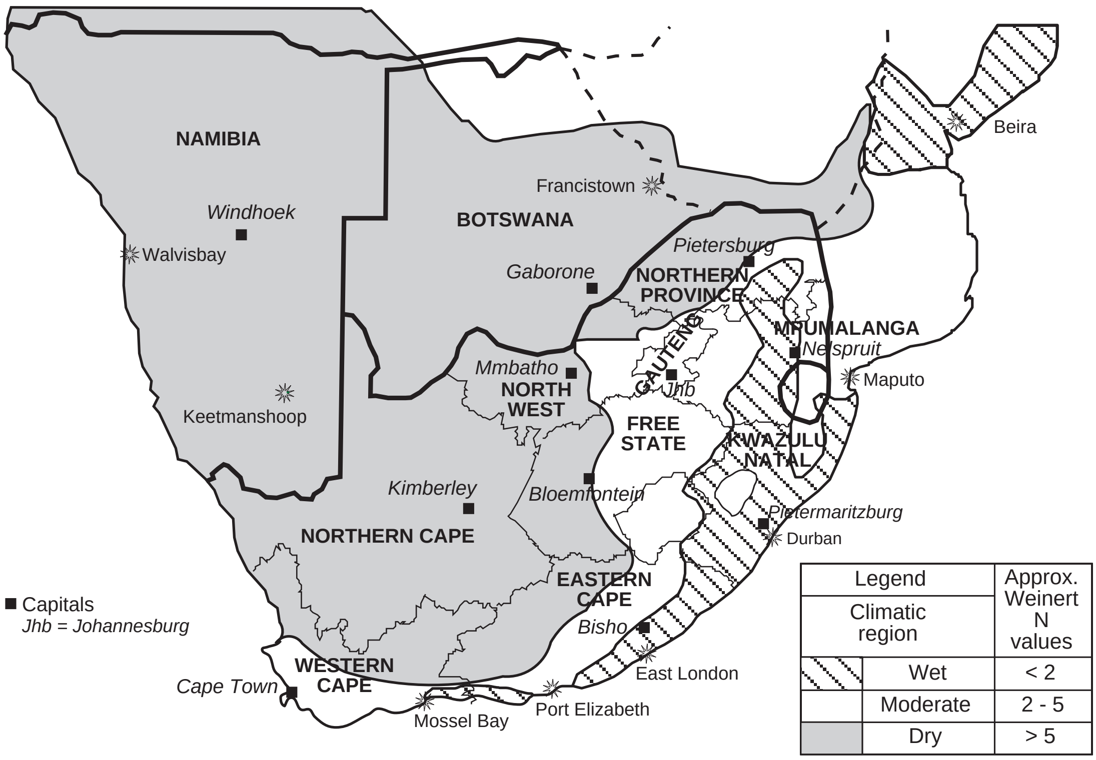

Figure 8.4: Macro-climatic regions of southern Africa

Southern Africa can be divided into three climatic regions:

- a large dry region;
- a moderate region; and
- a small wet region.

Figure 8.4 is a map of southern Africa, which indicates the different climatic regions. These are macroclimates and it should be kept in mind that different microclimates may occur within these regions. This is particularly important where such local microclimates have a high moisture content. This will have a direct influence on moisture-susceptible materials in basic access streets which require specific drainage considerations.

Climate and subgrade California Bearing Ratio (CBR)

The design parameter for the subgrade is the soaked CBR at a representative density. For structural design purposes, when a material is classified according to the CBR, it is implied that not more than 10% of the measured values for such a material will fall below the classification value. A proper preliminary soil survey should be conducted.

It is current practice to use soaked CBR values, but using them in dry regions may be over-conservative (Jordaan 1986). It is suggested that the CBR value of a material be increased if the in situ conditions are expected to be unsoaked, e.g. in dry regions (Haupt 1980). An estimate of the CBR at the expected moisture conditions, i.e. at optimum moisture content (OMC) or, say, 75 per cent of OMC, can be determined in the laboratory by refraining from soaking the samples before CBR testing or even drying back to the required moisture content.

The dynamic cone penetrometer (DCP) can be used to determine the in-situ CBR and variations in in-situ strengths (Jordaan 1986). The in-situ CBRs determined with the DCP can be calibrated by doing laboratory-soaked CBRs. If material parameters such as grading modulus (GM), plastic limit (PL) and dry density (DD) are included in the analysis, typical relations can be used to derive CBR values (Sampson 1984). The relevant equation is:

$$\log_e CBR = 1{,}1\ (\log_e DCP) + 0{,}85\ (GM) - 0{,}031\ (PL) - 0{,}001\ (DD) + 7{,}4 \qquad (8.9)$$

where loge is the natural logarithm.

For the material types under consideration, the CBR is determined at a 2,54 mm depth of penetration, with DCP penetration in millimetres per blow.

It is current practice for the design parameter for subgrade to be the soaked California Bearing Ratio (CBR) for paved streets. It is recommended that unsoaked (field) CBR values should be used particularly in dry regions (Haupt 1980; Emery 1984 and 1987). The dynamic cone penetrometer (DCP) is the ideal instrument for such an approach (Kleyn and van Zyl 1987; Kleyn 1982). However, it should be pointed out that soaked CBR values may be required for wet regions where no proper drainage can be provided or for wet-season passability on unpaved streets. When the DCP is used, care should be taken that the moisture content is a fair representation of the moisture content over long periods of time.

The requirement for subgrade or fill CBR is a soaked CBR of at least 3 at 90% Mod AASHTO density in wet areas, and an in-situ CBR of 3 in dry and moderate areas. The material should also have a maximum swell of 1,5% at 100% Mod AASHTO compaction to ensure that it is not too expansive. If the CBR values are determined in the field with the DCP, the subgrade areas with a field CBR of less than 3 will need special treatment. If the field CBR values are in excess of 45 over a depth of at least 150mm at a density of 95% Mod AASHTO, the subgrade can be considered to be subbase quality, and only a base would be needed.

