix asphalt (HMA) base pavements, both permanent deformation (or rutting) and fatigue cracking are possible. Two types of subbase are recommended, namely either an untreated granular subbase or a weakly stabilised cemented subbase. Rutting may originate in either the bituminous or the untreated layers, or in both. This is illustrated in Figure 1.5(b). If the subbase is cemented, there is a probability that shrinkage or thermal cracking will reflect through the base to the surfacing, especially if the bituminous layer is less than 150 mm thick or if the subbase

is excessively stabilised ( $\sim >5\%$  cement). Maintenance usually consists of a surface treatment to provide better skid resistance and to seal small cracks, an asphalt overlay in cases where riding quality needs to be restored and when it is necessary to prolong the fatigue life of the base, or recycling of the base when further overlays are no longer adequate.

### (iii) Bitumen stabilised base pavements

Although the bituminous binders in emulsion and foam-treated materials are viscous, the material is stiff and brittle, much like a cement-treated material after curing. The initial field stiffness values of these materials may vary between 800 and 2 000 MPa, depending on the bitumen binder content and parent material quality. These values will gradually decrease with increasing traffic loading in these layers to values typical for granular materials roughly between 150 and 500 MPa.

Field performance of pavements with emulsion- and foam-treated base layers indicates that they are not as sensitive to overloading as a pavement with a cement-treated base, and do not pump fines from the subbase during wet conditions under traffic, which is the first mechanism and indication of the formation of potholes in road pavements.

### (iv) Cemented base pavements

In these pavements, most of the traffic stresses are absorbed by the cemented layers and a little by the subgrade. It is likely that some block cracking will be evident very early in the life of the cemented bases; this is caused by the mechanism of drying shrinkage and by thermal stresses in the cemented layers. Traffic-induced cracking will cause the blocks to break up into relatively smaller ones. These cracks may propagate through to the surfacing. The ingress of water through the surface cracks may cause the blocks to rock under traffic, resulting in the pumping of fines from the lower layers. Rutting or roughness will generally be low up to this stage, but is likely to accelerate as the extent of the cracking increases, especially in wet conditions. See Figure 1.7(a).

Pavements consisting of cemented bases on granular subbases are very sensitive to overloading and to ingress of moisture through the cracks. When both the base and the subbase are cemented, the pavement will be less sensitive to traffic overloading and moisture. The latter type of pavement is generally used. The shrinkage cracks form early in the life of the pavement and should be rehabilitated by proper inspection and surface sealing. Once traffic-load-associated cracking has become extensive, rehabilitation involves either the reprocessing (recycling) of the asphalt base, or the application of a substantial bituminous or granular overlay.

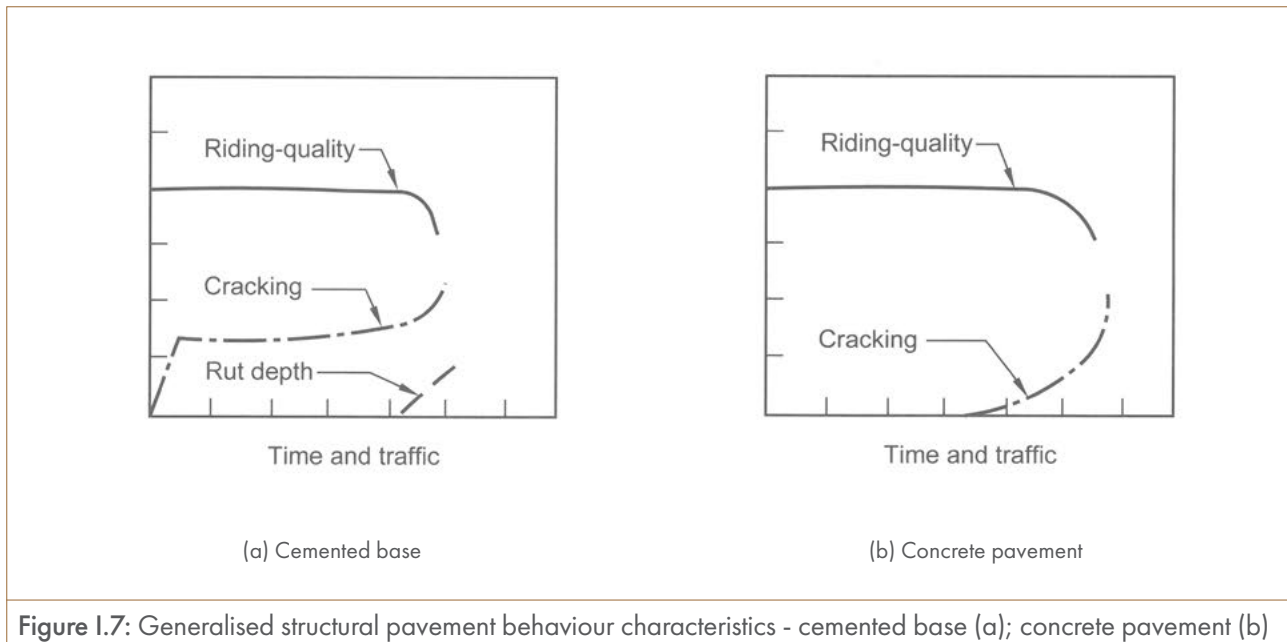


Figure 1.7: Generalised structural pavement behaviour characteristics - cemented base (a); concrete pavement (b)

#### 1.4.2.4.2 Rigid pavements

In concrete (rigid) pavements, most of the traffic loading is carried by the rigid concrete slab and little stress is transferred through to the subgrade. The cemented subbase provides a uniform foundation and limits pumping of subbase and subgrade fine materials. Through the use of tied shoulders, most of the distress stemming from the edge of the pavement can be eliminated and slab thickness can also be reduced. Distress of the pavement usually appears first as spalling near the joints, and then may progress to cracking in the wheel paths. Once distress becomes evident, deterioration is usually rapid. See Figure 1.7(b). Maintenance consists of patching, joint repair, crack repair, under-sealing, grinding, or thin concrete or bituminous overlays. In cases of severe distress, thick concrete, bituminous or granular overlays will be used, or the concrete may be recycled.

#### 1.4.2.4.3 Semi-rigid pavements

Concrete blocks (semi-rigid pavements) spread concentrated loads over a wide area of earthworks layers. This means that blocks do not merely act as a wearing course, but also as a load-bearing course. The blocks have significant structural capacity when properly installed. The blocks themselves are generally hardly affected by high surface stresses. However, wear or abrasion of the blocks has been observed in some applications. Under traffic, concrete block pavements tend to stiffen, provided the blocks are "locked" in between kerbs or concrete beams on the edges to prevent widening of the joints between the blocks. This leads to the pavements achieving a quasi-equilibrium or 'lockup' condition, beyond which no further deformation occurs. Many types of interlocking and non-interlocking segmental blocks are used in a wide variety of applications, which range from footpaths to driveways to heavily loaded industrial stacking and servicing yards. The popularity of paving blocks is increasing due to a number of factors: the blocks are manufactured from local materials; they can either provide a labour-intensive operation or can be manufactured and laid by machine; they are aesthetically acceptable in a wide range of applications; and they are versatile as they have some of the advantages of both flexible and concrete pavements.

A small plate vibrator is usually used to bed the blocks into a sand bedding of approximately 20 mm thick and also to compact jointing sand between individual blocks. The selection of the right type of sand for these purposes is important, since a non-plastic material serves best as bedding, while some plastic content in the sand is required to fill the joints between blocks.

Properly laid block pavements are adequately waterproofed and ingress of large quantities of water into foundations does not occur. The joints between the blocks on steep gradients may form the drainage paths for rainwater. In such cases the pattern of the blocks is an important consideration. In most cases a herringbone pattern is best for use on steep gradients and for industrial paving. The current recommended minimum strength for structural use is given as a wet compressive strength of not less than 25 MPa.

Block pavements require the paved area to be “contained” either by kerbs or by other means of stopping lateral spread of the block. This is a requirement for both interlocking and non-interlocking shapes. Lateral movements are induced by trafficking and these movements cause breaks in the jointing sand. The associated opening-up of the block pavement makes it more susceptible to the ingress of surface water. In heavily loaded areas, interlocking shapes have advantages over non-interlocking shapes, especially if heavy vehicles with a slewing action are involved.

It is usually recommended that joints should be 2 to 5 mm wide. Geometric design should follow practices for other pavements. Variable street widths, curves and junctions do not present problems in practice, since the blocks are small and can easily be cut and placed to suit the geometry of the pavement. The minimum cross-fall for block pavements should be 1%. For wide areas of industrial paving, special care should be taken to ensure that the cross-fall of the surface is adequate for effective drainage. Cambered cross-sections could also be acceptable under certain conditions.

An advantage of the blocks is that they can be re-used. They can be lifted if repairs have to be done to failed areas of subbase or if services have to be installed and can be re-laid afterwards. As far as the design of segmental block pavements is concerned, this re-use of the blocks has no disadvantages. Little maintenance work is required with segmental block paving. Maintenance involves the treatment of weeds and the correcting of surface levels if the initial construction has been poor. The correction of surface levels is done by removing the area of blocks affected, levelling the subbase, compacting the subbase (often with hand hammers) and replacing the blocks.

