# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DESIGN CONTROLS</strong></td>
<td></td>
</tr>
<tr>
<td>3.1 INTRODUCTION</td>
<td>3-1</td>
</tr>
<tr>
<td>3.2 HUMAN FACTORS</td>
<td></td>
</tr>
<tr>
<td>3.2.1 Drivers</td>
<td>3-1</td>
</tr>
<tr>
<td>3.2.2 Other road users</td>
<td>3-4</td>
</tr>
<tr>
<td>3.3 SPEED</td>
<td></td>
</tr>
<tr>
<td>3.3.1 General</td>
<td>3-5</td>
</tr>
<tr>
<td>3.3.2 Speed classification</td>
<td>3-6</td>
</tr>
<tr>
<td>3.3.3 Design speed</td>
<td>3-6</td>
</tr>
<tr>
<td>3.3.4 Operating speed</td>
<td>3-9</td>
</tr>
<tr>
<td>3.3.5 Application of design speed</td>
<td>3-9</td>
</tr>
<tr>
<td>3.4 DESIGN VEHICLES</td>
<td></td>
</tr>
<tr>
<td>3.4.1 Introduction</td>
<td>3-10</td>
</tr>
<tr>
<td>3.4.2 Vehicle classifications</td>
<td>3-11</td>
</tr>
<tr>
<td>3.4.3 Vehicle characteristics</td>
<td>3-11</td>
</tr>
<tr>
<td>3.4.4 Selecting a design vehicle</td>
<td>3-13</td>
</tr>
<tr>
<td>3.5 SIGHT DISTANCE</td>
<td></td>
</tr>
<tr>
<td>3.5.1 General</td>
<td>3-14</td>
</tr>
<tr>
<td>3.5.2 Deceleration rates</td>
<td>3-14</td>
</tr>
<tr>
<td>3.5.3 Object height</td>
<td>3-14</td>
</tr>
<tr>
<td>3.5.4 Stopping sight distance</td>
<td>3-15</td>
</tr>
<tr>
<td>3.5.5 Effect of gradient on stopping sight distance</td>
<td>3-16</td>
</tr>
<tr>
<td>3.5.6 Variation of stopping sight distance for trucks</td>
<td>3-16</td>
</tr>
<tr>
<td>3.5.7 Passing sight distance</td>
<td>3-18</td>
</tr>
<tr>
<td>3.5.8 Decision sight distance</td>
<td>3-19</td>
</tr>
<tr>
<td>3.5.9 Headlight sight distance</td>
<td>3-20</td>
</tr>
<tr>
<td>3.5.10 Barrier sight distance</td>
<td>3-21</td>
</tr>
<tr>
<td>3.5.11 Obstructions to sight distance on horizontal curves</td>
<td>3-21</td>
</tr>
<tr>
<td>3.6 ENVIRONMENTAL FACTORS</td>
<td></td>
</tr>
<tr>
<td>3.6.1 Land use and landscape integration</td>
<td>3-23</td>
</tr>
<tr>
<td>3.6.2 Aesthetics of design</td>
<td>3-23</td>
</tr>
<tr>
<td>3.6.3 Noise abatement</td>
<td>3-24</td>
</tr>
<tr>
<td>3.6.4 Air pollution by vehicles</td>
<td>3-24</td>
</tr>
<tr>
<td>3.6.5 Weather and geomorphology</td>
<td>3-25</td>
</tr>
<tr>
<td>3.7 TRAFFIC CHARACTERISTICS</td>
<td></td>
</tr>
<tr>
<td>3.7.1 General</td>
<td>3-26</td>
</tr>
<tr>
<td>3.7.2 Traffic volumes</td>
<td>3-26</td>
</tr>
<tr>
<td>3.7.3 Directional distribution</td>
<td>3-27</td>
</tr>
<tr>
<td>3.7.4 Traffic composition</td>
<td>3-27</td>
</tr>
<tr>
<td>3.7.5 Traffic growth</td>
<td>3-28</td>
</tr>
<tr>
<td>3.7.6 Capacity and design volumes</td>
<td>3-28</td>
</tr>
<tr>
<td>3.8 ROAD CLASSIFICATION</td>
<td></td>
</tr>
<tr>
<td>3.8.1 Classification criteria for South African roads</td>
<td>3-30</td>
</tr>
<tr>
<td>3.8.2 Functional classification concept</td>
<td>3-31</td>
</tr>
<tr>
<td>3.8.3 Administrative classification</td>
<td>3-32</td>
</tr>
<tr>
<td>3.8.4 Design type classification</td>
<td>3-32</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 3.1: Typical design speeds ................................................................. 3-8
Table 3.2: Dimensions of design vehicles (m) .............................................. 3-12
Table 3.3: Minimum turning radii ................................................................. 3-13
Table 3.4: Object height design domain ...................................................... 3-15
Table 3.5: Recommended stopping sight distances for design ......................... 3-16
Table 3.6: Passing sight distance ................................................................. 3-18
Table 3.7: Decision sight distance ............................................................... 3-20
Table 3.8: Equivalent passenger car units ................................................... 3-28
Table 3.9: Road functional classification ..................................................... 3-31

LIST OF FIGURES

Figure 3.1: Five Axle Vehicles and Multi Vehicle Combinations ..................... 3-12
Figure 3.2: Stopping distance corrected for gradient .................................... 3-17
Figure 3.3: Horizontal restrictions to stopping sight distance ......................... 3-22
Figure 3.4: Relationship of functional road classes ....................................... 3-33
Chapter 3

DESIGN CONTROLS

3.1 INTRODUCTION

The design of a road is that of a three-dimensional structure which should ideally be safe, efficient, functional and economical for traffic operations, and which should also be aesthetically pleasing in its finished form. However, the designer uses dimensions and related criteria within a design context that recognizes a series of design controls constraining what can be achieved. These limitations are imposed by the characteristics of vehicle and driver performance as well as by environmental factors. The designer should, therefore, relate the physical elements of the road to the requirements of the driver and vehicle so that consistency in the driver’s expectations is achieved and, at the same time, ensures that environmental and other constraints are accommodated.

Good road design is the art of combining and balancing the various controls in a perceptive fashion and is not merely an exercise in three-dimensional geometry. In this chapter, the constraints and controls on the design process are discussed.

3.2 HUMAN FACTORS

3.2.1 Drivers

An appreciation of driver performance as part of the road traffic system is essential for effective road design and operation. When a design is incompatible with human capabilities (both of the driver and any other road user) the opportunities for errors and accidents increase. Knowledge of human performance, capabilities and behavioural characteristics is thus a vital input into the design task.

Road users do not all behave in the same way and designs should cater for substantial differences in the range of human characteristics and a wide range of responses. However, if the perceptual clues are clear and consistent, the task of adaptation is made easier and the response of drivers will be more appropriate and uniform. For roadway design this translates into some useful principles, viz:

• A roadway should confirm what drivers expect based on previous experience; and
• Drivers should be presented with clear clues about what is expected of them

Driver Workload and Expectations

The driver workload comprises:

• Navigation: trip planning and route following;

• Guidance: following the road and maintaining a safe path in response to traffic conditions; and

• Control: steering and speed control

These tasks require the driver to receive and process inputs, consider the outcome of alternative actions, decide on the most appropriate, execute the action and observe its effects through the reception and processing of new information. There are numerous problems inherent in this sequence of tasks, arising from both the capabilities of the human driver, and the interfaces between the human and other
components of the road traffic system (the road and the vehicle). These include inadequate or insufficient input available for the task at hand (e.g. during night time driving, as a result of poor sight distance, or because of complex intersection layouts). When they become overloaded, drivers shed part of the input to deal with that judged to be more important. Most importantly, drivers are imperfect decision-makers and may make errors, including in the selection of what input to shed.

The designer must provide all the information the driver needs to make a correct decision timeously, simultaneously ensuring that the information is provided at a tempo that does not exceed the driver's ability to absorb it. In the words of the American Association of State Highway and Transportation Officials: (AASHTO)

"A common characteristic of many high-accident locations is that they place large or unusual demands on the information-processing capabilities of drivers. Inefficient operation and accidents usually occur where the chance for information-handling errors is high. At locations where the design is deficient, the possibility of error and inappropriate driver performance increases."

Prior experience develops into a set of expectancies that allows for anticipation and forward planning, and these enable the driver to respond to common situations in predictable and successful ways. If these expectancies are violated, problems are likely to occur, either as a result of a wrong decision or of an inordinately long reaction time. There are three types of driver expectancy:

Continuation expectancy. This is the expectation that the events of the immediate past will continue. It results, for example, in small headways, as drivers expect that the leading vehicle will not suddenly change speed. One particularly perverse aspect of continuation expectancy is that of subliminal delineation, e.g. a line of poles or trees or lights at night which suggests to the driver that the road continues straight ahead when, in fact, it veers left or right. These indications are subtle, but should always be looked out for during design.

Event expectancy. This is the expectation that events that have not happened will not happen. It results, for example, in disregard for "at grade" railway crossings and perhaps for minor intersections as well, because drivers expect that no hazard will present itself where none has been seen before. A response to this situation is more positive control, such as an active warning device at railway crossings that requires that the driver respond to the device and not to the presence of a hazard.

Temporal expectancy. This is the expectation that, where events are cyclic (e.g. traffic signals), the longer a given state prevails, the greater is the likelihood that change will occur. This, of course, is a perfectly reasonable expectation, but it can result in inconsistent responses. For example, some drivers may accelerate towards a green signal, because it is increasingly likely that it will change, whereas others may decelerate. A response to this is to ensure, to the extent possible, that there is consistency throughout the road traffic system to encourage predictable and consistent driver behaviour.
The combined effect of these expectancies is that:

- drivers tend to anticipate upcoming situations and events that are common to the road they are travelling;
- the more predictable the roadway feature, the less likely will be the chance for errors;
- drivers experience problems when they are surprised;
- in the absence of evidence to the contrary, drivers assume that they will only have to react to standard situations;
- the roadway and its environment upstream create an expectation of downstream conditions; drivers experience problems in transition areas and locations with inconsistent design or operation, and
- expectancies are associated with all levels of driving performance and all aspects of the driving situation and include expectancies relative to speed, path, direction, the roadway, the environment, geometric design, traffic operations and traffic control devices.