Material depth

The term “material depth” is used to denote the depth below the finished level of the street to which soil characteristics have a significant effect on pavement behaviour. Below this depth, the strength and density of the soils are assumed to have a negligible effect on the pavement. The depth approximates the cover for a soil with CBR of 1 - 2. However, in certain special cases this depth may be insufficient. These cases are listed in the section dealing with practical considerations (subgrade below material depth).

Table 8.11 specifies the materail depth used for determing the design CBR of the subgrade for different street categories.

Table 8.11: Material depths to be used for determining the design CBR of the subgrades

ROAD CATEGORY	MATERIAL DEPTH (mm)
UA	1 000
UB	800
UC	600
UD	400

Delineation of subgrade areas

Any street development should be subdivided into significant subgrade areas. However, if the delineation is too fine it could lead to confusion during construction. The preliminary soil survey should delineate subgrade design units on the basis of geology, pedology, topography and drainage conditions - or major soil boundaries - on site so that an appropriate design CBR for each unit can be defined.

The designer should distinguish between very localised good or poor soils and more general subgrade areas. Localised soils should be treated separately from the rest of the pavement factors. Normally, localised poor soils will be removed and replaced by suitable material.

Design CBR of subgrade

For construction purposes the design subgrade CBR is limited to four groups, as shown in Table 8.12.

Table 8.12: Subgrade CBR groups used for structural design

CLASS	SUBGRADE CBR
SG1	>15
SG2	7 to 15
SG3	3 to 7
SG4	<3*

* Special treatment required.

The CBR is normally determined after samples have been soaked for four days. Special measures are necessary if a material with a CBR of less than 3 is encountered within the material depth. These measures include stabilisation (chemical or mechanical), modification (chemical), or the removal or addition of extra cover. After the material has been treated, it will be classified under one of the remaining three subgrade groups.

Design CBR on fill

When the street is on fill, the designer must avail himself of the best information available on the local materials that are likely to be used. The material should be controlled to at least the material depth. TRH10 (NITRR 1984) should be consulted when a material with a CBR of less than 3 is used in the fill.

Design CBR in cut

The design CBR of the subgrade in a cut should be the 10 percentile CBR encountered within the material depth.

STRUCTURAL DESIGN METHODS

Design methods for paved streets

There are a number of design methods of varying complexity at the disposal of the designer. Some of these are purely empirical and others incorporate some measure of rationality, and were developed both locally and abroad.

The designer must always bear the limitations of a particular design method in mind. Most of the purely empirical design methods were developed from data where the design bearing capacity did not exceed 10 to 12 million standard axles. The purely empirical design methods are also limited in their application to conditions similar to those for which they were developed. The designer must therefore make a critical assessment of the applicability of the design method to his design problem. Locally developed methods should then also have an advantage in this regard.

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

The "Catalogue" design method

This document focuses mainly on the use of the catalogue of pavement designs (CSRA 1996; CUTA 1987; Hefer 1997; Theyse 1997) included in Appendix A. However, this does not exclude the use of any of the other proven design methods. Most of the pavement designs in the catalogue were developed from mechanistic-empirical design, although some are based on the DCP design method and others are included on the basis of their field performance.

The catalogue approach is a fairly straightforward pen-and-paper method and does not require access to a computer.

The California Bearing Ratio (CBR) cover design method

The California Bearing Ratio (CBR) design method was developed in the 1950s from empirical data (Yoder and Witczak 1975). The method is based on the approach of protecting the subgrade by providing enough cover of sufficient strength to protect the subgrade from the traffic loading. CBR-cover design charts were developed for different subgrade CBR strengths and traffic loadings. The applicability of this method should be evaluated critically before it is applied to local environmental and traffic conditions.

This method is a pen-and-paper method and no access to a computer is required.

The AASHTO Guide for Design of Pavement Structures

The AASHTO Guide for Design of Pavement Structures provides the designer with a comprehensive set of procedures for new and rehabilitation design and provides a good background to pavement design (AASHTO 1993). The design procedures in the guideline document are, however, empirical, and were mostly developed from the results of the AASHTO Road Test carried out in the late 1950s and early 1960s.

Although some software based on the procedures in the AASHTO design guide is commercially available, the procedure may be applied just as well by hand.

The Dynamic Cone Penetrometer (DCP) method

The DCP design method was developed locally during the 1970s. The original method was based on the CBR-cover design approach and later correlated with heavy vehicle simulator (HVS) test results. This method incorporates the concept of a balanced pavement structure in the design procedure (Kleyn and van Zyl 1987). If used properly, designs generated by this method should have a well-balanced strength profile with depth, meaning that there will be a smooth decrease in material strength with depth. Such balanced pavements are normally not very sensitive to overloading. Some knowledge of typical DCP penetration rates for road-building material is required to apply this method.

DCP design may be done by hand, but if DCP data need to be analysed, access to a computer and appropriate software is necessary.

South African Mechanistic Design Method

The South African Mechanistic Design Method (SAMDM) (van Vuuren et al 1974; Walker et al 1977; Paterson and Maree 1978; Theyse et al 1996) was developed locally and is one of the most comprehensive mechanistic-empirical design methods in the world (Freeme, Maree and Viljoen 1982). This method may be used very effectively for new and rehabilitation design. Some knowledge of the elastic properties of materials as used by the method is required, and experience in this regard is recommended. In the case of rehabilitation design or upgrading, field tests such as the DCP and Falling Weight Deflectometer (FWD) may be used to determine the input parameters for the existing structure.