#### 1.4.2.4.4 Pavement type selection per road category

Certain road pavement types may not be suitable for some road categories or traffic classes. Table I.15 gives the recommended pavement types for road categories and traffic classes. The availability of material and costs will also influence the selection of pavement type.

**Table I.15:** Recommended pavement types for road category and traffic class (modified after SAPEM)

Pavement type		Functional class/category & Typical traffic loading class						Reasons for exclusion
		U2-B, U3-B			U4-C, U5-D, U6-E			
Base	Subbase	ES10	ES3	ES1	ES3	ES1	< ES0.3	
Concrete	Granular	Yes	Yes	Yes	Yes	Yes	Yes	Granular subbases prone to erosion at joints and cracks
	Cemented	Yes	Yes	Yes	Yes	Yes	Yes	
Granular	Granular	Yes	Yes	Yes	Yes	Yes	Yes	Uncertain behaviour for high traffic demand
	Cemented	Yes	Yes	Yes	Yes	Yes	Yes	
Hot mix asphalt	Granular	Yes	Yes	No	Yes	No	No	Cost effectiveness
	Cemented	Yes	Yes	No	Yes	No	No	
Cemented	Granular	No	No	No	No	No	Yes	Cracking, crushing, rocking blocks and pumping
	Cemented	No	Yes	Yes	Yes	Yes	Yes	
Bitumen stabilised	Granular	Yes	Yes	Yes	Yes	Yes	Yes	Cost effectiveness, permanent deformation

According to NTR 1 the surfaces along sidewalks are required to be smooth, stable and slip resistant. It is recommended that, along NMT routes, no bevel edge pavers, cobble stones or uneven floor surface finishes, with raised or chamfered edges, be used. All pavers should be installed to be level with an even surface, where no steps exceeding 5 mm occur. Preferred surface finishes include wire-cut clay pavers, wood-floated concrete and tarmacadam.

#### 1.4.2.5 Environmental considerations for pavement design

##### 1.4.2.5.1 Material depth

The term “material depth” is used to denote the depth below the finished level of the road/street up to which soil characteristics have a significant effect on pavement behaviour. Above this depth, the pavement strength must be sufficient for the traffic-imposed stresses. Below this depth, the traffic-imposed stress conditions are assumed to have dissipated and the material quality exceeds strength requirements. The moisture condition above the material depth has a major influence on the material strength, and needs to be controlled by providing adequate surface and subsurface drainage. The material depths recommended for the different road categories for flexible and concrete block pavements are shown in Table I.16. Material depths are normally not considered for concrete pavements, provided that the support is consistent.

**Table I.16:** Material depths to be used for determining the design California Bearing Ratio (CBR) of the subgrades

Functional class/category	Material depth (mm)
U2-B, U3-B	800 – 1 000
U4-C	800
U5-D, U6-E	700



**1.4.2.5.2 Subgrade strength and delineation**

A key pavement design principle is that the subgrade should provide an adequate foundation for the pavement layers. The classification of the subgrade material is based on the soaked California Bearing Ratio (CBR) at representative density. A minimum CBR of 15% is generally required for flexible and concrete block pavements.

Any road/street development should be subdivided into significant subgrade areas. However, if the delineation is too fine, it could lead to confusion during construction. The preliminary soil survey should delineate subgrade design units on the basis of geology, pedology, topography and drainage conditions – or major soil boundaries – on site so that an appropriate design CBR for each unit can be defined. A distinction should be made between localised good or poor soils and more general subgrade areas. Localised soils should be treated separately from the rest of the pavement factors. Normally, localised poor soils will be removed and replaced by suitable material. If the strength of a particular subgrade section does not meet the minimum strength requirement, layers of increasing quality are imported to ensure that the minimum strength requirement is achieved. For construction purposes, the design subgrade CBR is classified into four classes (see Table I.17) along with actions to be taken during the construction of pavement foundation. Special measures are necessary if a material with a CBR of less than 3% is encountered within the material depth. These measures include stabilisation (chemical or mechanical), modification (chemical), or the removal or addition of extra cover. After the material has been treated, it will be classified under one of the remaining three subgrade groups. The following should be considered:

- When the road/street is on fill, the best information available on the local materials that are likely to be used should be accessed. The material should be controlled to at least the material depth.
- The design CBR of the subgrade in a cutting should be the 10 percentile CBR encountered within the material depth.

<b>Subgrade (SG) class</b>	<b>CBR (%)<sup>*</sup> of delineated subgrade sections</b>	<b>Action<sup>***</sup></b>
<b>SG1</b>	>15	In-situ subgrade of a G7 standard and of sufficient strength to support structural layers <ul style="list-style-type: none"> <li>• Rip and recompact to 93% of modified AASHTO density</li> </ul>
<b>SG2</b>	7 to 15	In-situ subgrade of a G9 standard <ul style="list-style-type: none"> <li>• Rip and recompact in situ material to 93% of modified AASHTO density</li> <li>• Import a 150 mm thick layer of G7 standard material</li> </ul>
<b>SG3</b>	3 to 7	In-situ subgrade of a G10 standard <ul style="list-style-type: none"> <li>• Rip and recompact in situ material to 93% of modified AASHTO density</li> <li>• Import a 150 mm thick layer of G9 standard material</li> <li>• Import a second 150 mm thick layer of G7 standard material</li> </ul>
<b>SG4</b>	<3 <sup>**</sup>	Do one of the following: <ul style="list-style-type: none"> <li>• Chemical/mechanical stabilisation</li> <li>• Remove and import new material</li> <li>• Add additional cover to place poor quality in situ material below material depth</li> </ul>

\* CBR at 93% modified AASHTO density

\*\* Special treatment required

\*\*\* Material codes G7 and compaction standards from TRH4 (1996) and TRH14 (1987)



For rigid concrete pavements, slab support influences the performance. It is more important to have a uniform slab support than a strong, but variable, support. A strong foundation support is not necessarily required, because of the high stiffness and therefore the good load-spreading ability of concrete.

#### 1.4.2.6 Structural design

The purpose of structural pavement design methods is to provide a method for the unbiased estimate of the structural capacity of alternative design options, to select the most economical option that ensures the traffic demand will be met. A number of design methods of varying complexity are available.

The commonly used methods for the estimation of the structural capacity of flexible, rigid and semi-rigid pavements are discussed below. Other documents, including SANRAL guides, should also be consulted for more details on the methods discussed. The limitations of a particular design method should always be taken into consideration. Most of the purely empirical design methods were developed from data where the design-bearing capacity did not exceed 10 to 12 million standard 80 kN axles. The purely empirical design methods are also limited in their application to conditions similar to those for which they were developed.

It must also be kept in mind that, although these design methods will predict a certain bearing capacity for a pavement structure, there are many factors that will influence the actual bearing capacity of the pavement, and the predicted value should be regarded only as an estimate. It is therefore better to apply various design methods, with each method predicting a somewhat different bearing capacity. This will assist the designer to develop a feeling for the range of bearing capacity for the pavement.

##### 1.4.2.6.1 The design of flexible pavements

###### (i) The "Catalogue" design method

TRH4 (1996) contains catalogues of candidate road pavement structures for different combinations of pavement type, road category and design structural capacity for flexible pavements. The catalogues contained in TRH4 have been tried and tested, and should be used to benchmark any initial pavement structural design. However, this does not exclude the use of any of the other proven design methods. Consult TRH4 for a catalogue of pavement designs. For the different road materials used in TRH4, consult TRH 14 (1987).

###### (ii) The Dynamic Cone Penetrometer method

The Dynamic Cone Penetrometer (DCP) method incorporates the concept of a structurally balanced pavement structure in the design procedure. If used properly, designs generated by this method should have a well-balanced strength profile with depth, meaning that there will be a smooth decrease in material strength with depth. Such balanced pavements are normally not very sensitive to overloading. Some knowledge of typical DCP penetration rates for road-building material is required to apply this method.

The DCP method is suitable for the design of light pavement structures with mostly unbound granular or lightly cemented layers, for new and rehabilitation pavement design. DCP design may be done by hand, but if DCP data needs to be analysed, appropriate software has to be used.

### (iii) The California Bearing Ratio cover design method

The California Bearing Ratio (CBR) method is based on the principle that the subgrade should be protected from the traffic loading by providing enough cover of sufficient strength. CBR-cover design charts were developed for different subgrade CBR strengths and traffic loadings. The applicability of this method should be evaluated critically before it is applied to local environmental and traffic conditions.

### (iv) The AASHTO Guide for Design of Pavement Structures

The *AASHTO Guide for Design of Pavement Structures*<sup>20</sup> provides the designer with a comprehensive set of procedures for new and rehabilitation design and provides a good background to pavement design. This method must be applied with caution for a number of reasons, including the following: The method is an empirical method, based on performance data collected almost 50 years ago; the subgrade and pavement materials, as well as the pavement structures, used in the AASHTO road test are foreign to South Africa; the method is in imperial units and conversion to metric units must be done correctly.

Although some software based on the procedures in the AASHTO design guide is commercially available, the procedure may also be applied manually.

### (v) South African Mechanistic Design Method

The South African Mechanistic Design Method (SAMDM) contains ranges of typical resilient modulus and material strength input values and was published for South African road-building materials. Damage models were calibrated for each of the main material groups used in South African road construction.