**Driver Reaction**

It takes time to process information. After a person's eyes detect and recognize a given situation, a period of time elapses before muscular reaction occurs. Reaction time is appreciable and differs between persons. It also varies for the same individual, being increased by fatigue, drinking, or other causes. The AASHTO brake reaction time for stopping has been set at 2.5 s to recognize all these factors. This value has been adopted in South Africa.

Often drivers face situations much more complex than those requiring a simple response such as steering adjustments or applying the brakes. Recognition that complex decisions are time-consuming leads to the axiom in highway design that drivers should be confronted with only one decision at a time, with that decision being binary, e.g. "Yes" or "No" rather than complex, e.g. multiple choice. Anything up to 10 seconds of reaction time may be appropriate in complex situations.

**Design Response**

Designers should strive to satisfy the following criteria:

- Driver’s expectations are recognized, and unexpected, unusual or inconsistent design or operational situations avoided or minimized.
- Predictable behaviour is encouraged through familiarity and habit (e.g. there should be a limited range of intersection and interchange design formats, each appropriate to a given situation, and similar designs should be used in similar situations).
- Consistency of design and driver behaviour is maintained from element to element (e.g. avoid significant changes in design and operating speeds along a roadway).
- The information that is provided should decrease the driver’s uncertainty, not increase it (e.g. avoid presenting several alternatives to the driver at the same time).
- Clear sight lines and adequate sight distances are provided to allow time for decision-making and, wherever possible, margins are allowed for error and recovery.

With the major response to drivers' requirements being related to consistency of design, it
is worthwhile considering what constitutes consistency. Consistency has three elements that are the criteria offered for the evaluation of a road design:

**Criterion I**  Design consistency - which corresponds to relating the design speed to actual driving behaviour which is expressed by the 85th percentile speed of passenger cars under free-flow conditions;

**Criterion II**  Operating speed consistency which seeks uniformity of 85th percentile speeds through successive elements of the road and

**Criterion III**  Consistency in driving dynamics - which relates side friction assumed with respect to the design speed to that demanded at the 85th percentile speed.

In the case of Criterion 1, if the difference between design speed and 85th percentile speed on an element such as a horizontal curve is less than 10 km/h, the design can be considered good. A difference of between 10 km/h and 20 km/h results in a tolerable design and differences greater than 20 km/h are not acceptable.

In the case of Criterion 2, the focus is on differences in operating speed in moving from one element, e.g. a tangent, to another, e.g. the following curve. A difference in operating speed between them of less than 10 km/h is considered to be good design and a difference of between 10 and 20 km/h is tolerable. Differences greater than 20 km/h result in what is considered to be poor design.

For the third Criterion the side friction assumed for the design should exceed the side friction demanded by 0.01 or more. A difference between -0.04 and 0.01 results in a fair design. A value of less than -0.04 is not acceptable. A negative value for the difference between side friction assumed for design and the side friction demanded means that drivers are demanding more side friction than is assumed to be available - a potentially dangerous situation.

### 3.2.2 Other road users

**Pedestrians**

The interaction of pedestrians and vehicles should be carefully considered in road design, principally because 50 per cent of all road fatalities are pedestrians.

Pedestrian actions are less predictable than those of motorists. Pedestrians tend to select paths that are the shortest distance between two points. They also have a basic resistance to changes in gradient or elevation when crossing roadways and tend to avoid using underpasses or overpasses that are not convenient.

Walking speeds vary from a 15th percentile speed of 1.2 m/s to an 85th percentile of 1.8 m/s, with an average of 1.4 m/s. The 15th percentile speed is recommended for design purposes.

Pedestrians' age is an important factor that may explain behaviour that leads to collisions. It is recommended that older pedestrians be accommodated by using simple designs that minimize crossing widths and assume lower walking speeds. Where complex elements such as channelisation and separate turning lanes are featured, the designer should assess alternatives that will assist older pedestrians.
Pedestrian safety is enhanced by the provision of:

- median refuge islands of sufficient width at wide intersections, and
- lighting at locations that demand multiple information gathering and processing.

**Cyclists**

Bicycle use is increasing and should be considered in the road design process. Improvements such as:

- paved shoulders;
- wider outside traffic lanes (4.2 m minimum) if no shoulders exist;
- bicycle-safe drainage grates;
- adjusting manhole covers to the grade, and
- maintaining a smooth, clean riding surface

can considerably enhance the safety of a street or highway and provide for bicycle traffic:

At certain locations it may be appropriate to supplement the existing road system by providing specifically designated cycle paths. The design elements of cycle paths are discussed in Chapter 4.

### 3.3 SPEED

#### 3.3.1 General

Drivers, on the whole, are concerned with minimising their travel times, and speed is one of the most important factors governing the selection of alternate routes to gain time savings. The attractiveness of a specific road or route is generally judged by its convenience in travel time, which is directly related to travel speed.

Various factors influence the speed of vehicles on a particular road. These include:

- Driver capability, driver culture and driver behaviour;
- Vehicle operating capabilities;
- The physical characteristics of the road and its surroundings;
- Weather;
- Presence of other vehicles, and
- Speed limitations (posted speed limits).

Speeds vary according to the impression of constraint imparted to the driver as a result of these factors.

The objective of the designer is to satisfy the road users' demands for service in a safe and economical way. This means that the facility should accommodate nearly all reasonable demands (speed) with appropriate adequacy (safety and capacity) but should not fail completely under severe load, i.e. the extremely high speeds maintained by a small percentage of drivers. Roads should, therefore, be designed to operate at a speed that satisfies most, but not necessarily all, drivers.

Various studies have shown that the 85th percentile speed generally exceeds the posted speed limit by a margin of at least 10 km/hr when weather and traffic conditions are favourable. For this reason, design speed is typically equated to the 85th percentile speed.

The relationship between road design and speed is interactive. While the designer shapes the elements of the road by the anticipated speed at which they will be used, taking into account the inherent economic trade-offs between construction and environmental costs of alternative alignments (vertical and horizontal) to match desired travel speed, the speed at
which they will be used depends to a large extent on the chosen design features.

### 3.3.2 Speed classification

The term "speed" is often used very loosely when describing the rate of movement of road traffic. Road design recognizes various definitions or classifications of speed, all of which are interrelated. The sub-divisions are:

- Desired Speed - the speed at which a driver wishes to travel, determined by a combination of motivation and comfort.
- Design Speed - the speed selected as a safe basis to establish appropriate geometric design elements for a particular section of road and which should be a logical one with respect to topography, anticipated operating speed, the adjacent land use and the functional classification of the road.
- Operating Speed - observed speeds during free flow conditions. For an individual driver, operating speed is generally lower than desired speed since operating conditions are not usually ideal.
- Running Speed - the average speed maintained over a given route while a vehicle is in motion. The running time is the length of the road section divided by the time required for the vehicle to travel through the section. Thus, in determining the running speed, the times en route when the vehicle is at rest are not taken into account in the calculations. Running speeds are generally used in road planning and capacity and service level analyses. The difference between running speed and design speed is strongly affected by traffic volumes.
- Posted Speed - is a speed limitation set for reasons of safe traffic operations rather than for geometric design considerations and is aimed at encouraging drivers to travel at appropriate speeds for all prevailing conditions.

### 3.3.3 Design speed

The most important factor in geometric design is the design speed. This was previously defined as the highest continuous speed at which individual vehicles can travel with safety on the road when weather conditions are favourable, traffic volumes are low and the design features of the road are the governing condition for safety. The current definition is simply states that the design speed is the speed selected as the basis for establishing appropriate geometric elements for a section of road. These elements include horizontal and vertical alignment, superelevation and sight distance. Other elements such as lane width, shoulder width and clearance from obstacles are indirectly related to design speed.

The chosen design speed should be a logical one consistent with the road function as perceived by the driver and also one that takes into account the type of road, the anticipated operating speed, and the terrain that the road traverses. Where a difficult condition is obvious, drivers are more apt to accept a lower speed than where there is no apparent reason for it.

Other relevant factors include traffic characteristics, land costs, speed capabilities of vehicles, aesthetics, economics and social or political impacts. A highway of higher functional classification may justify a higher design speed than a less important facility in similar topography, particularly where the savings in vehicle operation...
and other operating costs are sufficient to offset the increased costs of right-of-way and construction. A low design speed, should not be assumed where the topography is such that drivers are likely to travel at high speeds.

When carefully selected, these factors should result in a design speed which is acceptable to all but a very few drivers. Above minimum design values should be used where feasible though consistency is essential.

When a substantial length of road is being designed, it is desirable to adopt a constant design speed to maintain consistency. Changes in terrain and other physical controls may, however, dictate a change in design speed on certain sections. Each section, however, should be relatively long, compatible with the general terrain or development through which the road passes. The justification for introducing a reduced design speed should be obvious to the driver. A case in point is where a road leaves relatively level terrain and starts traversing hilly or mountainous terrain. Moreover, the introduction of a lower or higher design speed should not be effected abruptly but over sufficient distance to encourage drivers to change speed gradually.