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

Design methods for unpaved streets

Unlike sealed roads, where the application of a bituminous surfacing results in a semi-permanent structure (for up to 20 years) in which deformation or failure is costly to repair and usually politically unacceptable, unsealed roads are far more forgiving. Routine maintenance is essential and localised problems are rectified relatively easily. For this reason, the design process for unsealed roads has never progressed to the sophisticated techniques developed for sealed roads.

The main principles in designing unsealed roads are

- to prevent excessive subgrade strain; and
- to provide an all-weather, dust-free surface with acceptable riding quality.

These two requirements are achieved by providing an adequate thickness of suitable material, constructed to a suitable quality. A simple design technique covering thickness and materials has been developed for South Africa and is summarised in TRH14 *Guidelines for road construction materials* (NITRR 1984c).

PRACTICAL CONSIDERATIONS

Surface drainage

Experience has shown that inadequate drainage is probably responsible for more pavement distress in southern Africa than inadequate structural or material design. Effective drainage is essential for good pavement performance, and it is assumed in the structural design procedure.

Drainage for basic access streets

Effective drainage is a prerequisite in the structural design of basic access streets. Drainage design is integral in stormwater management. As outlined in the principles of stormwater management, the design should allow for non-structural and structural measures to cope with minor and major storms. The non-structural measures are related to optimising the street layout and the topography to retard stormwater flow and curb the possible associated damage. Structural measures include not only the provision of culverts, pipes or channels, but also the street itself. With minor storms, structural measures should ensure that water is shed from the street into side drainage channels, and with major storms, these measures should limit the period of impassability while the street functions as a drainage channel itself. In the latter case the street should be paved.

In addition to paving basic access streets for reasons of drainage, erosion control and wet-weather accessibility, other factors such as dust and social issues may play a role.

Included in the social issues are politics, adjacent schools and hospitals, and the use of the streets as public areas.

Unpaved basic access streets therefore require side drainage channels that are lower than the street level to ensure that water is drained off the street into the side channel. These side channels should be carried through the main street at intersections. A maximum cross-fall of 5% is suggested for the street. For paved streets this cross-fall can be reduced to 3%. In Figure 8.5 typical cross-sections of basic access streets are illustrated. For basic access streets, excess water can be handled in side channels or even on the street itself, acting as a channel-and-street combination, and be led to open areas (e.g. sports fields, parks) for dissipation. For an unpaved network, channels - as shown in Figure 8.6 - and not pipes are required. Pipes can be considered only where all the basic access streets are surfaced owing to the problem of silting, or where the gradient of the pipe and design of inlets and outlets are such that silting and blocking will not occur (NITRR, 1984a).

Channels should be designed to prevent silting or ponding of stagnant water, yet avoid excessive erosion. Ponding is of particular importance as it can result in water soaking into the structural layers of the pavement. The draft TRH17 (NITRR, 1984b) gives guidelines on the design of open channels to prevent silting.

The longitudinal gradient of a channel and the material used determine the amount of scouring or erosion of such channels. Table 8.13 provides the scour velocities for various materials and guidance on the need to line or pave channels. Linings of hand-packed stone can be as functional as concrete linings. As a rough guide it is suggested that an unpaved channel should not be steeper than 2% (1:50).

Accesses to dwelling units should provide a smooth entry, whilst preventing stormwater in the street or channel from running onto properties. Where side drainage is provided to streets, special attention should be paid to the design of access ramps, or the elimination of the need for ramps to safeguard the functioning of the drainage channels.

Kerbing is not used extensively on basic access streets if they are surfaced, but edging may be used as an alternative when the shoulder or sidewalk material is of inadequate stability. However, it should be stressed that the shoulder of a surfaced basic access street should be constructed with

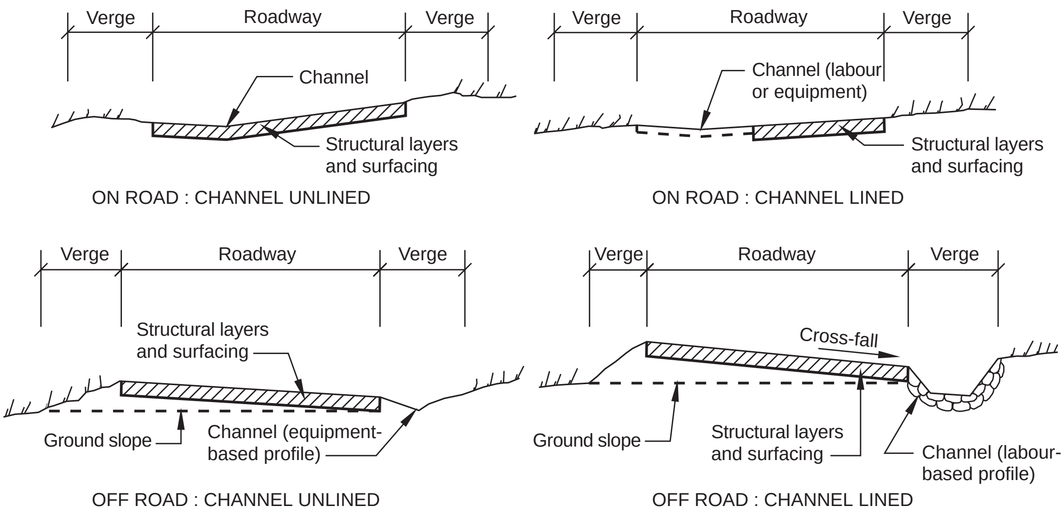

Figure 8.5: Typical basic access street cross-sections

material of at least the same quality as the subbase (Netterberg and Paige-Green 1988).

The shoulder should preferably be protected with a bituminous surfacing. The cost of this can be high however, and the decision will have to be based on affordability.