This SAMDM may be used very effectively for new and rehabilitation design. Some knowledge of the elastic properties of materials as used by the method is required, and experience in this regard is recommended. In the case of rehabilitation design or upgrading, field tests such as the DCP and Falling Weight Deflectometer (FWD) may be used to determine the input parameters for the existing structure.

Access to appropriate computer software is essential for effective use of this method, as well as for analysing DCP and FWD data.

#### 1.4.2.6.2 The design of rigid pavements

The principle of pavement balance does not apply to concrete pavements. The concrete layer thus carries the majority of the applied load, and the distribution of stresses to the lower layers is low. The long-term behaviour of concrete pavements is different for plain jointed, jointed reinforced, or continuously reinforced concrete pavements (CRCPs).



A mechanistic-empirical design method for concrete pavements is implemented in the software package referred to as cncPAVE. cncPAVE is based on the principles used in the 1995 Manual M10 Concrete Pavement Design and Construction, which was developed from the AASHTO method for concrete pavements. cncPAVE was developed as a mechanistic software design tool to design cost-effective rigid concrete pavements.

cncPAVE can quickly assess a design, evaluate its quality and thus facilitate competent decision making. The approach is based on the evaluation of consequences. The consequences of a certain pavement design are expressed in terms of decision variables, namely shattered concrete surface, pumping concrete surface, faulting in the concrete pavement (in the case of plain and dowelled concrete), crack spacing (in the case of continuously reinforced concrete), and life cost of the pavement, in R/m<sup>2</sup>. cncPAVE treats input variables and all output items as random variables. cncPAVE is available from the website of The Concrete Institute.<sup>21</sup>

#### 1.4.2.6.3 The design of semi-rigid pavements

The methods for the design of concrete block pavements can be grouped into four categories: the catalogue design method; equivalent thickness concept; research-based design methods; and mechanistic design methods.

For more detailed information on methods available for the design of concrete block pavement, consult *Concrete Block Paving - Book 2: Design Aspects*.<sup>22</sup>

#### 1.4.2.6.4 The design of unpaved roads

Unlike sealed roads, where the application of bituminous surfacing results in a semi-permanent structure (for up to 20 years) in which deformation or failure is costly to repair, unsealed roads are far more forgiving. Routine maintenance is essential and localised problems are rectified relatively easily. The main objectives when designing unsealed roads are to prevent excessive subgrade strain, and to provide an all-weather, dust-free surface with acceptable riding quality. These two objectives are achieved by providing an adequate thickness of suitable material, constructed to a suitable quality. A simple design technique covering gravelling thickness and associated materials has been developed for South Africa and is summarised in *TRH 14: Guidelines for road construction materials*, and *TRH 20: The structural design, construction and maintenance of unpaved roads*.

### 1.4.2.7 Practical considerations

This section discusses some practical considerations regarding road pavements, namely drainage, compaction, pavement cross-sections, road/street levels, and kerbs and channels.

#### 1.4.2.7.1 Drainage

Effective drainage is essential for good pavement performance, hence adequate surface and subsurface drainage should be provided. Drainage design is an integral part of stormwater management and is addressed in **Section L** (Stormwater). The *Drainage Manual*<sup>23</sup> published by SANRAL provides useful guidelines for drainage design. The following should be considered:

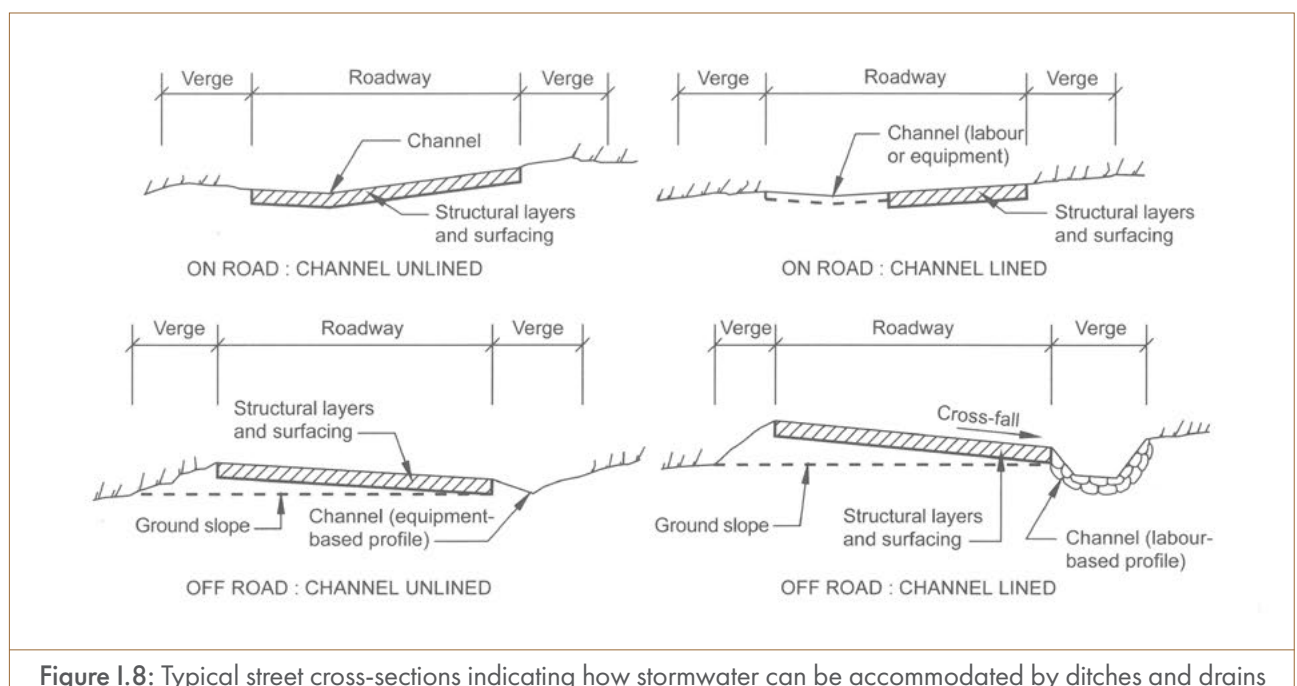
- Attention needs to be paid to subsurface drainage. Effective drainage should be provided to at least the material depth.
- The use of permeable pavements such as porous asphalt has the benefit of improving surface drainage.
- Unpaved roads/streets require side drainage channels that are lower than the street level to ensure that water is drained off the street into the side channels, culverts or pipes.

The longitudinal gradient of a channel and the material used determine the amount of scouring or erosion of such channels. Table I.18 provides the scour velocities for various materials and guidance on the need to line or pave channels.

Material	Allowable velocity (m/s)
Fine sand	0.6
Loam	0.9
Clay	1.2
Gravel	1.5
Soft shale	1.8
Hard shale	2.4
Hard rock	4.5

Erosion control is very important to increase the life of road pavements. Control measures should be provided where necessary, especially for tertiary ways. Stormwater must be accommodated by ditches and drains on the sides of the tertiary ways. In Figure I.8, typical detail is given of such ditches and drains. When low points are reached, drifts and dished drains can be used to give preference to the flow of water without major structural requirements. Erosion protection on the approaches must be provided for. Details of typical drifts and dish drains are shown in Figure I.9 to Figure I.14.

Tertiary ways would normally be constructed from the in-situ material. The use of vegetation to prevent erosion is recommended and can be achieved by various means. These should, however, be regularly maintained to avoid a build-up of grass and silt.