Where design speeds exceed 90 km/h the variation between successive speeds should be limited to 10 km/h and, below 80 km/h, this variation should be limited to 20 km/h. Where it is necessary to change the design speed, the new design speed should apply to an extended section of road. Even if properly signposted, isolated design speed variations are hazardous as they do not match driver expectations and it is always possible that the signpost may be obscured, illegible, removed or even simply not perceived by the driver. Isolated design speed changes are, therefore, to be avoided.

The need for a multilane cross-section suggests that traffic volumes are high. A design speed of at least 120 km/h should be used if the topography permits. Major roads, even if two-lane two-way roads, should also be designed to this speed if possible. Rolling terrain may, however, necessitate a reduction to 100 km/h in the design speed and, in the case of mountainous terrain, it may even be necessary to reduce the design speed to 80 km/h.

Secondary and tertiary roads may have lower design speeds than those advocated for the primary road network. However, where traffic is likely to move at relatively high speeds on these roads, higher design speeds should be selected.

There is still debate as to whether speeds greater than 120 km/h should be used for design purposes on freeways. Higher design speeds not only safeguard against early obsolescence of the highway, but also provide an increased margin of safety for those driving at high speeds. That there is some validity in this statement is reflected by the fact that the design speed of high-type roads is now at least 120 km/h as compared with 56 km/h in 1927, a change brought about by the continuing increase in vehicle performance.

The choice of a design speed for a dual carriageway is much less influenced by construction cost than that for other rural roads. In prac-
tice, lower design speeds are often accepted on single carriageway roads in order to keep construction costs within certain limits. There is danger in this philosophy since, although drivers will obviously accept lower speeds in what are clearly difficult locations, repeated studies have shown that they do not adjust their speeds to the importance of the facility. Instead they endeavour to operate at speeds consistent with the traffic on the facility and its physical limitations.

Ideally, then, design speed should be chosen to reflect the 85th percentile desired speed that is likely to materialize. This is often achievable for roads for which the primary function is mobility and where severe physical constraints do not exist. Limited studies in South Africa have shown that the 85th percentile speed exceeds 120 km/h for unhindered vehicles on a four-lane divided roadway. Use of a design speed of 130 km/h should therefore satisfy driver demands in most areas.

The selected design speed should be logical and in harmony with the topography and the functional classification of a road. Careful consideration should also be given to its relationship to other defined speeds. While no hard relationships have been established, choice of design speed can simultaneously accommodate and influence desired, operating, running and posted speeds.

Table 3.1 provides an indication of typical design speeds for different classes of roads.

<table>
<thead>
<tr>
<th>Road type</th>
<th>Design speed (km/h)</th>
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<tbody>
<tr>
<td><strong>Limited Access Roads</strong></td>
<td></td>
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<tr>
<td>Freeways in urban areas</td>
<td>90-130</td>
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<tr>
<td>Freeways and expressways in rural areas</td>
<td>110-130</td>
</tr>
<tr>
<td>Expressways in urban areas</td>
<td>80-110</td>
</tr>
<tr>
<td><strong>Conventional Roads</strong></td>
<td></td>
</tr>
<tr>
<td>Rural</td>
<td></td>
</tr>
<tr>
<td>Flat terrain</td>
<td>90-120</td>
</tr>
<tr>
<td>Rolling terrain</td>
<td>80-100</td>
</tr>
<tr>
<td>Mountainous terrain</td>
<td>60-80</td>
</tr>
<tr>
<td>Urban</td>
<td></td>
</tr>
<tr>
<td>Arterial streets</td>
<td>60-100</td>
</tr>
<tr>
<td>Arterial streets with extensive development</td>
<td>50-70</td>
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</tbody>
</table>
3.3.4 Operating speed

Operating speed is measured under free flow conditions. The term "spot speed" is sometimes used to denote operating speed. For an individual driver, operating speed is generally lower than desired speed since operating conditions are not usually ideal. When reference is made to the operating speed of all vehicles in the traffic stream, this is taken as being the 85th percentile of all observed speeds.

Operating speed has a variety of uses. It is generally used as a measure of level of service at uninterrupted flows. It can also be used to monitor the effect of flow constrictions, such as intersections or bridges. Since operating speeds at ideal sections of road are indicative of speeds desired by motorists, they can be used to guide the selection of design speed on improved or new facilities.

When the design speed is less than the desired speed, drivers should be warned to modify their speed, as studies have shown that crash rates increase as the operating speed of a particular vehicle deviates from the mean operating speed of the other vehicles on the roadway.

The typical driver can recognize or sense a logical operating speed for a given roadway based on knowledge of the system, posted speed limits, appraisal of the ruggedness of the terrain, traffic volumes and the extent, density and size of development. Studies have shown that characteristics, such as the number of access points, nearby commercial development, road width and number of lanes, have a significant influence on vehicle speeds. Based on these factors, the driver's initial response is to react to the anticipated situation rather than to the actual situation. In most instances, the two are similar enough not to create conflicts. If the initial response is incorrect, operation and safety may be severely affected.

Some agencies conduct speed surveys to determine operating speeds at various points along a section of roadway. The results can be compared with the design speed, and may lead to a policy change in the selection of design speeds.

3.3.5 Application of design speed

Consistency of design is fundamental to good driver performance, based on satisfying the driver's expectations. Design consistency exists when the geometric features of a continuous section of road are consistent with the operational characteristics as perceived by the driver. The traditional approach to achieving design consistency has been through the application of the design speed process. Once selected, the design speed is used to determine values for the geometric design elements from appropriate design domains.

However, application of this procedure alone does not guarantee design consistency. There are several limitations of the design speed concept that should be considered during design:

1. Selection of dimensions to accommodate specified design speed does not necessarily ensure a consistent alignment design. Design speed is significant only when physical road characteristics limit the speed of travel. Thus, a road can be designed with a constant design speed, yet have considerable variation in
speeds achievable and therefore to a driver appear to have a wide variation in character. For example, the radii of curves within a section should be consistent, not merely greater than the minimum value.

2. For horizontal alignments, design speed applies only to curves, not to the connecting tangents. Design speed has no practical meaning on tangents. As a result, the operating speed on a tangent, especially a long one, can often significantly exceed the design speed of the road as a whole.

3. The design speed concept does not ensure sufficient coordination among individual geometric features to ensure consistency. It controls only the minimum value of the maximum speeds for the individual features along an alignment. For example, a road with an 80 km/h design speed may have only one curve with a design speed of 80 km/h and all other features with design speeds of 120 km/h or greater. As a result, operating speeds approaching the critical curve are likely to exceed the 80 km/h design speed. Such an alignment would comply with an 80 km/h design speed, but it would violate a driver’s expectancy and result in undesirable alignment.

4. Vehicle operating speed is not necessarily synonymous with design speed. Drivers normally adjust speed according to their desired speed, posted speed, traffic volumes and perceived alignment hazards. The perception of hazard presented by the alignment may vary along a road designed with a constant design speed. The speed adopted by a driver tends to vary accordingly and may exceed the design speeds. A report on studies in Australia and the US concluded that 85th percentile operating speeds consistently exceed design speeds where the design speeds are less than 100 km/h at horizontal curves on rural two-lane highways.

5. In addition, different alignment elements may have quite different levels of perceived hazard. Entering a horizontal curve too fast will almost certainly result in loss of control, so drivers adjust their speed accordingly. However, the possibility of a curtailed sight distance concealing a hazard is considered as a remote occurrence. Unfortunately drivers do not generally adjust their speed to compensate for sight distance restrictions.

To help overcome these weaknesses in the use of design speed to design individual geometric elements, speed profiles are used. A speed profile is a graphical depiction (which can be modelled) showing how the 85th percentile operating speed varies along a length of road. This profile helps to identify undesirably large differentials in the 85th percentile operating speed between successive geometric elements, e.g. a curve following a tangent.

When an existing road is being improved, actual operating speeds can be measured to create a speed profile, but interpretation of the profile can be difficult, depending on the complexity of geometric and other features that may cause drivers to change speed. For a new road, prediction of operating speeds is needed to create a speed profile model.

3.4 DESIGN VEHICLES

3.4.1 Introduction

The physical characteristics of vehicles and the proportions of the various sizes of vehicles...
using a road are positive controls in design and define several geometric design elements, including intersections, on- and off-street parking, site access configurations and specialized applications such as trucking facilities. It is necessary to identify all vehicle types using the facility, establish general class groupings and select hypothetical representative design vehicles, within each design class. The dimensions used to define design vehicles are not averages or maxima, nor are they legal limiting dimensions. They are, in fact, typically the 85th percentile or 15th percentile value of any given dimension. The design vehicles are therefore hypothetical vehicles, selected to represent a particular vehicle class.

The dimensions in the previous Geometric Design Manual were based on typical design vehicles in South Africa pertinent to 1965. The range of vehicle types and their operating characteristics have changed significantly since then. The vehicle size regulations have also undergone substantial revisions which have generally resulted in larger trucks on the roads as well as in an increased use of recreational utility vehicles.

### 3.4.2 Vehicle classifications

Three general classes of vehicles have been selected for this design guide: passenger cars, trucks and buses. The passenger car class includes compacts and subcompacts, recreational utility vehicles and all light vehicles and light delivery trucks (vans and pickups). The truck class includes single-unit trucks, truck tractor-semi trailer combinations, and trucks or truck tractors with semi trailers in combination with full trailers. Buses include single unit buses, articulated buses and intercity buses. In establishing the design dimensions for the various vehicle classes, this guide focuses on vehicles in regular operation only.

Vehicles defined in the Road Traffic Act include:
- Passenger cars and minibuses (kombis);
- Standard single unit buses;
- Articulated buses (“Bus Train”);
- Two axle trucks, with and without trailers;
- Three and four axle vehicles;
- Three, four and five axle articulated trucks;
- Five and six axle articulated trucks, and
- Multi vehicle combinations.

### 3.4.3 Vehicle characteristics

The dimensions adopted for the various design vehicles are given in Table 3.2.