Erosion control for tertiary ways

Erosion control is considered to be the main criterion in the design of tertiary ways. Stormwater must be accommodated by ditches and drains on the sides of the tertiary ways. In Figure 8.6 typical detail is given of such ditches. Detail is also given of stilling ponds, catchwater drains and check dams. These should be seen as typical examples illustrating the principles involved. Check dams are used on downhill tertiary ways to dissipate the energy of the stormwater and to form natural steps.

Table 8.13: Scour velocities for various materials

MATERIAL	ALLOWABLE VELOCITY(m/s)
Fine sand	0,6
Loam	0,9
Clay	1,2
Gravel	1,5
Soft shale	1,8
Hard shale	2,4
Hard rock	4,5

When low points are reached, drifts and dished drains can be used to give preference to the flow of water without major structural requirements. Erosion protection on the approaches must be provided for. Details of typical drifts and dish drains are shown in Figures 8.7 and 8.8.

Tertiary ways would normally be constructed from the in situ material. The use of vegetation to prevent erosion is highly recommended and can be achieved by various means. Grass-blocks are but one example where vegetation is used to prevent erosion (Figure 8.9). These should, however, be regularly maintained to avoid a build-up of grass and silt.

Subsurface drainage

Subsurface drainage design is a specialised subject and both the infiltration of surface water and the control of subsurface water have to be considered. The basic philosophy is to provide effective drainage to (at least) material depth so that the pavement structure does not become excessively wet.

Subsurface drainage problems can be reduced most effectively by raising the road above natural ground level. This cannot always be done in the urban situation and the provision of side drains adjacent to the road, to a depth as low as possible beneath the road surface is equally effective.

If neither of these two options is practical, and ground water or seepage flows prevail, some form of cut-off trench with an interceptor drain may be necessary. These are expensive and other options (such as a permeable layer beneath the subbase) could also be considered.