**Figure I.8:** Typical street cross-sections indicating how stormwater can be accommodated by ditches and drains

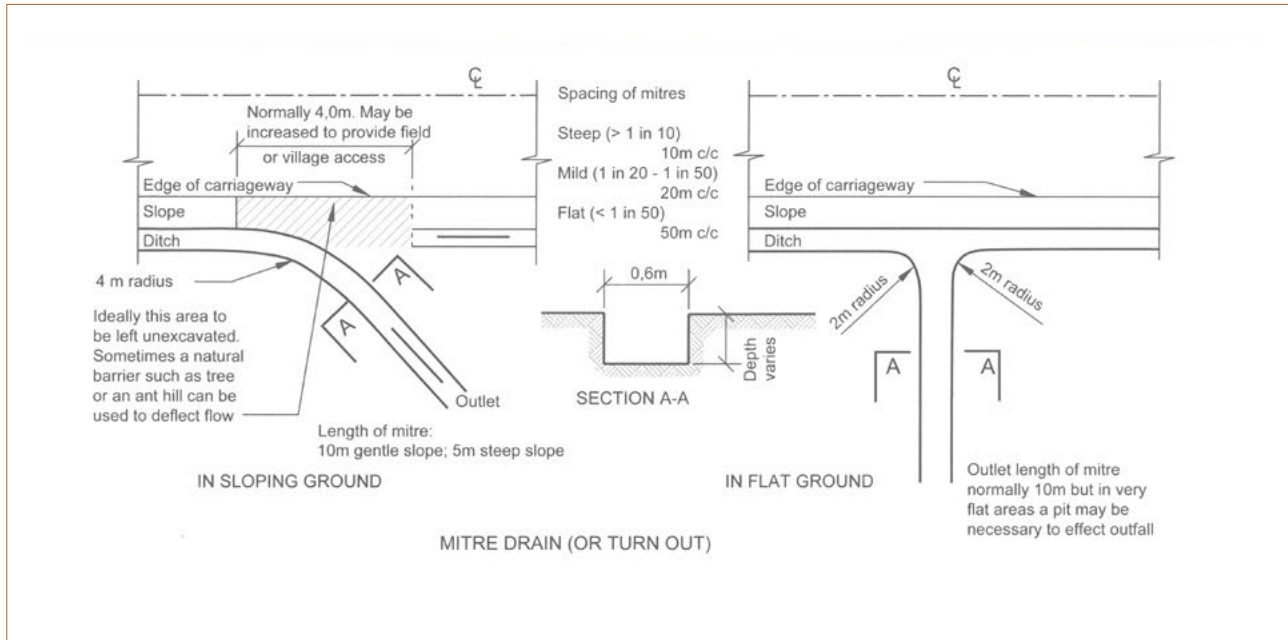


Figure I.9: Tertiary ways: ditches and drains - mitre drain

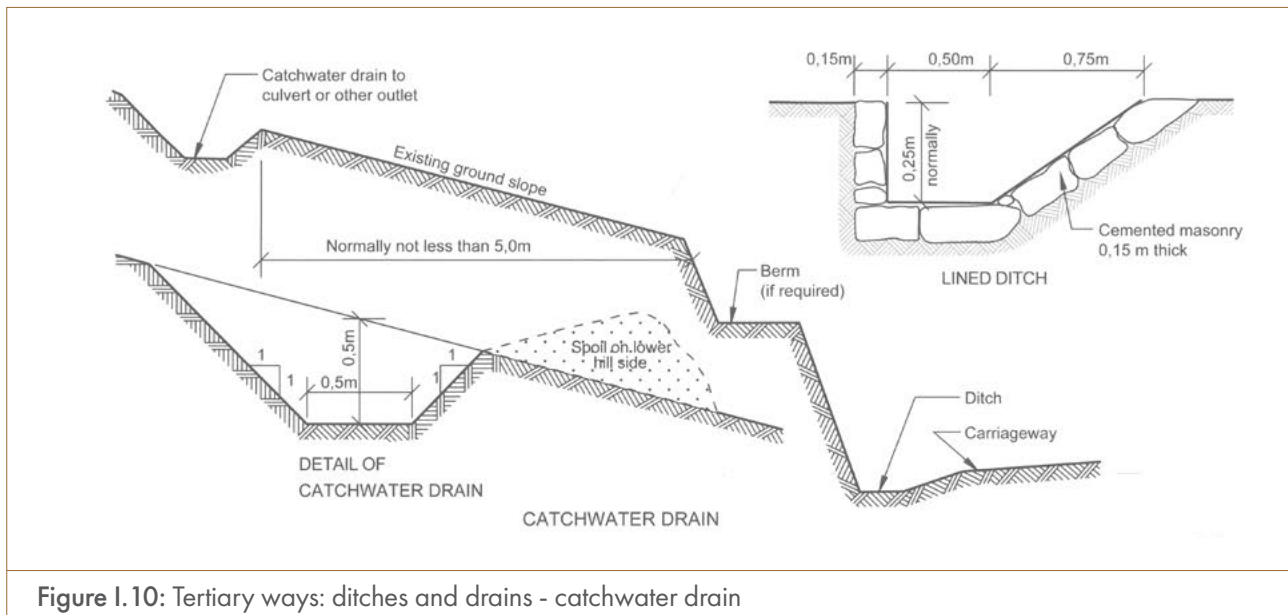


Figure I.10: Tertiary ways: ditches and drains - catchwater drain

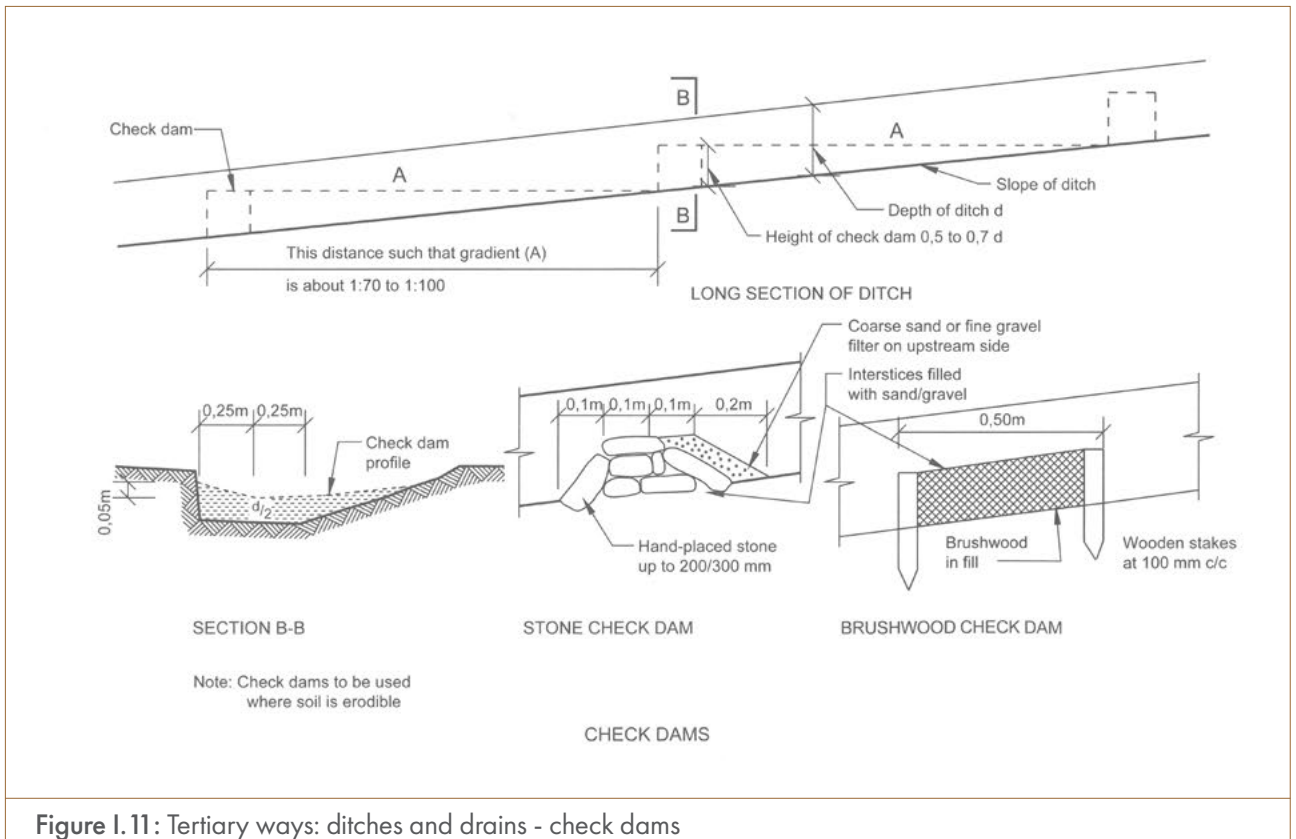
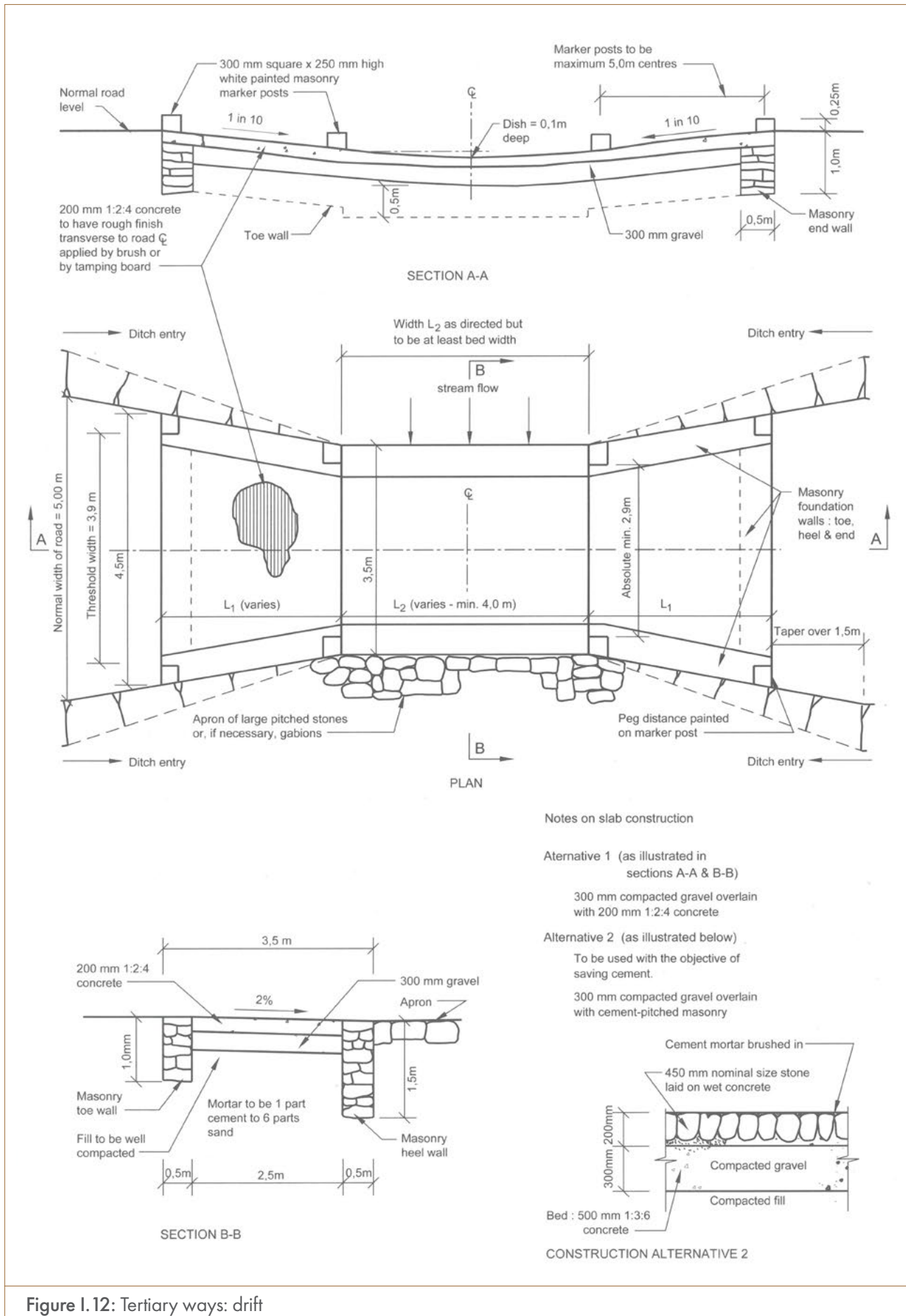