The WB15 vehicle has an overall length of 17 m, whereas the regulations allow for a semi-trailer to have an overall length of 18.5 m. The multiple vehicle combination, being a semi-trailer plus trailer and typically in an Interlink configuration, can have a maximum overall length of 22 m. Examples of these vehicles are illustrated in Figure 3.1.

If these vehicles are expected to use a route with any frequency, the designer will have to carefully plan the layout of the intersections to ensure that they can be accommodated. As described below, accommodation does not necessarily require lane widths sufficient to complete a turning movement within the lane. A degree of
Turning Radii

In constricted situations where the templates are not appropriate, the capabilities of the design vehicle become critical. Minimum turning radii for the outer side of the vehicle are given in Table 3.3. It is stressed that these radii are appropriate only to crawl speeds.

Table 3.2: Dimensions of design vehicles (m)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Wheel base</th>
<th>Front overhang</th>
<th>Rear overhang</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car (P)</td>
<td>3,1</td>
<td>0,7</td>
<td>1,0</td>
<td>1,8</td>
</tr>
<tr>
<td>Single unit (SU)</td>
<td>6,1</td>
<td>1,2</td>
<td>1,8</td>
<td>2,5</td>
</tr>
<tr>
<td>Single unit + trailer (SU+T)</td>
<td>6,7+3.4+6,1</td>
<td>1,2</td>
<td>1,8</td>
<td>2,5</td>
</tr>
<tr>
<td>Single unit bus (BUS)</td>
<td>7,6</td>
<td>2,1</td>
<td>2,6</td>
<td>2,6</td>
</tr>
<tr>
<td>Semi-trailer (WB-15)</td>
<td>6,1+9.4</td>
<td>0,9</td>
<td>0,6</td>
<td>2,5</td>
</tr>
</tbody>
</table>

* Distance between SU rear wheels and trailer front wheels

Figure 3.1: Five Axle Vehicles and Multi Vehicle Combinations

encroachment on adjacent lanes is permissible depending on the frequency of occurrence.

In terms of regulation 355 (a) of the Road Traffic Act, all vehicles must be able to describe a minimum turning radius not exceeding 13,1m.

Turning Radii

In constricted situations where the templates are not appropriate, the capabilities of the design vehicle become critical. Minimum turning radii for the outer side of the vehicle are given in Table 3.3. It is stressed that these radii are appropriate only to crawl speeds.

Vehicle height

Regulation 354 in the Road Traffic Act limits the overall height of a double decker bus to 4,6 metres, and that of any other vehicle to 4,3 metres. The 15th percentile height of a passenger car has been established to be 1,3 m. This has been selected for design purposes as the...
passenger car is also an object that has to be seen by the driver in the cases of passing and intersection sight distance.

**Driver Eye Height**
The passenger car is taken as the critical vehicle for driver eye height and a figure of 1.05 metres is recommended. For buses and single unit vehicles a typical value is 1.8 metres and for semi-trailer combinations the height of the eye can vary between 1.9 metres and 2.4 metres.

**Vehicle Turning Paths**
The designer should allow for the swept path of the selected design vehicle as it turns. The swept path is established by the outer trace of the front overhang and the path of the inner rear wheel. This turn assumes that the outer front wheel follows the circular arc defining the minimum turning radius as determined by the vehicle steering mechanism.

It is assumed that the turning movements critical to the design of roadway facilities are done at low speeds. At these speeds, the turning behaviour of vehicles is mainly determined by their physical characteristics. The effects of friction and dynamics can safely be ignored. It is also assumed that groups of evenly spaced axles mounted on a rigid bogie act in the turn as a single axle placed at the centre of the group for the purpose of measuring critical turning dimensions.

Commercially available templates and computer software define the turning envelope of vehicles in forward motion and also support plotting of the turning envelope of reversing non-articulated vehicles. Prediction of the reversing behaviour of articulated vehicles is, however, very complex, mainly because this behaviour is inherently unstable, and additional turning controls come into play.

### 3.4.4 Selecting a design vehicle

In general, buses and heavy vehicles should be used as the design vehicle for cross section elements, with the car as the design vehicle for the horizontal and vertical alignment. For most major intersections along arterial roads or within commercial areas, it is common practice to accommodate the semi trailer. The occasional larger vehicle may encroach on adjacent lanes while turning but not on the sidewalk.

Many authorities designate and signpost specific truck routes. The intersections of two truck routes or intersections where trucks must turn to remain on a truck route should be designed to accommodate the largest semi-trailer combination expected to be prevalent in the turning traf-
fic stream. Where local residential roads intersect truck routes or arterials, the intersections should be specifically designed not to accommodate trucks easily, in order to discourage them from travelling through the residential area.

On major haulage routes, large tractor-trailer combination trucks are prevalent and these routes should be designed to accommodate them. Raised channelising islands are typically omitted in recognition of low pedestrian volumes and other constraints such as right of way and construction costs. The absence of raised islands also allows more manoeuvring area for large trucks.

3.5 SIGHT DISTANCE

3.5.1 General

A critical feature of safe road geometry is adequate sight distance. As an irreducible minimum, drivers must be able to see objects in the road with sufficient time to allow them to manoeuvre around them or to stop. Other forms of sight distance are pertinent. They are:

- Passing sight distance, which is required for substantial portions of the length of two-lane roads;
- Intersection sight distance, to allow a driver on the minor road to evaluate whether it is safe to cross or enter the opposing stream of traffic;
- Decision sight distance where, for example, a driver must be able to see and respond to road markings;
- Headlight sight distance, typically applied to sag vertical curves, and
- Centre line barrier sight distance.

It is also necessary to consider the terrain or obstructions on the inside of horizontal curves when evaluating adequate sight distance.

3.5.2 Deceleration rates

Although research in North America has shown that drivers can choose (or apply) a deceleration of greater than 5 m/sec², there is a large degree of variability in driver and vehicle capabilities and the 90th percentile deceleration is of the order of 3.4 m/sec². The Institute of Transportation Engineers’ Traffic Engineering Handbook states that decelerations of up to 3.0 m/sec² are reasonably comfortable for passenger car occupants. This deceleration rate has been adopted for these guidelines.

3.5.3 Object height

The object height to be used in calculation of stopping sight distance is often a compromise between the length of the resultant sight distance and the cost of construction. Stopping is generally in response to another vehicle or large hazard in the roadway. To recognize a vehicle as a hazard at night, a line of sight to its headlights or taillights would be necessary. Larger objects would be visible sooner and provide longer stopping distances. To perceive a very small hazard, for example, a surface obstruction, a zero object height may be necessary. However, at the required stopping sight distances for high speeds, small pavement variations and small objects (especially at night) would not be easily visible. Thus, most drivers travelling at high speeds would have difficulty in stopping before reaching a small obstruction.
A driver will usually attempt to take evasive action rather than to stop for small objects on the roadway. Although not recommended as a design parameter, the time available to manoeuvre is a useful measure when examining variations of geometry in restricted situations or reconstruction projects. In this case, the appropriate object is the pavement surface.

The designer should adopt an object height based on the probability of a particular object occurring on the roadway, as shown in Table 3.4 below. For stopping sight distance, a conservative tail light height of 0.60 m is recommended. If fallen trees or rocks are a real risk, an object height of 0.15 m is recommended. In this context, research has established that the probability of a collision involving an object of a height of 0.15 m or less is infinitesimally small. For passing sight distance, an object height of 1.30 m will allow the driver to discern the top of an oncoming car. A zero object height is recommended where road washouts are a serious risk. It is also recommended for pavement markings in situations such as at intersections or interchanges, where these provide essential guidance.

### Table 3.4: Object height design domain

<table>
<thead>
<tr>
<th>Object Height (m)</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>Risk of road washouts</td>
</tr>
<tr>
<td></td>
<td>Pavement markings in critical locations</td>
</tr>
<tr>
<td>0.15</td>
<td>Risk of fallen trees or rocks</td>
</tr>
<tr>
<td></td>
<td>Risk of log or construction debris fallen from truck</td>
</tr>
<tr>
<td></td>
<td>Risk of fallen person</td>
</tr>
<tr>
<td>0.60</td>
<td>Vehicle tail or brake light</td>
</tr>
<tr>
<td>1.30</td>
<td>Passing sight distance for top of car</td>
</tr>
<tr>
<td></td>
<td>Intersection sight distance</td>
</tr>
</tbody>
</table>

3.5.4 Stopping sight distance

The minimum sight distance on a roadway should be sufficient to enable a vehicle travelling at the design speed on a wet pavement to stop before reaching a stationary object in its path.

Stopping sight distance is the sum of two distances:

- the distance traversed by the vehicle from the instant the driver sights an obstruction to the instant the brakes are applied, and
- the distance required to stop the vehicle from the instant the brakes are applied

These are referred to as brake reaction distance and stopping distance, respectively. These two components, using a reaction time of 2.5 seconds and a deceleration rate of 3.0 m/s², result in the relationship

\[ s = v (0.694 + 0.013v) \]

where: \( s = \) stopping sight distance, m
\( v = \) initial speed, km/h
Stopping sight distances calculated using this equation are given in Table 3.5, rounded up for design purposes. Also shown in the table for general interest are the values of stopping sight distance adopted in the 2000 AASHTO Policy on the Geometric Design of Highways and Streets, the "Green Book 2000".

In the measurement of stopping sight distance, the driver’s eye height is taken as being at 1.05 m and the object height is as defined in Table 3.4.

### 3.5.5 Effect of gradient on stopping sight distance

When a highway is on a gradient, the equation for stopping sight distance becomes

\[ s = v(0.694 + \frac{0.004v}{0.3 \pm G}) \]

in which G is the percentage gradient divided by 100, with upgrades being positive and downgrades negative and the other terms as previously stated. The brake reaction time is assumed to be the same as for level conditions. The stopping sight distance for design speeds from 30 to 130 km/h as corrected for gradient is illustrated in Figure 3.2.