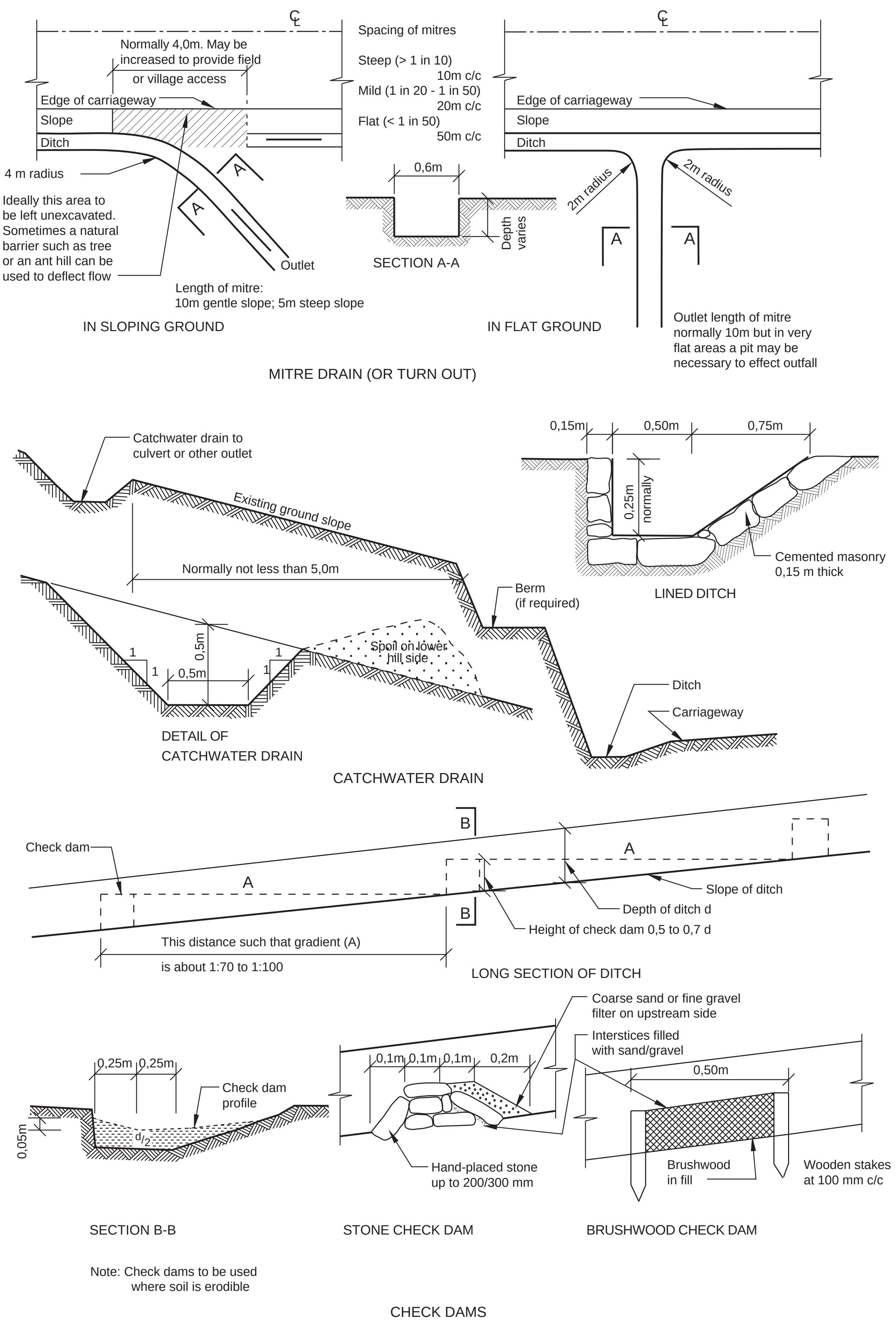

Figure 8.6: Tertiary ways: ditches and drains

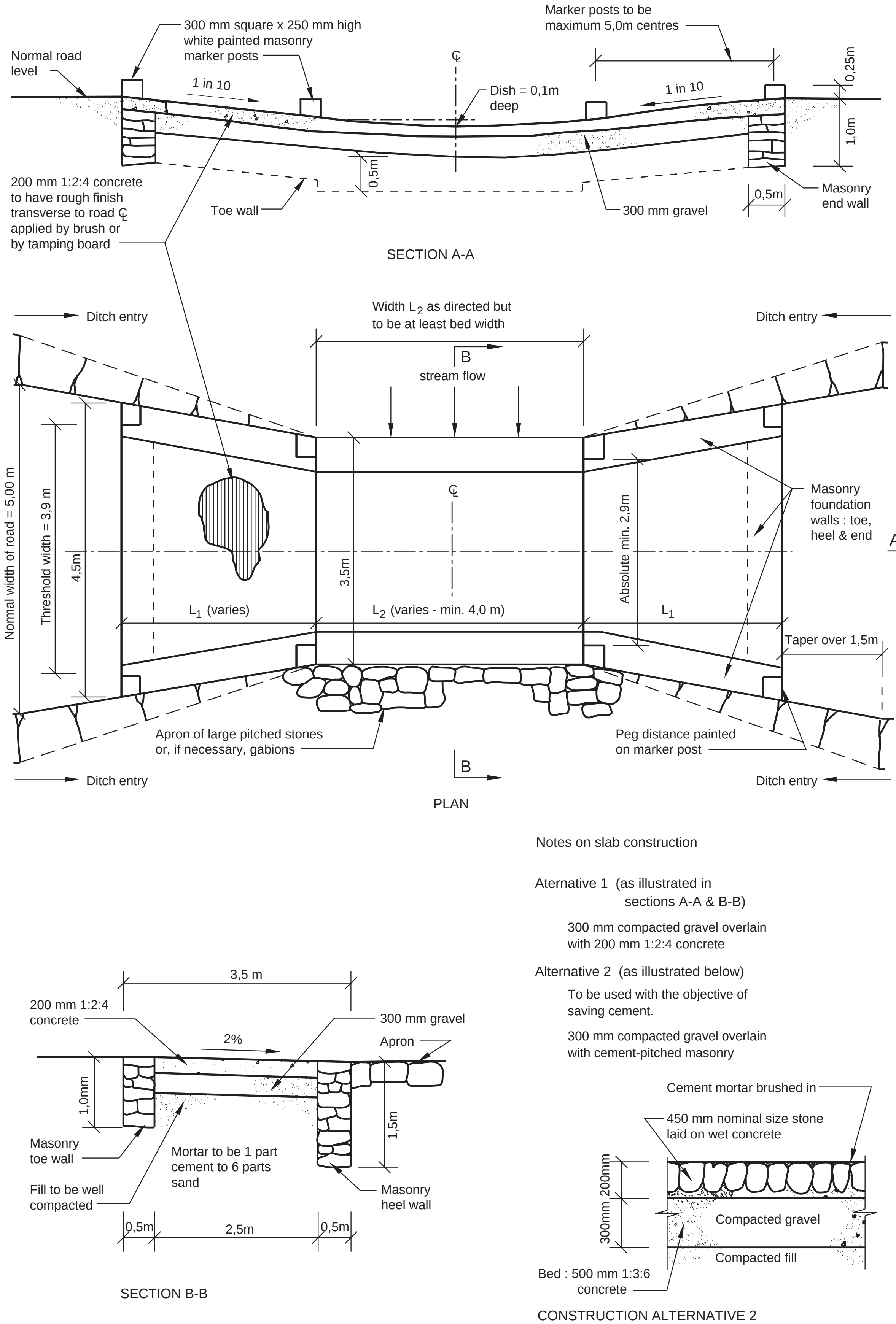

Figure 8.7: Tertiary ways: drift

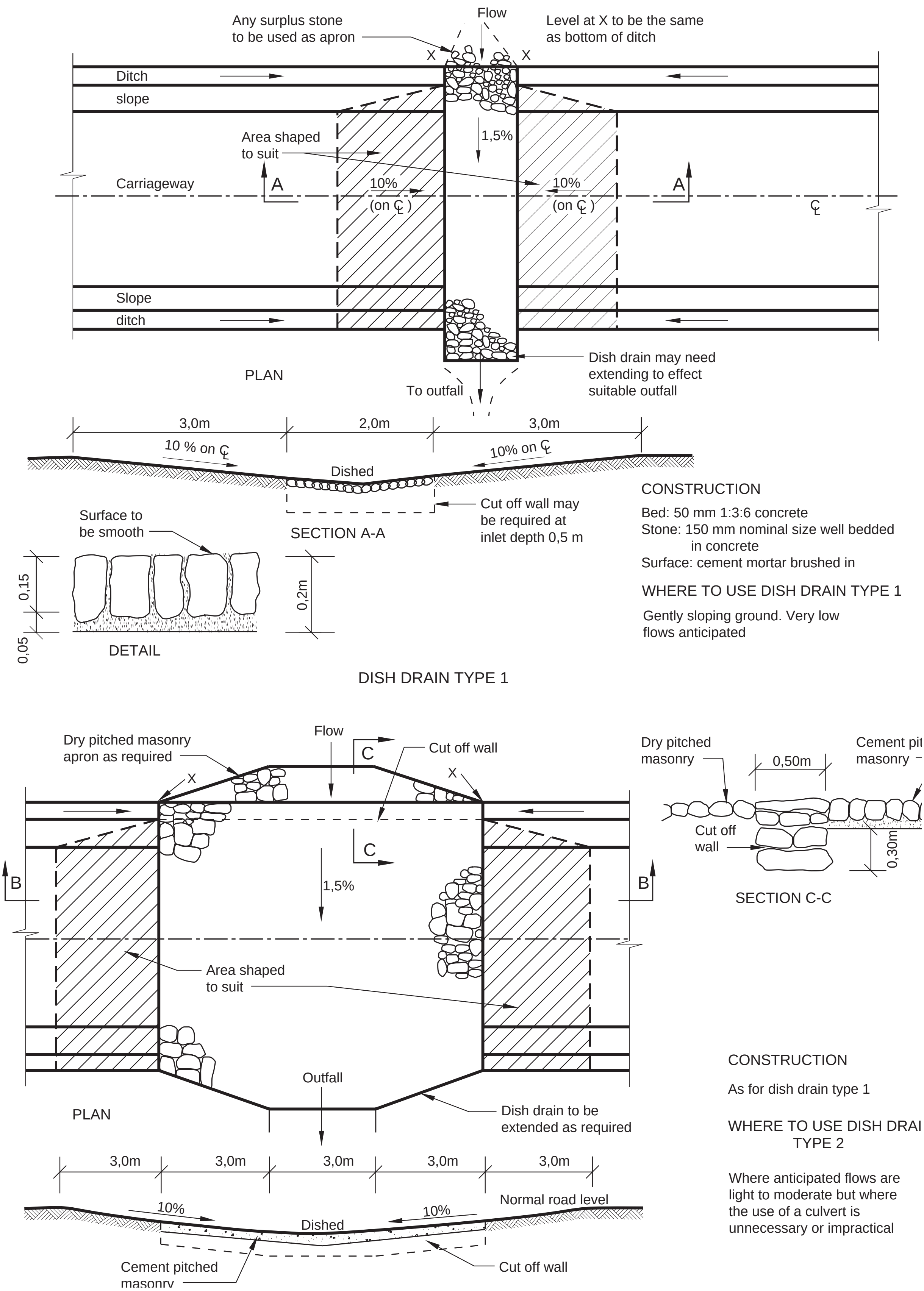

Figure 8.8: Tertiary ways: dish drains

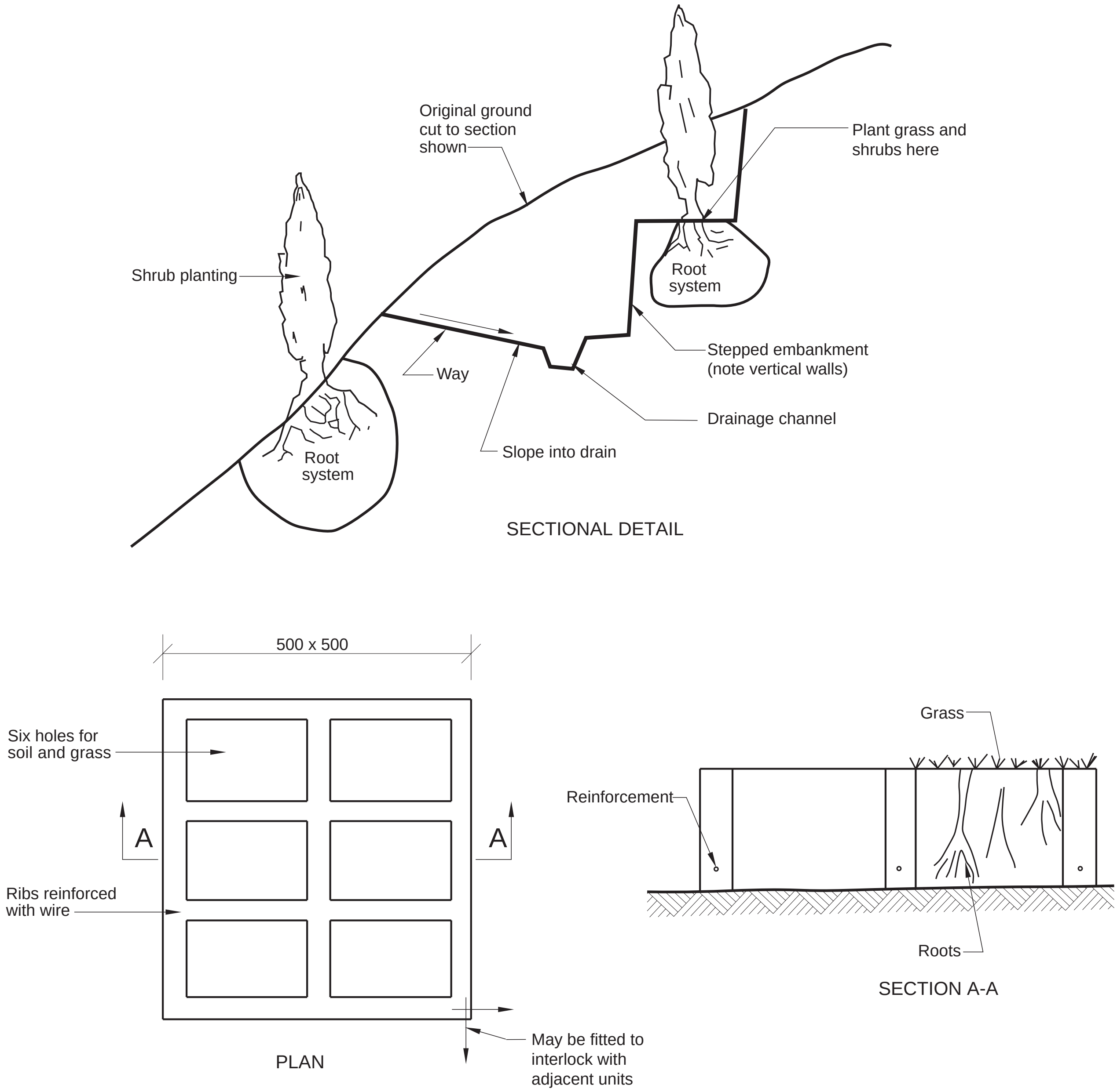

Figure 8.9: Typical grass block and vegetation

Subsurface water problems are frequently encountered where water provision in urban areas is by way of standpipes adjacent to roads. Apart from the surface runoff, significant seepage into the ground occurs and this frequently passes directly beneath the adjacent road. Careful drainage in the areas surrounding standpipes is thus essential.