Figure 1.11: Tertiary ways: ditches and drains - check dams



Notes on slab construction

Alternative 1 (as illustrated in sections A-A & B-B)

300 mm compacted gravel overlain with 200 mm 1:2:4 concrete

Alternative 2 (as illustrated below)

To be used with the objective of saving cement.

300 mm compacted gravel overlain with cement-pitched masonry

Figure I.12: Tertiary ways: drift



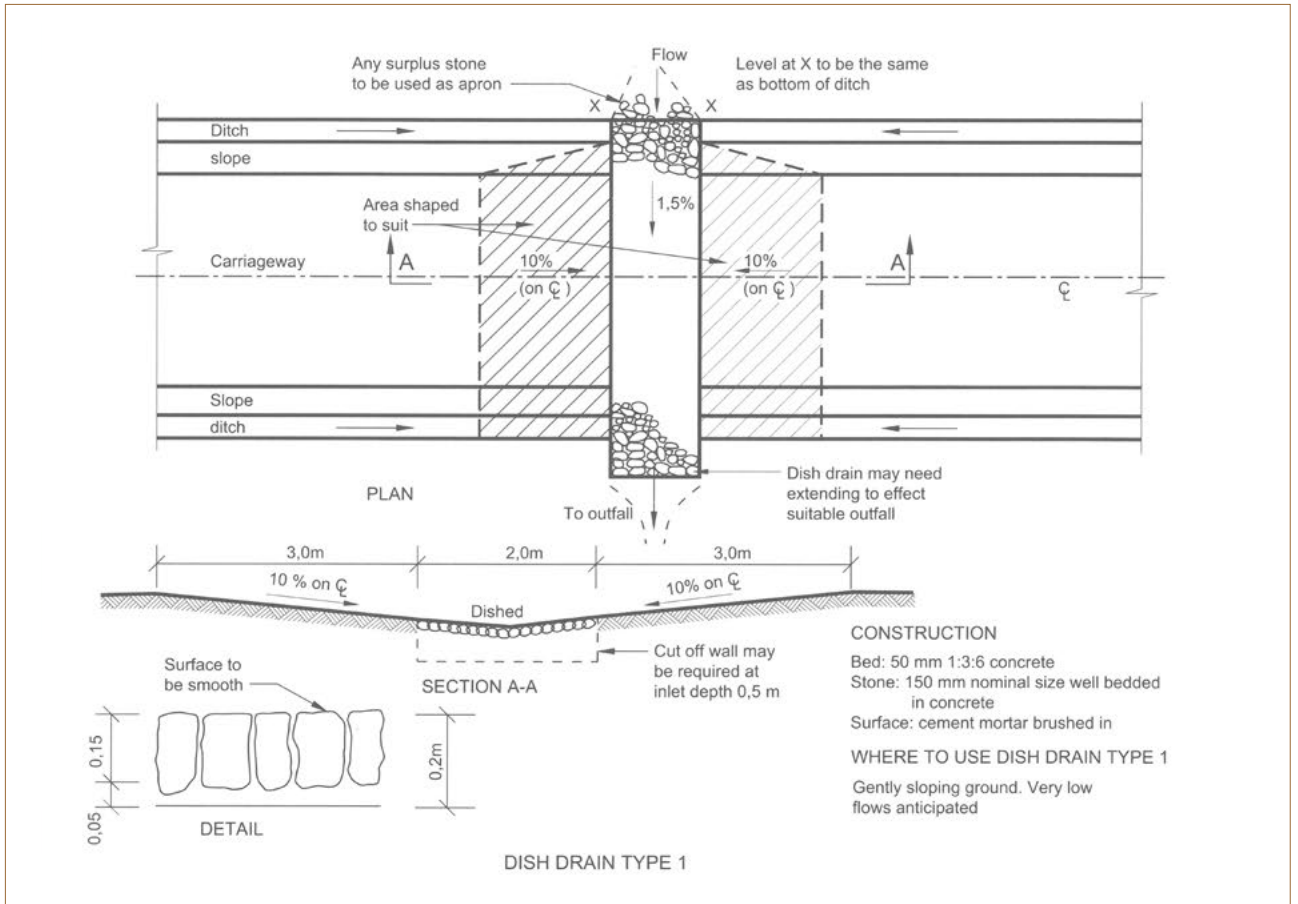


Figure I.13: Tertiary ways: dish drains - type 1

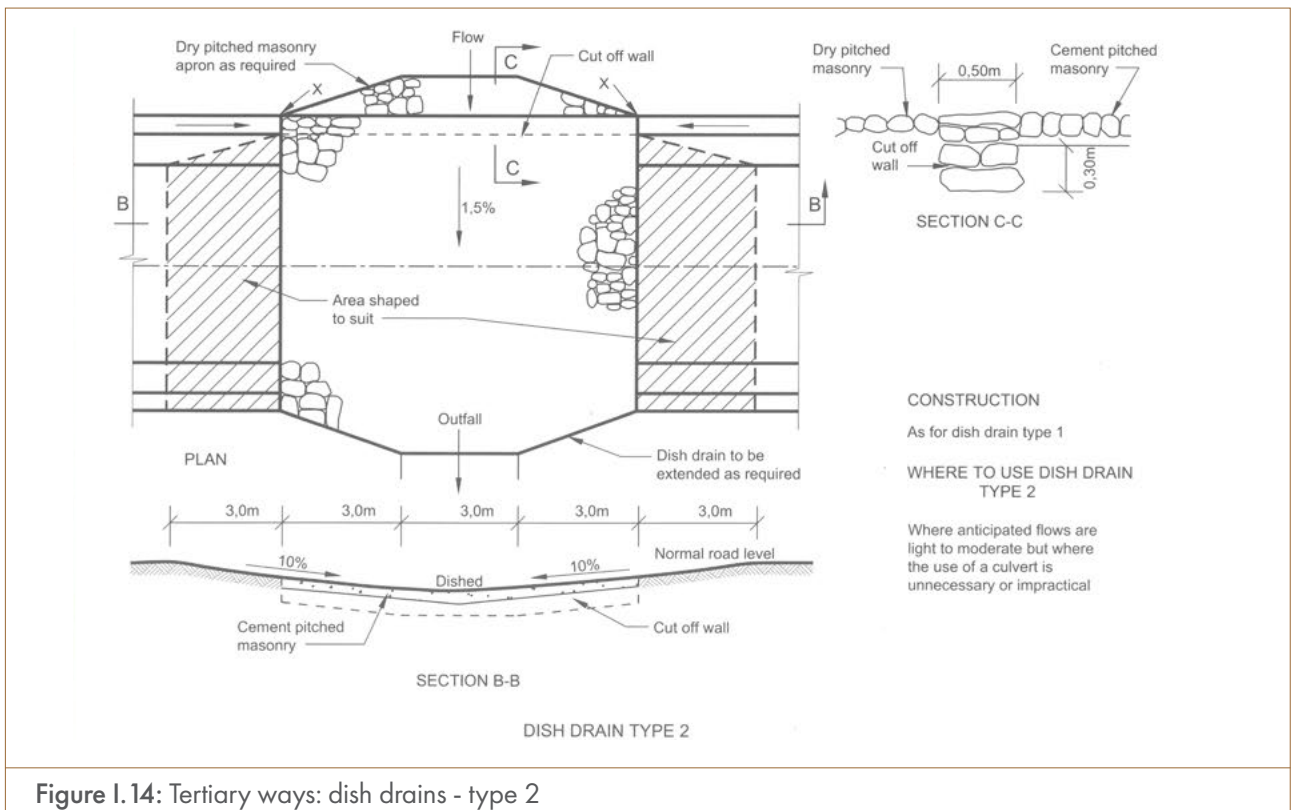


Figure I.14: Tertiary ways: dish drains - type 2

**1.4.2.7.2 Compaction of road layers**

The design procedures assume that the specified material properties obtained from a certified laboratory are satisfied in the field. Insufficient compaction may result in field densities below the minimum required. In such cases, the strength of the material is not fully utilised, and densification or failure may occur under traffic. The following should be considered:

- Compaction problems may result from material grading deficiencies or poor construction practices.
- Blending of material from different sources to improve the grading and compaction potential of the material may be better than trying to achieve density with excessive rolling.
- When compacting a layer, the support layer needs sufficient support to act as an anvil, otherwise the compaction energy is transmitted and lost through the pavement structure.
- The use of impact rollers can improve the strength and support from the subgrade substantially. Hand-held rollers may be inadequate to achieve the required density.