The sight distance at any point on the highway is generally different in each direction, particularly on straight roads in rolling terrain. As a general rule, the sight distance available on downgrades is longer than on upgrades, more or less automatically providing the necessary corrections for grade. This is because down grades are normally followed by sag vertical curves, with the following grade also being visible to the driver.

### 3.5.6 Variation of stopping sight distance for trucks

The recommended minimum stopping sight distance model directly reflects the operation of passenger cars and trucks with antilock braking.
systems. Trucks with conventional braking systems require longer stopping distances from a given speed than do passenger cars. However, AASHTO suggests that the truck driver is able to see the vertical features of the obstruction from substantially further because of the higher driver eye height. In addition, posted speed limits for trucks in South Africa are considerably lower than for passenger vehicles. Separate stopping sight distances for trucks and passenger cars are, therefore, not generally used in highway design.

There is, however, evidence to suggest that the sight distance advantages provided by the higher driver eye level in trucks do not always compensate for their inferior braking. Some reasons for the longer truck braking distances include:

- Poor braking characteristics of empty trucks. The problem relates to the suspension and tyres that are designed for maximum efficiency under load;
- Uneven load between axles;
- Propensity of truck drivers not to obey posted speed limits;
- Inefficient brakes of articulated trucks, and
- Effect of curvature, where some of the friction available at the road/tyre interface is used to hold the vehicle in a circular path.

To balance between the costs and benefits in designing for trucks, truck stopping sight distances should be checked at potentially hazardous locations. In general, the deceleration rate for trucks is 1.5 m/s². The driver’s eye height is taken as being at 1.8 m and the object height is as defined in Table 3.4.

The designer should also consider measures such as additional signs to improve road safety.

Figure 3.2: Stopping distance corrected for gradient
if stopping sight distance is found to be inadequate for trucks and it is not possible to improve the geometric design. However, it is emphasized that provision of signage is not a substitute for appropriate design practices.

3.5.7 Passing sight distance

On a two-lane rural road, the passing manoeuvre is one of the most significant yet complex and important driving tasks. The process is relatively difficult to quantify, primarily because of the many stages involved, the relative speed of vehicles and the lengthy section of road needed to complete the manoeuvre. Road safety, capacity and service levels are all affected by the passing ability of faster vehicles. This ability is influenced by a variety of factors, including traffic volumes, speed differentials, road geometry and human factors. The minimum sight distance required by a vehicle to overtake safely on two-lane single carriageway roads is the distance which will enable the overtaking driver to pass a slower vehicle without causing an oncoming vehicle to slow below the design speed.

It should be pointed out that there are a variety of models defined for the overtaking manoeuvre. The distances usually given are those required to enable an overtaking driver to complete or abort a manoeuvre already commenced, with safety. In addition to this distance, the Austroads approach introduces a distance that is needed for the driver to identify a length of road as a potential overtaking zone. This "establishment" distance is considerably longer than the overtaking manoeuvre distance.

Table 3.6 shows the minimum overtaking sight distances generally used for various design speeds. Passing manoeuvres involving trucks, particularly in South Africa, require longer distances than those indicated. Designers must take this into account for roads where significant percentages of heavy vehicles are expected in the traffic stream.

As mentioned above, the designer should seek opportunities to introduce passing lanes on two-lane roads, particularly where the terrain limits

<table>
<thead>
<tr>
<th>Design Speed (km/h)</th>
<th>Absolute Minimum Passing Sight Distance (m)</th>
<th>Desirable Minimum Passing Sight Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>220</td>
<td>250</td>
</tr>
<tr>
<td>40</td>
<td>290</td>
<td>350</td>
</tr>
<tr>
<td>50</td>
<td>350</td>
<td>400</td>
</tr>
<tr>
<td>60</td>
<td>410</td>
<td>450</td>
</tr>
<tr>
<td>70</td>
<td>490</td>
<td>550</td>
</tr>
<tr>
<td>80</td>
<td>550</td>
<td>650</td>
</tr>
<tr>
<td>90</td>
<td>610</td>
<td>750</td>
</tr>
<tr>
<td>100</td>
<td>680</td>
<td>900</td>
</tr>
<tr>
<td>110</td>
<td>730</td>
<td>1000</td>
</tr>
<tr>
<td>120</td>
<td>800</td>
<td>1100</td>
</tr>
<tr>
<td>130</td>
<td>860</td>
<td>1200</td>
</tr>
</tbody>
</table>
sight distance. A report on a review and evaluation of research studies concluded that passing and climbing lane installations reduce collision rates by 25 per cent compared to untreated two-lane sections. They provide safer passing opportunities for drivers who are uncomfortable in using the opposing traffic lane and for those who become frustrated when few passing opportunities exist, owing to terrain or traffic density.

Sections with adequate passing sight distance should be provided as frequently as possible. The appropriate frequency is related to operating speed, traffic volumes and composition, terrain and construction cost. As a general rule, if passing sight distance cannot be economically provided at least once every 2 km, passing lanes should be considered. The 2+1 cross-section currently in vogue in Europe has some merit. This three-lane cross-section has two lanes in one direction and a single lane in the opposing direction. At about two to three kilometre intervals, the second lane is allocated to movement in the opposite direction. A minimum shoulder width is required as discussed in Chapter 4.

### 3.5.8 Decision sight distance

Stopping sight distances are usually sufficient to allow reasonably competent and alert drivers to stop under ordinary circumstances. However, these distances are often inadequate when:

- Drivers must make complex decisions;
- Information is difficult to perceive, or
- Unexpected or unusual manoeuvres are required.

Limiting sight distances to those provided for stopping may also preclude drivers from performing evasive manoeuvres, which are often less hazardous and otherwise preferable to stopping. Even with an appropriate complement of standard traffic control devices, stopping sight distances may not provide sufficient visibility for drivers to corroborate advance warning and to perform the necessary manoeuvres. It is evident that there are many locations such as exits from freeways, or where lane shifts or weaving manoeuvres are performed where it would be prudent to provide longer sight distances. In these circumstances, decision sight distance provides the greater length that drivers need. If the driver can see what is unfolding far enough ahead, he or she should be able to handle almost any situation.

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

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

Because decision sight distance gives drivers additional margin for error and affords them sufficient length to manoeuvre their vehicles at the same or reduced speed rather than to just stop, it is substantially longer than stopping sight distance.
Drivers need decision sight distances whenever there is likelihood for error in either information reception, decision-making, or control actions. Critical locations where these kinds of errors are likely to occur, and where it is desirable to provide decision sight distance include:

- Approaches to interchanges and intersections;
- Changes in cross-section such as at toll plazas and lane drops;
- Design speed reductions, and
- Areas of concentrated demand where there is apt to be "visual noise", e.g. where sources of information, such as roadway elements, opposing traffic, traffic control devices, advertising signs and construction zones, compete for attention.

The minimum decision sight distances that should be provided for specific situations are shown in Table 3.7. If it is not feasible to provide these distances because of horizontal or vertical curvature or if relocation is not possible, special attention should be given to the use of suitable traffic control devices for advance warning.

Although a sight distance is offered for the right side exit, the designer should bear in mind that exiting from the right is in total conflict with driver expectancy and is highly undesirable. The only reason for providing this value is to allow for the remote eventuality that a right side exit has to be employed.

In measuring decision sight distances, the 1 050 mm eye height and 0 mm object height have been adopted.

### 3.5.9 Headlight sight distance

Headlight sight distance is typically used in establishing the rate of change of grade for sag vertical curves. At speeds above 80 km/h, only large, light coloured objects can be perceived at the generally accepted stopping sight distances. A five-fold light increase is necessary for a 15 km/h increase in speed and a 50 per cent reduction in object size.

<table>
<thead>
<tr>
<th>Design Speed (km/h)</th>
<th>Interchanges : Sight distance to nose (metres)</th>
<th>Lane drop, closure, merge. Sight distance to taper area (metres)</th>
<th>Lane shift Sight distance to beginning of shift (metres)</th>
<th>Intersections Sight distance to turn lane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left Exit</td>
<td>Right Exit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>N/A</td>
<td>N/A</td>
<td>150</td>
<td>85</td>
</tr>
<tr>
<td>60</td>
<td>200</td>
<td>275</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>80</td>
<td>250</td>
<td>340</td>
<td>250</td>
<td>150</td>
</tr>
<tr>
<td>100</td>
<td>350</td>
<td>430</td>
<td>350</td>
<td>200</td>
</tr>
<tr>
<td>120</td>
<td>400</td>
<td>500</td>
<td>400</td>
<td>250</td>
</tr>
</tbody>
</table>
For night driving on highways without lighting, the length of visible roadway is that which is directly illuminated by the headlights of the vehicle. This length is typically shorter than the minimum sight distance.

When headlights are operated on low beam, the reduced candlepower at the source and the downward projection angle significantly restrict the visible length of roadway surface.

For crest vertical curves, the area beyond the headlight beam point of tangency with the roadway surface is shadowed and receives only indirect illumination. Also, a general limit of 120 to 150 metres sight distance is all that can be safely assumed for visibility of an unilluminated object on a bitumen surfacing. This corresponds to a satisfactory stopping sight distance for 80 to 90 km/h or a decision time of about 5 seconds at 100 km/h.

Since the headlight mounting height (typically about 600 mm) is lower than the driver eye height (1,050 mm for design), sight distance is controlled by the height of the vehicle headlights and a one degree upward divergence of the light beam from the longitudinal axis of the vehicle. Any object within the shadow zone must be high enough to extend into the headlight beam to be directly illuminated.