As discussed earlier, subsurface drainage is a specialised field requiring a good knowledge of water flow regimes, drainage paths and filter criteria, and specialist assistance should be obtained.

Compaction

The design procedures assume that the specified material properties are satisfied in the field. A number of the traditional material properties (e.g. grading, plasticity) are independent of the construction process, but the strength is strongly dependent on the compaction achieved in the field. The design strength is based on the laboratory-determined strength of the material at a specified density. In order to ensure that this strength is obtained in the field, that particular density must be achieved during the field compaction. Table 8.14 gives the minimum compaction standards required for the various layers of the pavement structure. Note that, below base level, the standards are independent of the type of material used. As most

Table 8.14: Compaction requirements for the construction of pavement layers (and reinstatement of pavement layers)

PAVEMENT LAYER		COMPACTED DENSITY
Surfacing	Asphalt	95% 75-blow Marshall
Base (upper and lower)	Crushed stone	G1 86% to 88% apparent density G2 100% to 102% mod AASHTO
	Crushed stone G3 and gravel G4	98% mod AASHTO
	Asphalt	95% 75-blow Marshall 92% theoretical max
	Cemented	97% mod AASHTO
Subbase (upper and lower)		95% mod AASHTO
Selected subgrade		93% mod AASHTO
Subgrade (within 200 mm of selected subgrade) (within material depth)		 90% mod AASHTO 85% mod AASHTO
Fill (cohesionless sand)		90% mod AASHTO (100% mod AASHTO)

materials below base level will have a potential density somewhat in excess of the specified density which is relatively easily achieved if compaction is carried out at the correct moisture content, an attempt should be made to get as close to 100% Mod AASHTO density as possible. This has significant benefits in terms of an increased shear strength, a reduced potential to rut, and lower moisture susceptibility. Standard practice should be to roll the layer to refusal density based on proof rolling of a short section prior to its full compaction. Hand-held rollers may be inadequate to achieve the required density.

Subgrade below material depth

Special subgrade problems requiring specialist treatment may be encountered. The design procedure assumes that these have been taken into account separately. The main problems that have to be considered are the following:

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

The techniques available for terrain evaluation and soil mapping are given in TRH2 *Geotechnical and soil engineering mapping for roads and the storage of materials data* (NITRR 1978). Specialist advice should be obtained where necessary for specific problem areas. The design of embankments should be done in accordance with TRH10 *Site investigation and the design of road embankments* (NITRR 1984d).

Street levels

The fact that the provision of vehicular access adjoining streets, dwellings and commercial establishments is the primary function of an urban street means that street levels become a rather more important factor in urban areas than they are in rural or inter-urban street design. Urban street levels place some restrictions on rehabilitation and create special moisture/drainage conditions.

In some cases, rehabilitation in the form of an overlay may cause a problem, particularly with respect to the level of kerbs and channels, camber and overhead clearances. In these cases strong consideration should be given to bottom-heavy designs (i.e. designs with a cemented subbase and possibly a cemented base), which would mainly require the same maintenance as thin surfacings and little structural maintenance during the analysis period.

Urban streets are frequently used as drainage channels for surface-water runoff. This is in sharp contrast with urban, inter-urban and rural roads which are usually raised to shed the water to side table drains some distance from the road shoulder.

Service trenches

Trenches excavated in the pavement to provide essential services (electricity, water, telephone, etc) are frequently a source of weakness. This is a result of either inadequate compaction during reinstatement, or saturation of the backfill material.

Compaction must achieve at least the minimum densities specified in the catalogue of designs and material standards (Table 8.14). These densities are readily achieved when granular materials are used, but it becomes much more difficult when natural materials are used, particularly in the case of excavated clays. When dealing with clay subgrades it is recommended that, if it is economically feasible, a moderate-quality granular material be used as a trench backfill in preference to the excavated clay. In streets of Category UB and higher it is preferable to stabilise all the backfill material and in lower categories the provision of a stabilised "cap" over the backfill may be considered to eliminate settlement as far as possible. Care must be taken not to over-stabilise (i.e. produce a concrete) as this results in significant problems with adhesion of the surfacing and differential deflections causing failure around the particles.

Service trenches can also be the focal points of drainage problems. Settlement in the trench, giving rise to standing water and possibly to cracking of the surface, will permit the ingress of moisture into the pavement. Fractured water, sewerage or stormwater pipes lead to saturation in the subgrade and possibly in the pavement layers as well.

Alternatively, a trench backfilled with granular material may even act as a subsurface drain, but then provision for discharge must be made. It is, however, generally recommended that the permeability of the backfill material should be as close as possible to that of the existing layers in order to retain a uniform moisture flow regime within the pavement structure.

Pavement cross-section

Generally, it is preferable to keep the design of the whole carriageway the same, with no change in layer thickness across the street. However, where there are significant differences in the traffic carried by individual lanes (e.g. in climbing lanes), the pavement structure may be varied over the cross-section of the carriageway, provided that this is economical and practical. Under these circumstances, the actual traffic predicted for each lane should be used in determining the design traffic.

The cross-section can be varied with steps in the layer thickness, or wedge-shaped layers. Under no circumstances should the steps be located in such a way that the water can be trapped in them. Typical elements of the pavement cross-section for a paved urban street are shown in Figure 8.10.