Table I.19 gives the minimum compaction standards required for various layers of the pavement structure. For detailed compaction standards for various material, other relevant documents such as TRH 14 (1985) and COTO should be consulted.

**Table I.19:** Compaction requirements for the construction of granular and cemented pavement layers (and reinstatement of pavement layers)

Pavement layer/Material		Compacted density
Surfacing	Asphalt	93% to 94% MVD
Base	Crushed stone G1	86% to 88% AD
	Crushed stone G2	100% to 102% MDD
	Crushed stone G3	98% to 100% MDD
	Waterbound macadam	86% to 90% AD
	Natural gravel G4	86% to 88% MDD
	Cemented (C3/C4)	97% to 98% MDD
	BSM	97% to 100% MDD
	Asphalt	96% MVD
Subbase	Natural gravel	95% to 97% MDD
	Cemented (C3/C4)	95% to 96% MDD
Selected subgrade	Soils and gravel	93% to 95% MDD
Subgrade	Soils and gravel	90% MDD
Fill (cohesionless sand)		90% MDD

Note: MVD = Maximum Voidless Density (see SABITA Manual 35/TRH 8); AD = Apparent Density; MDD = Maximum Dry Density.

**1.4.2.7.3 Pavement subgrade**

Generally, it is preferable to keep the design of the whole street the same, with no change in layer thickness across the road/street. However, the pavement cross-section may vary if problematic subgrade conditions (i.e. expansive clay) are encountered, hence requiring special treatment. The main subgrade problems that have to be considered include the extreme changes in volume that occur in some soils as a result of moisture changes (e.g. in

expansive soils and soils with collapsible structures); flaws in structural support (e.g. sinkholes, mining subsidence and slope instability); the non-uniform support that results from wide variations in soil types or states; the presence of soluble salts which, under favourable conditions, may migrate upwards and cause cracking, blistering or loss of bond of the surfacing; disintegration of cemented bases and loss of density of untreated bases; and the excessive deflection and rebound of highly resilient soils during and after the passage of a load (e.g. in ash, micaceous and diatomaceous soils).

#### 1.4.2.7.4 Road/Street levels

One of the primary functions of a road/street is to provide access to dwellings and other land uses. To optimise accessibility, the design of road/street levels should consider that road/street levels place some restrictions on rehabilitation and create special moisture/drainage conditions. In some cases, rehabilitation in the form of an overlay may cause a problem, particularly with respect to the level of kerbs and channels, camber and overhead clearances. In these cases, strong consideration should be given to bottom-heavy designs (i.e. designs with a cemented subbase and possibly a cemented base), which would mainly require the same maintenance as thin surfacings and little structural maintenance during the analysis period.

#### 1.4.2.7.5 Service trenches

Trenches excavated in the pavement to provide essential services (electricity, water, telephone, etc.) are frequently a source of weakness in the structural design. This is a result of either inadequate compaction during reinstatement, or saturation of the backfill material. Service trenches can also be the focal points of drainage problems. To minimise problems related to service trenches, compaction must achieve at least the minimum densities specified for various materials. These densities are readily achieved when granular materials are used, but it becomes more difficult when natural materials are used, particularly in the case of excavated clays. When dealing with clay subgrades it is recommended to, if economically feasible, use a moderate-quality granular material as a trench backfill in preference to the excavated clay. The provision of a stabilised "cap" over the backfill may be considered to eliminate settlement as far as possible. Care must be taken not to over-stabilise (i.e. produce a concrete), as this results in significant problems with adhesion of the surfacing and differential deflections causing failure around the particles.

Settlement in the trench, giving rise to standing water and possibly to cracking of the surface, will permit the ingress of moisture into the pavement. Fractured water, sewerage or stormwater pipes lead to saturation in the subgrade and possibly in the pavement layers as well. Alternatively, a trench backfilled with granular material may even act as a subsurface drain, but then provision for discharge must be made. It is, however, generally recommended that the permeability of the backfill material should be as close as possible to that of the existing layers in order to retain a uniform moisture flow regime within the pavement structure.

#### 1.4.2.7.6 Kerbs and channels

Kerbs and channels are important to prevent edge erosion and to confine stormwater to the street surface. Consideration should be given to the type and method of construction of kerbs when deciding on a layer thickness for the base. It is common practice to construct kerbs upon the (upper) subbase layer to provide edge restraint for a granular base. This restraint will help to provide the specified density and strength. Care must be taken to ensure that this type of structure does not "box" moisture into the base course material. In the case of kerbing with a fixed size (i.e. precast kerbing or kerbing with fixed shutters cast in situ), it may be advantageous to design the base thickness

to conform with the kerb size (e.g. if the design calls for a 30 mm AG with a 125 mm G4 underlay, and the gutter face is 160 mm, rather use a 130 mm G4).

#### 1.4.2.8 Cost analysis

This section discusses how doing a cost analysis can assist the designer in selecting the optimal pavement type for a development project. The selection of the final pavement design is based on the life cycle assessment of a number of alternative designs. The purpose of the structural design method is therefore not the selection of the final design, but to provide the designer with a number of design alternatives with the required structural capacity. It should, however, be noted that a cost analysis may not take all the necessary factors into account and it should therefore not override all other considerations. Financial affordability should also be considered. The availability of funds for the initial construction, and the availability of maintenance funds must be considered, as these could influence the final design decision. The designer should consult TRH4, TRH12 and other relevant guideline documents for detailed information on cost analysis.

The main economic factors that determine the cost of a facility are the analysis period, the structural design period, the construction cost, the maintenance cost, the salvage value at the end of the analysis period and the real discount rate. The cost comparison of alternative pavement designs for a specific design case can be done using the Present Worth of Cost (PWOC), the Net Present Value (NPV) or the Internal Rate of Return (IRR) of the initial construction and anticipated maintenance and rehabilitation costs. The PWOC method is briefly discussed next.

##### 1.4.2.8.1 The Present Worth of Cost method

The PWOC method of cost analysis is recommended in this Guide, and should be used only to compare pavement structures in the same road/street category. This is because roads/streets in different categories are constructed to different standards and are expected to perform differently, with different terminal levels of service. The effect these differences have on street user costs is not taken into account directly. Although the economic principles presented in this document refer to flexible pavements, the same economic principles apply for concrete. A complete cost analysis should be done for functional classes/categories U2-B and U3-B roads/streets. For functional classes/categories U4-C to U6-E roads/streets, a comparison of the construction and maintenance costs will normally suffice. A difference in the economic indicator between two alternative designs of less than 10% is insignificant, and the designs are assumed to be equivalent in economic terms.

The total cost of a project over its life is the construction cost plus maintenance costs, minus the salvage value.

The present worth of costs can be calculated as follows:

$$PWOC = C + (M_1 (I + r)^{-x_1} + \dots + M_j (I + r)^{-x_j}) + \dots - S(I + r)^{-z} \quad \text{Eq 1.9}$$

Where:

$PWOC$  = present worth of cost

$C$  = present cost of initial construction

$M_j$  = cost of the  $j^{\text{th}}$  maintenance measure expressed in terms of current costs

$r$  = real discount rate

$x_j$  = number of years from the present to the  $j^{\text{th}}$  maintenance measure, within the analysis period

$z$  = analysis period

$S$  = salvage value of pavement at the end of the analysis period, expressed in terms of the present value

The construction cost should be estimated from current contract rates for similar projects. Maintenance costs should include the cost of maintaining adequate surfacing integrity (e.g. through resealing) and the cost of structural maintenance (e.g. the cost of an asphalt overlay). The salvage value of the pavement at the end of the analysis period can contribute to the next pavement. However, geometric factors such as minor improvements to the vertical and horizontal alignment and the possible relocation of drainage facilities make the estimation of the salvage value very difficult. The choice of analysis period and structural design period will influence the cost of a road/street. The final decision will not necessarily be based purely on economics, but will depend on the design strategy.

#### **(i) Construction costs**

The checklist of unit costs should be used to calculate the equivalent construction cost per square metre. Factors to be considered include the availability of natural or local commercial materials, their expected cost trends, the conservation of aggregates in certain areas, and practical aspects such as speed of construction and the need to foster the development of alternative pavement technologies. The potential for labour-based construction also needs to be considered. The cost of excavation should be included as certain pavement types will involve more excavation than others.

#### **(ii) Maintenance costs**

There is a relation between the type of pavement and the maintenance that might be required in the future. When different pavement types are compared on the basis of cost, these future maintenance costs should be included in the analysis to ensure that a sound comparison is made. This is critical for the planning of future maintenance activities.

It is important to consider that relaxations of material, drainage or pavement thickness standards will normally result in increased maintenance costs. The type of surfacing and water ingress into the pavement also plays an important part in the behaviour of some pavements. For this reason, planned maintenance of the surfacing is very important to ensure that these pavements perform satisfactorily. The service life of each type of surfacing will depend on the traffic and the type of base used.