3.5.10 Barrier sight distance

Barrier sight distance is not a geometric design factor, but is rather an operational guide to the driver to promote safety on two-lane roads.

Barrier sight distance is the limit below which overtaking is legally prohibited, in order to ensure that two opposing vehicles travelling in the same lane should be able to come to a stop before impact. A logical basis for the determination of the barrier sight distance is that it should at least equal twice the stopping distance. Values given in the South Africa Road Traffic Signs Manual approximate this approach.

Barrier sight distance is measured to an object height of 1,3 metre from an eye height of 1,05 m. The object height is the height of an approaching passenger car.

Hidden dip alignments are poor design practice, but are found on many rural roads. They typically mislead drivers into believing that there is more sight distance available than actually exists. In checking vertical alignment, designers should pay attention to areas where this deficiency exists, and ensure that drivers are made aware of any such inadequacies.

3.5.11 Obstructions to sight distance on horizontal curves

Physical features, such as a concrete barrier wall, a bridge pier, a tree, foliage, or the back slope of a cutting, can affect available sight distance. Accordingly, designs need to be checked in both the horizontal and vertical planes for obstructions.

Minimum radii of horizontal curvature are determined by application of vehicle dynamics and not through sight distance controls. It is, therefore, possible that the selected radius may not be adequate to ensure the safe stopping sight distance requirements. If the obstructions to
sight distance are immovable, realignment may be necessary.

The problem is illustrated in Figure 3.3. The driver’s eye is assumed to be at the centre of the nearside lane. The chord AB is the sight line and the curve ACB is the stopping sight distance. A zero gradient is assumed. It follows that selection of a radius for a given distance of

\[ C = (R - \frac{L}{2}) \left[ 1 - \left( \frac{28.62}{R - \frac{L}{2}} \right)^{0.5} \right] \]

where

\[ C = \text{distance from centre of inside lane to obstruction (m)} \]
\[ R = \text{radius of curve (m)} \]

Given the nature of the relationship, a trial-and-error approach to the solution is required.

### Figure 3.3: Horizontal restrictions to stopping sight distance

A radius to satisfy stopping sight distance criteria can be calculated from the following formula; A road is a key element in the modern environment with wide ranging implications. Planning for effective integration is therefore essential. In South Africa, the National Environmental Management Act of 1998 lays down prescriptions for the provision and operation of infrastructure, including roads. The designer should be aware of the constraints imposed by this law. For example, constraints may include avoiding a particular watercourse or wetland area, or accommodating prescribed mitigatory meas-

### 3.6 ENVIRONMENTAL FACTORS

A road is a key element in the modern environment with wide ranging implications. Planning for effective integration is therefore essential. In South Africa, the National Environmental Management Act of 1998 lays down prescriptions for the provision and operation of infrastructure, including roads. The designer should be aware of the constraints imposed by this law. For example, constraints may include avoiding a particular watercourse or wetland area, or accommodating prescribed mitigatory meas-
ures such as screening berms or sound fences. In carrying out their mandate to plan and design road systems, road designers should consider on the one hand, making facilities aesthetically pleasing and being "good neighbours" in the community and, on the other, providing safe and efficient transportation links to users.

3.6.1 Land use and landscape integration

With regard to environmental factors, the objective of route selection should be to choose a route that has both the minimum effect on landform and requires the smallest number of large earthworks. Integration with the existing landform can best be achieved by grading out cuttings and embankments to slopes that reflect the surrounding topography. This in turn may affect adjacent sites of conservation or heritage interest and, in such cases, a balance needs to be struck. A major consideration is that non-renewable resources, such as wetlands, should be avoided wherever possible.

Designs should aim to achieve the best possible use of excavated materials, thus minimizing the need for off-site spoil or borrow pits. If off-site works are necessary, they should be subject to the same good design principles as those used on site, achieved by liaison with the appropriate planning authority. Earthworks can only be integrated successfully if the new landform and its soil structure allow effective strategic rehabilitation. Restoration to agricultural use can be a particularly effective strategy.

Design objectives should be:
- To choose the route least damaging to the landscape and which respects existing landform best by avoiding disruption of major topographical features;
- To find an alignment that uses the existing landform to good effect and which minimizes the scale of earthworks;
- To design profiles which reflect existing natural slopes;
- To retain the least road footprint, by the return of land to its former use;
- To use existing landform to minimize noise and visual intrusion: for example, placing a road in a cutting or behind rising ground to protect settlements;
- To develop new landforms, including mounds and false cuttings, to screen the road from settlements, and
- To achieve a balance between horizontal and vertical alignment.

3.6.2 Aesthetics of design

Design aesthetics and attention to landform are very closely related topics. Aesthetic improvements can often be achieved without incurring additional costs, provided the designer approaches the subject in a sensitive manner. In fact, alignments that are visually pleasing are usually less hazardous than other alignments.

On any roadway, creating pleasing appearance is a worthwhile objective. Scenic values can be considered along with safety, utility, economy, and all the other factors considered in planning and design. This is particularly true of the many portions of the National Road system situated in areas of natural beauty. The location of the road, its alignment and profile, the cross section design, and other features should be in harmony with the setting. Economy consistent with traffic needs is of paramount importance,
although a reasonable additional expenditure can be justified to enhance the beauty of the highway.

This topic is addressed in detail in Chapter 5.

### 3.6.3 Noise abatement

Noise is defined as an unwanted sound, a subjective result of sounds that intrude on or interfere with activities such as conversation, thinking, reading or sleeping. Motor vehicle noise is generated by the functioning of equipment within the vehicle, by its aerodynamics, by the action of tyres on the roadway and, in metropolitan areas, by short-duration sounds such as braking squeal, exhaust backfires, hooters and sirens.

The decrease in sound intensity with distance from the source is influenced by several factors. Measurements taken near roads show that doubling the distance results in a lowering of 3 dBA over clean, level ground and 4.8 dBA over lush growth.

Some sustained (ambient) noise is always present. In a quiet residential neighbourhood at night, it is in the 32 to 43 dBA range; the urban residential daytime limits are about 41 to 53 dBA. In industrial areas the range is 48 to 66 dBA, while, in downtown commercial locations with heavy traffic, it is 62 to 73 dBA. Increases up to 9 dBA above ambient noise levels bring only sporadic protests. Protests become widespread with increases in the 9 to 16 dBA range. At increases greater than 16 dBA, there may be community action.

A design objective is to keep noise at or below acceptable levels and this can be achieved either by absorbing the noise or deflecting it upwards. Strategies addressing noise levels include, for example, depressing and sometimes covering the roadway or by installing sound barriers of earth or masonry. However, these may also trap air pollutants.

Special sound barriers may be justified at certain locations, particularly along ground level or elevated roads through noise-sensitive areas. Concrete, wood, metal, or masonry walls are very effective in deflecting noise. One of the more aesthetically pleasing barriers is the earth berm that has been graded to achieve a natural form that blends with the surrounding topography. The feasibility of berm construction should be planned as part of the overall grading plan for the roadway. There will be instances where an effective earth berm can be constructed within the normal right-of-way or with a minimal additional right-of-way purchase. If the right-of-way is insufficient to accommodate a three metre high berm, a lower berm can be constructed in combination with a wall or screen to achieve the desired height.

Shrubs, trees or ground covers are not very efficient in shielding sound because of their permeability to the flow of air. However, almost all buffer plantings offer some noise reduction, and exceptionally wide and dense plantings may result in substantial reductions in noise levels. Even where the noise reduction is not considered significant, the aesthetic effects of the plantings will produce a positive influence.

### 3.6.4 Air pollution by vehicles

The highway air-pollution problem has two dimensions: the area-wide effects of primarily
reactive pollutants; and the high concentrations of largely non-reactive pollutants at points or corridors along or near roads. The motor vehicle is a primary contributor to both forms, accounting for an estimated 70 per cent of the CO, 50 per cent of the HC, and 30 per cent of the NOx.

Area-wide conditions are exacerbated when temperature inversions trap pollutants near the ground surface and there is little or no wind, so that concentrations of pollutants increase. For some individuals, eyes burn and breathing is difficult. It is alleged that lives can be shortened and some deaths have actually resulted from these exposures. Also, certain kinds of vegetation are killed, stunted, or the foliage burned.

The quantity of air pollutants can be reduced by judicious design. Exhaust emissions are high while vehicle engines are operating at above-average levels of output, for example while accelerating from a stationary position or when climbing a steep hill. Smooth traffic flow at constant speeds, such as in "green wave" conditions on a signalised route, reduces exhaust emissions in addition to leading to a reduction in noise levels. By way of contrast, speed humps, which are popular as speed-reducing devices in residential areas, have the dual penalty of increased pollution and increased noise levels. In rural areas, vertical alignments should be designed with a minimum of "false rises".

In addition to being able to modify the quantity of pollutants in the atmosphere, the designer can influence the extent to which emissions impact on local communities. Temperature inversions that trap polluted air are typically associated with closed or bowl-shaped valleys. If at all possible, major routes should not traverse such areas but should rather be located on the higher ground surrounding inversion-prone valleys, with relatively low-volume road links serving developments in the valley areas. Attention should also be paid to prevailing wind directions so that routes bypassing local communities are located downwind of these settlements.

3.6.5 Weather and geomorphology

Land shape, on a broad scale, as well as prevailing weather conditions, which could influence the design, are factors over which the designer does not have any control. Certain areas of the country are prone to misty conditions and others subject to high rainfall. Both are factors that have to be taken into account in design.

Mist and rain both cause reduced visibility. Where these are a regular occurrence, they tend to lie in belts, sometimes fairly narrow, across the landscape. Designers should acquire local knowledge about the quirks of the weather patterns and seek ways to reduce their effect.