Table 1.20 gives guidelines regarding the service life that can be expected from various surfacing types. These values may be used for a more detailed analysis of future maintenance costs. Typical maintenance measures that can be used for the purpose of cost analysis are measures to improve the condition of the surfacing and structural maintenance measures applied at the end of the structural design period. Maintenance will also be influenced by the level of distress of the pavement (moderate or severe).

Other road/street-user costs should also be considered, although no proper guide for their determination is readily available. The factors that determine overall road/street-user costs are: running costs (fuel, tyres, vehicle maintenance and depreciation), which are largely related to the street alignment, but also to the riding quality (PSI); accident costs, which are related to street alignment, skid resistance and riding quality; and delay costs, which are related to the maintenance measures applied and the traffic situation on the streets.

**Table I.20:** Suggested typical ranges of period of service of various surfacing types (modified from SAPEM)

Base type	Surfacing type (50 mm thickness)	Typical range of surfacing life (years) per functional class/category	
		U2-B, U3-B (ES1-ES10)	U4-C, U5-D, U6-E (ES0.003-ES3)
Granular	Bitumen sand or slurry seal	-	2-8
	Bitumen single surface treatment	6-10	8-11
	Bitumen double surface treatment	6-12	8-13
	Cape seal	10-12	8-18
	Continuously graded asphalt	-	-
	Gap-graded asphalt premix	-	-
Hot mix asphalt	Bitumen sand or slurry seal	-	2-8
	Bitumen single surface treatment	6-10	8-11
	Bitumen double surface treatment	6-12	8-13
	Cape seal	8-15	8-18
	Continuously graded asphalt	8-12	-
	Gap-graded asphalt premix	10-15	-
	Porous asphalt	10-15	-
Cemented	Bitumen sand or slurry seal	-	-
	Bitumen single surface treatment	4-7	5-8
	Bitumen double surface treatment	5-8	5-9
	Cape seal	5-10	5-11
	Continuously graded asphalt	5-10	-
	Gap-graded asphalt premix	6-12	-

- Surface type not normally used.

### (iii) Real discount rate

When a 'present-worth' analysis is done, a real discount rate must be selected to express future expenditure in terms of present-day values. This discount rate should correspond to the rate generally used in the public sector. For public projects, the discount rate used is published by the National Treasury. 8% is recommended for general use. A sensitivity analysis using rates of say 6, 8 and 10% could be carried out to determine the importance of the value of the discount rate.

### (iv) Salvage value

If the road/street is to remain in the same location, the existing pavement layers may have a salvage value but, if the road/street is to be abandoned at the end of the period, the salvage value could be small or zero. The assessment of the salvage value can be approached in a number of ways, depending on the method employed to rehabilitate or reconstruct the pavement.

The salvage values of individual layers of the pavement may differ considerably, from estimates as high as 75% to possibly as low as 10%. The residual salvage value of gravel and asphalt layers is generally high, whereas

that of concrete pavements can be high or low, depending on the condition of the pavement and the method of rehabilitation. The salvage value of the whole pavement would be the sum of the salvage values of the individual layers. In the absence of better information, a salvage value of 30% of initial construction cost is recommended.

(v) Optimisation of life cycle costs

The main purpose of the determination of a representative Level of Service (LoS) for a road/street (see **Section 1.4.2.1**) is to illustrate the associated life cycle costs. This identification can enable authorities and decision makers to select a design that will be affordable and upgradable. The costs associated with a typical road/street are made up of design and construction costs, maintenance costs and road/street-user costs. Construction costs are high for high LoS values and low for low LoS values. Maintenance costs, on the contrary, are low for high LoS values and high for low LoS values.

This concept is illustrated in Figure 1.15 with typical, present worth-of-cost versus LoS values. The combined cost curve has a typical minimum value between the highest and lowest LoS values. Street-user costs are low for high LoS streets and high for low LoS streets.

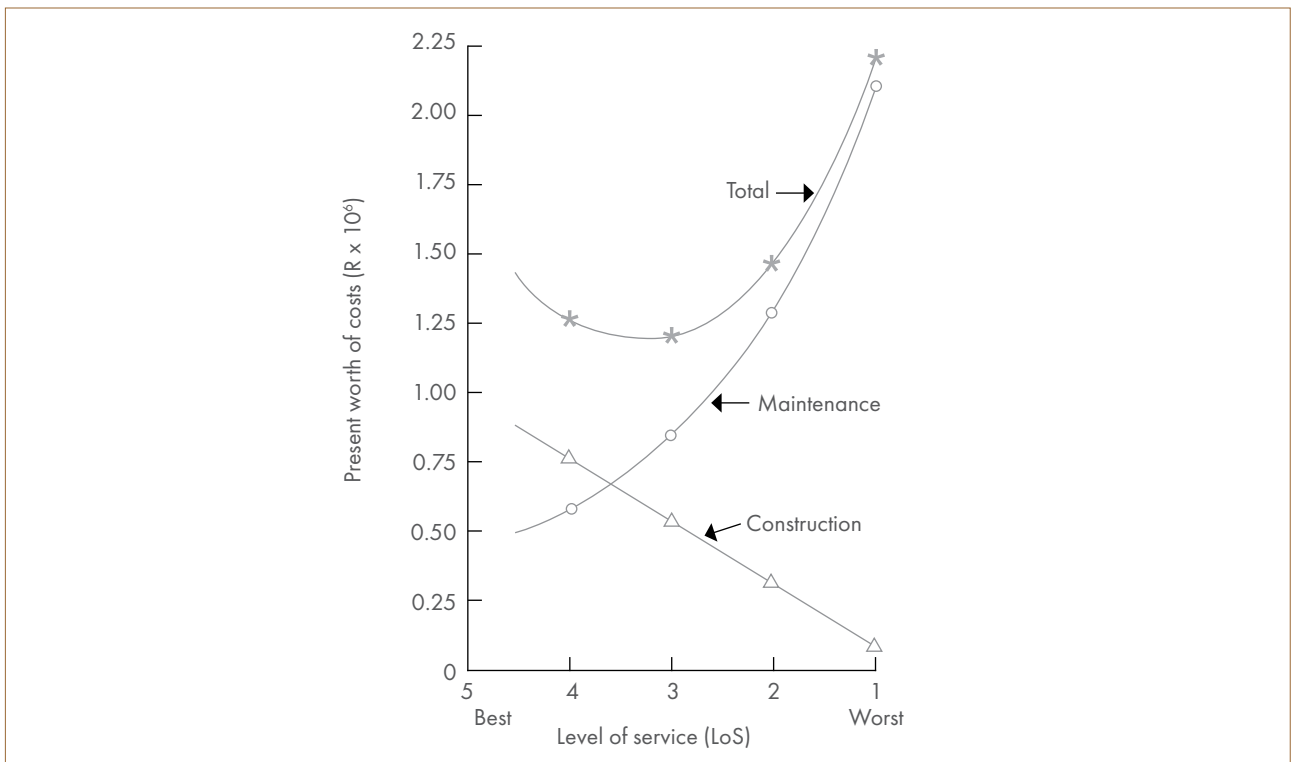


Figure 1.15: Typical cost versus level of service curve values

**1.4.2.9 Construction aspects**

**1.4.2.9.1 Staged construction and upgrading**

Two concepts that need to be considered as part of the life cycle strategy of a street during design are staged construction and upgrading. Although it is difficult to exactly define and completely separate these concepts, certain characteristics may be more typical of one than of the other.

The aim of staged construction is to spread some of the financial load from the initial construction period to some stage later during the life cycle of the facility. However, right from the onset, the aim is to provide a particular level of service for the duration of the structural design and analysis period of the facility. There may be slight changes in, for instance, the riding quality of the facility, but these should have a marginal influence on the operating cost of the facility to the user. On the other hand, upgrading will normally take place when the demands placed on an existing facility far exceed the level of service the facility can provide. The new facility has to provide a much higher level of service at a much reduced cost to the user. An example would be the upgrading from a gravel to a surfaced street.

Staged construction may be done by adding a final layer, or reworking an existing layer at some stage early during the structural design period of the facility. Most of the money spent during the initial construction of the facility should therefore be invested in the lower layers of the structure, providing a sound foundation to build on in the future.

During the upgrading process, maximum use should be made of the existing foundation provided by the pavement being upgraded. Dynamic Cone Penetrometer (DCP) and Falling Weight Deflectometer (FWD) surveys may provide the information required to incorporate the remaining strength of the existing pavement in the design of the future facility. Special equipment may also be used to maximise the bearing capacity of the in-situ material. With impact roller equipment, it is usually possible to compact the in-situ material to a depth of 600 mm at densities well above those normally specified for the subgrade and selected layers of a pavement, without excavating and replacing any material. This results in few layers or thinner layers being required in the pavement structure.

One of the problems that may be associated with staged construction is the limitation placed on street levels by the other services in the street reserve, particularly the stormwater drainage system. If a system of kerbs, gutters and stormwater pipes is used, it may not be possible to add an additional structural layer to the pavement system at a later stage. In such cases, consideration should be given to initially providing a subbase-quality gravel base, and to rework this layer at some early stage in the structural design period of the pavement by doing deep in-place recycling and stabilisation with cement, bitumen emulsion or a combination of the two. A second problem that requires consideration is the cost of repeated mobilisation on a project. The mobilisation of plant and resources for a light pavement structure in an urban area (usually of short length) is often a significant portion of the total cost.

In general, staged construction spreads the financial burden of construction and is economically more viable than initial full construction. The economics of each project must, however, be considered on merit. It must also be kept in mind that because some of the cost of construction is shifted a few years into the life cycle of a pavement, future budgets must allow for this cost plus inflation.

The details of upgrading from a gravel street to a surfaced street will depend largely on individual projects and will be determined by the bearing capacity of the material on the existing street. As already mentioned, the strength of the existing pavement should be optimally utilised in the new design and if material is imported to the gravel street, the possible utilisation of this material in a future upgrading to a paved street should be kept in mind. The cost analysis for upgrading from a gravel to a surfaced street must at least include the savings in vehicle-operating cost as part of the benefit to the street user. The cost of upgrading should be weighed against the benefits by means of a cost-benefit analysis, expressing the benefits as a ratio to the cost. Software is available for this type of analysis.

#### **1.4.2.9.2 Construction approaches**

Construction of streets within settlements has become a highly mechanised process but, over the past few years, the possibility of creating employment opportunities has led to greater use of labour-intensive technologies. Local people are often appointed as subcontractors to established contractors or as contractors for small projects.



These initiatives have not only contributed to local economic development and the transfer of skills, but have also contributed to the successful completion of construction projects by providing local knowledge and getting buy-in from local communities.

A choice between conventional construction (mechanised) and labour-intensive construction may have some impact on the selection of materials and the structural design of the pavement.

Conventional construction is suited to most new street construction assignments, perhaps with the exception of construction in confined areas. Advantages may include rapid mobilisation and completion, while disadvantages may include limited involvement of the local community.

In order to ensure the maximisation of job creation to the extent that it is economic and feasible, the terms of reference for technical consultants engaged to carry out feasibility studies should require the consultant to examine the appropriateness of designs that are inherently labour intensive; to report on the economic implications of using such designs; and to ultimately design a project based on designs and technology appropriate for construction that maximises labour-intensive methods.

Labour-intensive construction should strive to obtain the standards set for conventional construction. However, the design should ensure that the standards specified are appropriate. This necessitates a critical review of all specifications during the design stage.

All construction activities cannot always be executed by means of labour-intensive methods. This must be recognised in the design. Examples of activities demanding greater mechanisation are the following:

- Deep excavation (apart from safety considerations, material can only be thrown a certain height by shovel)
- Excavation and spreading of very coarse material
- In-situ mixing of stabilising material (cement or lime) effectively into coarse aggregates
- Application of tar (due to safety considerations)
- Compaction of thick layers or very large aggregates (e.g. rock fill) with small (pedestrian) rollers
- Mixing of high-strength concrete
- Excavation of medium to hard material
- Haulage by wheelbarrows over long distances
- Placement of heavy pipes

To investigate the potential for employment creation through construction, it is useful to select the construction activities that have the biggest impact on employment creation (where the contribution of this activity forms a significant part of the project cost and the activity has the potential for employment creation). Table 1.21 provides an indication of the relative contribution of the main construction activities to the total project cost. A preliminary cost analysis can be done. It is further necessary to consider using a local plant and materials (i.e. rent plant and purchase material from the community).

The result of this investigation may indicate that some activities cannot be done by means of manual labour, due to construction practicalities or the availability of materials. A more detailed cost analysis can then be done. Make sure that the design can be specified.

**Table I.21:** Relative contribution of main activities

Description	% contribution towards project costs		
	Rehabilitation	Paved	Gravel
Site accommodation	3	2	4.5
Accommodation of traffic	5	5	4
Clearing and grubbing	0.5	1	2
Drainage	3	3	7.5
Culverts	3	15	11
Kerbs and edging	3.5	8.5	0
Earthworks	6	4	22
Pavement layers	10	14	16
Base	8	10	0
Prime and seal work	35	15	0
Ancillary works	5	4	6.5
Landscaping	2	1	1.5

Table I.22 illustrates the potential of one of these main activities (pavement layers) for using labour-intensive methods.

**Table I.22:** Potential of pavement layers for labour-intensive construction methods

Layer	Type	Potential
Subbase	In-situ soil	Good
	Imported	Good*
	Stabilised soil	Fair, not practical
Base	In-situ soil	Good
	Natural gravel	Good
	Emulsion-treated gravel	Good
	Crusher run	Fair, not practical
	Cement-stabilised gravel	Not practical**
	Lime-stabilised gravel	Fair, good***
	Bituminous premix	Fair, good
	Waterbound macadam	Good
Penetration macadam	Good	
Surfacing	Sand seal	Good#
	Slurry	Good
	Double seal	Good#
	Cape seal	Good#
	Asphalt	Fair
	Roller-compacted concrete	Good
	Concrete (plain)	Good
	Concrete (reinforced)	Good
	Segmental blocks	Good##

Notes:

\* The suitability of this will depend entirely on the haul distance.

\*\* Cement-stabilised gravel is not suitable for labour-intensive methods due to its quick setting time.

\*\*\* Lime-stabilised gravel is more suitable as it reacts and sets more slowly, but achieving an even mix is difficult by entirely manual means and labourers must take extreme care to avoid contact between the lime and skin during application. Protective clothing is essential.

- # In the case of bitumen surfacing, only certain types of emulsion have a non-critical application temperature and are suitable for hand laying.
- ## Quality control of on-site manufacture is critical.

A further breakdown of possible activities that are labour-intensive in road pavement construction is provided in Table I.23.

Component	Activities
Accommodation of traffic	Watering of gravel diversions
Clearing and grubbing	As required
Drainage	Catch pits and manholes
	Excavation of open drains
	Lined open drains
	Subsoil drains
Culverts	Inlet and outlet structures
	Excavation of trenches
	Installation of lightweight pipes
	Manufacture of reinforced concrete slabs, walls and decks
	Masonry walls
Kerbing and edging	Manufacture of concrete elements
	Laying of kerbing and edging
Earthworks	Minor earthworks
Pavement layers	Crushing of aggregates
	Screening of stockpiles
	Haulage of materials
	Spreading of materials
	Removal of oversize materials
Base	Construction of labour-intensive base types (waterbound macadam, emulsion-treated base, stabilised or un-stabilised gravel)
	Manufacture of paving blocks
	Laying of paving blocks
Prime and seal work	Hand spraying of prime
	Manufacture and laying of slurry
	Seals (Cape seal, double seal, single seal)
Ancillary works	Fencing
	Masonry walls
	Gabions
	Concrete structures
	Painting of road markings
Landscaping	Grassing
	Planting of trees

# Glossary, acronyms, abbreviations

## Glossary

### AASHO Road Test

The AASHO (American Association of State Highway Officials) Road Test was a series of experiments carried out in the 1950s by the American Association of State Highway and Transportation Officials (AASHTO) to determine how traffic contributed to the deterioration of highway pavements.

### Annual Average Daily E80 (AADE)

The annual average daily is the total E80 per lane allied during one year divided by 365 days. The AADE cannot be determined from a single survey conducted over a short period of time because of cyclic and random variations in traffic loading which occur during the calendar year. Since axle load surveys are normally conducted over short periods ranging from several days to two weeks, adjustment factors derived from permanent classification count stations are often applied to convert the measured average daily E80 to estimated AADE values.

### Average Annual Daily Traffic (AADT)

The average annual daily traffic includes all vehicles and all directions. The total year's traffic is divided by 365 days. Heavy vehicles are often given as a percentage of the AADT or ADT.

### Average Daily E80 (ADE)

The average daily E80 per lane per day over the survey period during which the axle load survey was conducted.

### Average Daily Traffic (ADT)

The average daily traffic includes all vehicles (light and heavy) travelling in all directions.

### E80

The standard axle load used in South Africa is 80 kN (approximately 8 165 kg), and the damage caused by any other axle load relative to the standard axle is defined as the equivalent standard axle, or E80.

## Acronyms and abbreviations

AADT	Average Annual Daily Traffic
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transport Officials
ADE	Average Daily E80
ADT	Average Daily Traffic
BRT	Bus Rapid Transit
BSMs	Bitumen Stabilised Materials
CBR	California Bearing Ratio
CITP	Comprehensive Integrated Transport Plan
COTO	Committee of Transport Officials

CRCP	Continuously Reinforced Concrete Pavements
DCP	Dynamic Cone Penetrometer
DJCP	Doweled Jointed Concrete Pavement
EVU	Equivalent Vehicle Units
HMA	Hot mix asphalt
IDP	Integrated Development Plan
JCP	Jointed Concrete Pavement
LEF	Load Equivalency Factor
LoS	Level of Service
NATMAP	National Transport Master Plan
NMT	Non-motorised Transport
PWOC	Present Worth of Cost
RA	Reclaimed Asphalt
SABITA	Southern African Bitumen Association
SABS	South African Bureau of Standards
SAMDM	South African Mechanistic Design Method
SANRAL	South African National Roads Agency
SAPEM	South African Pavement Engineering Manual
SARDS	South African Road Design System
TLC	Traffic Loading Class
TMH	Technical Methods for Highways
TRH	Technical Recommendations for Highways
UTRCP	Ultra-Thin Reinforced Concrete Pavement

## Endnotes

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