Where it is not possible to avoid a mist belt, the designer should pay particular attention to the concept of the "forgiving highway", by providing flat side slopes and avoiding alignments where short radius curves follow each other in quick succession. Steep downgrades followed by short radius horizontal curves are particularly to be avoided. A real effort should also be put into avoiding high fills. In conditions of heavy mist, vehicles will tend to move very slowly but, even
at speeds significantly below the design speed of the road, the restricted visibility will lead to high levels of stress. Drivers are more likely to make incorrect decisions when under stress and designers should thus do everything possible to keep stress levels within manageable limits.

### 3.7 TRAFFIC CHARACTERISTICS

#### 3.7.1 General

Factual information on expected traffic volumes is an essential input to design. This indicates the need for improvements and directly affects the geometric features and design.

Traffic flows vary both seasonally and during the day. The designer should be familiar with the extent of these fluctuations to enable him or her to assess the flow patterns. The directional distribution of the traffic and the manner in which its composition varies are also important parameters. A thorough understanding of the manner in which all of these behave is a basic requirement of any realistic design.

#### 3.7.2 Traffic volumes

Traffic flow is measured by the number of vehicles passing a particular station during a given period of time. Typically, the flow of interest is the Average Daily Traffic (ADT). Flows may also be reported per hour, such as the "hourly observed traffic volume" or the "thirtieth-highest hour" or "hundredth-hour", which are commonly used for design purposes. Very short duration flows, such as for a five-minute period, are typically applied to studies of signalised intersections.

If hourly flows are ordered from highest to lowest, it is customary, in rural areas, to design for the thirtieth highest hourly flow, i.e that flow which is exceeded in only 29 hours of the year. This is because rural roads have very high seasonal peaks and it is not economical to have a road congestion-free every hour throughout the year. In urban areas, seasonal peaks are less pronounced and the 100th highest hourly flow is considered a realistic flow level for design purposes.

To predict hourly flows, it is necessary to know the ADT and the peaking factor, $\beta$. The parameter, $\beta$, is a descriptor of the traffic flow on a given road and depends on factors such as the percentage and incidence of holiday traffic, the relative sizes of the daily peaks, etc. The peaking factor can fluctuate between -0.1 and -0.4. A value of -0.1 indicates minimal seasonal peaking. This value of $\beta$ should be used in urban designs. A value of -0.4 suggests very high seasonal peaks and would normally be applied to roads such as the N3. As a general rule, a value of -0.2 could be used as being a typical value. Equation 3.1 below can be used to estimate flows between the highest and 1030th highest hour. Although not a particularly good model, flows beyond the 1030th hour can be estimated by using a straight line relationship from the 1030th flow to zero veh/hr at the 8760th or last hour of the year.

\[
Q_N = 0.072ADT(N/1030)^\beta
\]

where
- $Q_N$ = two-directional flow in N-th hour of year (veh/hr)
- $ADT$ = average daily traffic (veh/day)
- $N$ = hour of year
- $\beta$ = peaking factor.
It is interesting to note that the peak hour factor, \( K \), quoted in the Highway Capacity Manual is often assumed for design purposes to be 0.15. Reference is commonly made to the 30th highest hour of the year as being the design hour. Applying a value of -0.2 to \( \beta \), and assuming \( N \) to be 30, \( Q_N \) according to Equation 3.1 is 0.146 x ADT for the thirtieth highest hour.

Designers need to estimate future traffic flows for a road section. It is recommended that a design period of 20 years be used for forward planning. The 30th or 100th highest flow used in the design is that occurring in the design year, typically twenty years hence. Staged construction or widening of roads over this period can be a feature of an economical design.

The capacity of rural road sections is influenced by the following key characteristics:
- Road configuration - e.g. two-lane two-way, multi-lane divided or undivided;
- Operating speed;
- Terrain;
- Lane and shoulder width;
- Traffic composition, and
- Gradients.

In the case of two-lane two-way roads, the following additional factors are important:
- Directional distribution of traffic flow; and
- Passing opportunities - sight distance, overtaking lanes, climbing lanes or slow vehicle turnout lanes.

### 3.7.3 Directional distribution

Directional distribution of traffic is an indication of the tidal flow during the day. In urban areas, the morning peak traffic is typically inbound towards the central business district (with relatively low outward-bound flows), whereas the afternoon peak is in the reverse direction. It is important to realize that the design flow is actually a composite and not a single value. A road must be able to accommodate the major flow in both directions.

The actual distribution to be used for design purposes should be measured in the field. If an existing road is to be reconstructed, the field studies can be carried out on it beforehand. For new facilities, measurements should be made on adjacent roads from which it is expected the traffic will be diverted and modelling techniques applied.

Directional distribution is relatively stable and does not change materially from year to year. Relationships established from current traffic movements are normally also applicable to future movements.

### 3.7.4 Traffic composition

Vehicles of different sizes and mass have different operating characteristics. Trucks have a higher mass/power ratio and occupy more roadway space than passenger cars. Consequently, they constitute a greater impedance to traffic flow than passenger vehicles, with the overall effect that one truck is equivalent to several passenger cars. For design purposes, the percentage of truck traffic during the peak hours has to be estimated.

For design of a particular highway, data on the composition of traffic should be determined from traffic studies. Truck traffic is normally
expressed as a percentage of total traffic during the design hour in the case of a two-lane road; and as a percentage of total traffic in the predominant direction of travel in the case of a multi-lane road.

It is not practical to design for a heterogeneous traffic stream and, for this reason, trucks are converted to equivalent Passenger Car Units (PCUs). The number of PCU’s associated with a single truck is a measure of the impedance that it offers to the passenger cars in the traffic stream. This topic is exhaustively addressed in the Highway Capacity Manual and is not discussed further here.

Passenger car unit equivalents have, in general, been derived from observations as illustrated in Table 3.8. The values offered serve only as a rough indication and the designer should refer to the Highway Capacity Manual for detailed calculation of PCU’s appropriate to the different environments and circumstances.

### 3.7.5 Traffic growth

The design of new roads or of improvements to existing roads should be based on the future traffic expected to use the facilities.

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Rural roads</th>
<th>Urban Streets</th>
<th>Roundabouts</th>
<th>Traffic Signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars and light vans</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Commercial vehicles</td>
<td>3,0</td>
<td>1,75</td>
<td>2,8</td>
<td>1,75</td>
</tr>
<tr>
<td>Buses and coaches</td>
<td>3,0</td>
<td>3,0</td>
<td>2,8</td>
<td>2,25</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>1,0</td>
<td>0,75</td>
<td>0,75</td>
<td>0,33</td>
</tr>
<tr>
<td>Pedal cycles</td>
<td>0,5</td>
<td>0,33</td>
<td>0,5</td>
<td>0,2</td>
</tr>
</tbody>
</table>

It is difficult to define the life of a “road” because major segments may have different lengths of physical life. Each segment is subject to variations in estimated life expectancy because of influences not readily subject to analysis such as obsolescence and unexpected changes in land use, resulting in changes in traffic volumes, pattern and load. Regardless of the anticipated physical life of the various elements of the road, it is customary to use a single value as the “design life”. In essence, the road is expected to provide an acceptable level of service for this period. Whether or not any of its various components have a longer physical life expectancy than this design life is irrelevant. For example, the alignment and, in some instances, the surfacing of roads built during Roman times are still in use today without there being any reference to a design life of 2 000 years.

A typical value of design life is twenty years. In the case of major and correspondingly expensive structures a design life of fifty years may be assumed. This should not, however, be confused with the concept of a bridge being able to withstand the worst flood in fifty years.

### 3.7.6 Capacity and design volumes

The term capacity is used here to define the ability of a road to accommodate traffic under
given circumstances. Factors to be taken into account are the physical features of the road itself and the prevailing traffic conditions.

**Prevailing road conditions**

Capacity figures for uninterrupted flow on highways have to be modified if certain minimum physical design features are not adhered to. Poor physical features that tend to cause a reduction in capacity are:

- Narrow traffic lanes. Lane widths of 3.65 m are accepted as being the minimum necessary for heavy volumes of mixed traffic, i.e. before capacity of the lane is reduced.
- Inadequate shoulders. The narrowness, or lack of, shoulders alongside a road cause vehicles to travel closer to the centre of the carriageway, thereby increasing the medial traffic friction. In addition, vehicles making emergency stops must, of necessity, park on the carriageway. This causes a substantial reduction in the effective width of the road, thereby reducing capacity.
- Side obstructions. Vertical obstructions such as poles, bridge abutments, retaining walls or parked cars that are located within about 1.5 m of the edge of the carriageway contribute towards a reduction in the effective width of the outside traffic lane.
- Imperfect horizontal or vertical curvature. Long and/or steep hills and sharp bends result in restricted sight distance. As drivers then have reduced opportunities to pass, the capacity of the facility will be reduced.

In addition to the above, the capacities of certain rural roads and the great majority of urban roads are controlled by the layouts of intersections.

Physical features having considerable influence are the type of intersection, i.e. whether plain, channelised, roundabout or signalised, the number of intersecting traffic lanes and the adequacy of speed-change lanes.

Unlike the physical features of the highway, which are literally fixed in position and have definite measurable effects on traffic flows, the prevailing traffic conditions are not fixed but vary from hour to hour throughout the day. Hence, the flows at any particular time are a function of the speeds of vehicles, the composition of the traffic streams and the manner in which the vehicles interact with each other, as well as of the physical features of the roadway itself.

**Capacity**

The term "capacity" was introduced in the USA in the Highway Capacity Manual, in which it is defined as "the maximum number of vehicles that can pass a given point on a roadway or in a designated lane during one hour without the traffic density being so great as to cause unreasonable delay, hazard, or restriction to the drivers' freedom to manoeuvre under the prevailing roadway and traffic conditions". This definition gives a reasonable method of approach but, in practice, it is necessary to choose one or more arbitrary criteria of what constitutes restriction of traffic movement, or "congestion".

The Highway Capacity Manual procedure must however be used for specific road capacity designs.

For typical South African conditions and to balance financial, safety and operational consider-
ations it is recommended that the capacity of a two-lane rural road be taken on average as being between 10 000 and 12 000 vehicles per day while, for freeways, consideration could be given to changing from a four-lane to a six-lane freeway when the traffic flow is of the order of 35 000 to 40 000 vehicles per day.

3.8 ROAD CLASSIFICATION

The classification of roads into different operational systems, functional classes or geometric types is necessary for communication between engineers, administrators and the general public. Classification is the tool by which a complex network of roads can be subdivided into groups having similar characteristics. A single classification system, satisfactory for all purposes, would be advantageous but has not been found to be practicable. Moreover, in any classification system the division between classes is often arbitrary and, consequently, opinions differ on the best definition of any class. There are various schemes for classifying roads and the class definitions generally vary depending on the purpose of classification.

The principal purposes of road classification are to:-

- Establish logical integrated systems that, because of their particular service, should be administered by the same jurisdiction;
- Relate geometric design control and other design standards to the roads in each class, and
- Establish a basis for developing long-range programmes, improvement priorities and financial plans.

Classification of roads by design types based on the major geometric features (e.g. freeways) is the most helpful one for road location and design purposes. Classification by route numbering is the most helpful for road traffic operational purposes, whilst administrative classification is used to denote the level of government responsible for, and the method of, financing road facilities. Functional classification, the grouping of roads by the character of service they provide, was developed for transportation planning purposes.

3.8.1 Classification criteria for South African roads

Although numerous classification criteria are used on road networks world-wide, in South Africa there are basically three criteria used to classify road types. These are:

- Functional classification;
- Administrative classification, and
- Design Type classification, based on traffic usage.

This document uses the third type for design purposes.

As a result of growing awareness of the interdependency of the various modes of transport as well as the creation of Metropolitan Transport Authorities within South Africa's major metropolitan areas there is considerable overlap between the functional and administrative classification criteria. Within these metropolitan areas, the general public is more dependent on, and understands, a route numbering or functional classification than on an administrative classification of roads within the area.
Although these guidelines are based on a design type classification, the three different approaches mentioned above are briefly described in order to provide a picture of the road system hierarchy in South Africa.

### 3.8.2 Functional classification concept

For transportation planning purposes, roads are most effectively classified by function. The functional classification system adopted for the South African road network is illustrated in Table 3.9. This was used for the South African Rural Road Needs Study carried out during the early 1980s.

Another and less comprehensive form of functional classification was developed for the purposes of road signing as shown in the South African Road Traffic Signs Manual. As stated in SARTSM, "There are definite limits to the number of ways in which GUIDANCE signs and specifically DIRECTION signs can be made to indicate with sufficient immediate recognition potential, the different classes into which the road network is divided for signing purposes."

Classification for signing thus differentiates mainly between numbered and unnumbered routes and, in respect of numbered routes, also draws a distinction between freeways and other roads.

<table>
<thead>
<tr>
<th>Functional Classification</th>
<th>Description of Road Function or Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Roads which form the principal avenues of communication between:</td>
</tr>
<tr>
<td></td>
<td>- Major regions of the RSA and/or</td>
</tr>
<tr>
<td></td>
<td>- Defined or proposed metropolitan areas and/or</td>
</tr>
<tr>
<td></td>
<td>- Major regions of the RSA and other countries</td>
</tr>
<tr>
<td></td>
<td>and which are declared National roads or the extensions of these.</td>
</tr>
<tr>
<td>1a*</td>
<td>Roads which comply with the above but which are not declared National roads or extensions of these.</td>
</tr>
<tr>
<td>2</td>
<td>Roads, not being Class 1 or 1a, which form main avenues of communication between:</td>
</tr>
<tr>
<td></td>
<td>- Important centres** and class 1 and 1a roads and/or</td>
</tr>
<tr>
<td></td>
<td>- Important centres and/or</td>
</tr>
<tr>
<td></td>
<td>- Of an arterial nature within a town in a rural area.</td>
</tr>
<tr>
<td>3</td>
<td>All other surfaced roads for which the road authorities are responsible and which are not Class 1, 1a, 2 or 5 roads.</td>
</tr>
<tr>
<td>4</td>
<td>All Gravel Roads for which the road authorities are responsible, excluding Class 5 roads.</td>
</tr>
<tr>
<td>5***</td>
<td>Special Purpose Roads:</td>
</tr>
<tr>
<td></td>
<td>Roads which provide for some particular activity or function and which are not assigned to Classes 1 to 4, e.g.:</td>
</tr>
<tr>
<td></td>
<td>- For minerals development;</td>
</tr>
<tr>
<td></td>
<td>- For strategic or defence purposes;</td>
</tr>
<tr>
<td></td>
<td>- For social need; or</td>
</tr>
<tr>
<td></td>
<td>- For agricultural or other development.</td>
</tr>
</tbody>
</table>

**NOTES:**
- * Class 1a roads include declared National roads which do not follow an "N" route.
- ** Important centres are centres with population of 5 000 or more.
- *** Class 5 roads may be either surfaced or gravel roads
Roads have two functions: to provide mobility and to provide land access. However from a design standpoint, these functions are incompatible. For mobility, high or continued speeds are desirable and variable or low speeds undesirable; for land access, low speeds are desirable and high speeds undesirable. For example, freeways provide a high degree of mobility, with access provided only at spaced interchanges to preserve the high-speed, high-volume characteristics of the facility. The opposite is true for local, low-speed roads that primarily provide local access. The general relationship of functionally classified systems in serving mobility and land access is illustrated in Figure 3.4.

Given a functional classification, design criteria can be applied to encourage the use of the road as intended. Design features that can convey the level of functional classification to the driver include width of roadway, continuity of alignment, spacing of intersections, frequency of access points, building setbacks, alignment and grade standards, and traffic controls.

### 3.8.3 Administrative classification

Legislation and, in some instances, the Constitution, assigns to certain levels of government the responsibilities for providing, regulating and operating roads and streets for public use. This concept and the principles of law that support it were developed in Great Britain, and even earlier by the Romans. Within the limits of its constitutional powers, a particular road authority may delegate its authority for roads to bodies such as a Roads Board or a Toll Road Concessionaire. In South Africa, the three separate levels of government each have a roads function mandated to them. Despite this separation of authority for various classes or roads, it is essential to bear in mind that roads act as a total system or network and that the subdivision of roads into administrative classes bears no relation to the functional type of a road under the control of a specific authority. The administrative classification approach thus divides the South African road network into:

- National,
- Provincial, and
- Local Authority roads.

This administrative classification of roads also bears no relation to the design type of a road under the control of a specific authority. Thus, until the turn of the 21st century, there were sections of National Roads that were unsurfaced, with very low traffic volumes, the most heavily trafficked roads in South Africa, also up to the turn of the century, often being the responsibility of a local authority. Furthermore certain "routes" in the country comprise both National and Provincial roads, and could even include local authority roads. Administratively, a National Road, which is denoted as such by a legal proclamation, in general comprises those roads that form the principal avenues of communication between major regions of the country, and/or between major population conurbations and/or between major regions of South Africa and other countries.

### 3.8.4 Design type classification

The most widely accepted design type criteria are those developed by AASHTO which classify a road system into:

- Freeways;
• Arterial roads other than freeways, and
• Collector roads.

For each classification, specific design standards and criteria and access and other policies have been developed and are applied.

For use in the present document the following service or design classifications are proposed,

Design designations of these specific National Roads are as follows;

**Class I**  
**Primary Roads**

**Class IA**  
*Primary Freeways in rural areas*  
- Illustrative threshold ADT (with more than 12% heavy vehicles) = 15,000 veh/d.

**Class IB**  
*Primary Freeways in metropolitan areas*  
- Average travel distances on links indicated by at least 45 per cent of the trips being more than 2 hours in duration;
- May be provided for network continuity purposes, and
- Minimum design speed 130 km/h.

- Illustrative threshold ADT = 20,000 veh/d.

---

**Figure 3.4: Relationship of functional road classes**

- Average travel distances on links indicated by at least 45 per cent of the trips being more than 2 hours in duration;
- May be provided for network continuity purposes, and
- Minimum design speed 130 km/h.

**Class IB**  
*Primary Freeways in metropolitan areas*  
- Illustrative threshold ADT = 20,000 veh/d.
• Average travel distance on links indicated by majority of trips being less than 2 hours in duration
• Form integral element of Metropolitan Road Network
• Generally extension of Rural Freeways (Class IA roads)
• Minimum design speed 130 km/h

Class II Primary Arterials, 4 lane single carriageway roads

Class IIA Primary Rural Arterials
• Generally provided when 2 lane single carriageway road reaches capacity and freeway not financially affordable
• Illustrative threshold ADT: 8 000 - 10 000 veh/d, with bottom end of scale applicable where percentage of truck traffic exceed 15 per cent
• Minimum design speed 120 km/h

Class IIB Primary Metropolitan Arterial
• Design in context in which it operates.

Class III Secondary Rural Arterial
• Provided to address inter-regional travel demands, or providing access to tourist or National resource areas
• Provided to address inter-regional travel demands, or providing access to tourist or National resource areas
• Provided to address inter-regional travel demands, or providing access to tourist or National resource areas
• Two lane, single carriageway roads
• Class IIIA
• Design ADT greater than 4 000 veh/d
• Minimum design speed 120 km/h
• Class IIIB
• Design ADT 500 - 4 000 veh/d
• Minimum design speed 110 km/h
• Class IIIC
• Design ADT less than 500 veh/d
• Minimum design speed 100 km/h.