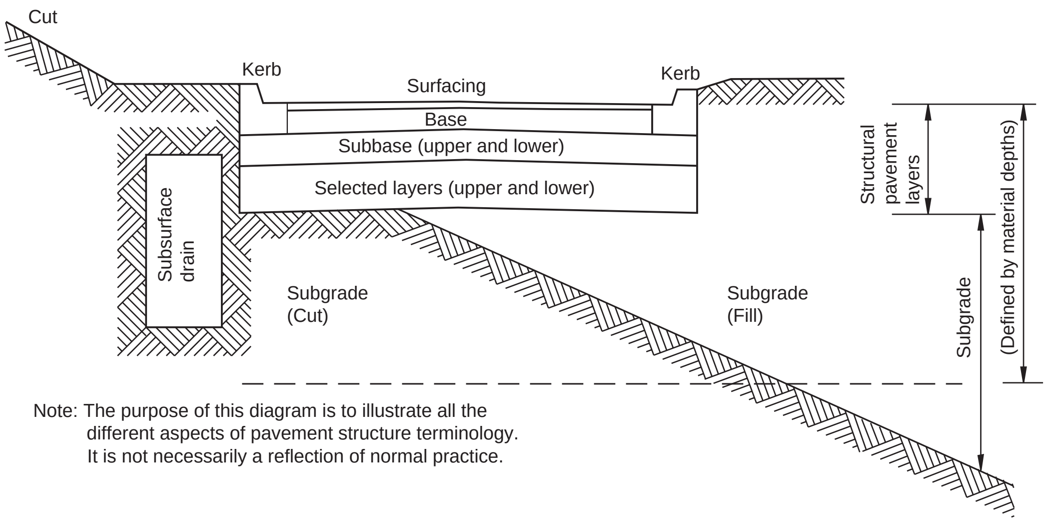

Figure 8.10: Illustrative pavement cross-section

Considerations for concrete pavements

Details on the design of concrete pavements are beyond the scope of this document. However, some basic practical recommendations are offered below (SA Department of Transport 1977):

- The subgrade should be prepared to provide a uniform support.
- The subbase should be stabilised to a high quality to provide a non-pumping, erosion-resistant, homogeneous pavement support.
- When jointed concrete pavements are used, attention should be given to joint details such as spacing, type and sealing.

Kerbs and channels

Kerbs and channels are important to prevent edge erosion and to confine stormwater to the street surface.

Consideration should be given to the type and method of construction of kerbs when deciding on a layer thicknes for the base.

It is common practice to construct kerbs upon the (upper) subbase layer to provide edge restraint for a granular base. This restraint will help to provide the specified density and strength. Care must be taken to ensure that this type of structure does not "box" moisture into the base course material.

In the case of kerbing with a fixed size (i.e. precast kerbing or kerbing with fixed shutters cast in situ) it may be advantageous to design the base thickness to conform with the kerb size (e.g. if the design calls for a 30 mm AG with a 125 mm G4 underlay, and the gutter face is 160mm, rather use a 130 mm G4).

Edging

Instead of kerbs, edging could be used for low-traffic streets when the shoulder or sidewalk material is of adequate stability. This material should be shaped to the correct level and the edge may be sealed with a prime coat, a sand seal, a slurry seal or a premix. A degree of saving may be possible by utilising trimmed grass verges where longitudinal gradients are low and stormwater flows are not likely to be high.

Accessibility

Access to dwelling units should be provided for in such a way that adequate sight distances and a smooth entry are provided, but the access ways should at the same time keep stormwater on the street from running into adjacent properties.

At pedestrian crossings special sloped openings in the kerbs should be provided to accommodate the handicapped and hand-pushed carts.

COST ANALYSIS

General

Alternative pavement designs should be compared on the basis of cost. The cost analysis should be regarded as an aid to decision-making. However, a cost analysis may not take all the necessary factors into account and it should therefore not override all other considerations. The main economic factors that determine the cost of a facility are the analysis period, the structural design period, the construction cost, the maintenance cost, the salvage value at the end of the analysis period and the real discount rate.

A complete cost analysis should be done for Category UA and UB streets. For Category UC and UD streets, a comparison of the construction and maintenance costs will normally suffice.

The method of cost analysis put forward in this document should be used only to compare pavement structures in the same street category. This is because streets in different street categories are constructed to different standards and are expected to perform differently, with different terminal levels of service. The effect these differences have on street user costs is not taken into account directly.

The choice of analysis period and structural design period will influence the cost of a street. The final decision will not necessarily be based purely on economics, but will depend on the design strategy.

The construction cost should be estimated from current contract rates for similar projects. Maintenance costs should include the cost of maintaining adequate surfacing integrity (e.g. through resealing) and the cost of structural maintenance (e.g. the cost of an asphalt overlay). The salvage value of the pavement at the end of the analysis period can contribute to the next pavement. However, geometric factors such as minor improvements to the vertical and horizontal alignment and the possible relocation of drainage facilities make the estimation of the salvage value very difficult.

Present worth

The total cost of a project over its life is the construction cost plus maintenance costs, minus the salvage value. The total cost can be expressed in a number of different ways but, for the purpose of this document, the present worth of costs (PWOC) approach has been adopted.

The present worth of costs can be calculated as follows:

$$PWOC = C + M_1 (1 + r)^{-x_j} + \ldots M_j(1 + r)^{-x_j} + \ldots -S(1 + r)^{-z} \qquad (8.10)$$

where

PWOC = present worth of cost

C = present cost of initial construction

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

r = real discount rate

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

z = analysis period

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

Construction costs

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

The cost of excavation should be included as certain pavement types will involve more excavation than others.

Maintenance costs

There is a relation between the type of pavement and the maintenance that might be required in the future. When different pavement types are compared on the basis of cost, these future maintenance costs should be included in the analysis to ensure that a sound comparison is made. It should also be noted that relaxations of material, drainage or pavement thickness standards will normally result in increased maintenance costs.

Figures 8.2 and 8.3 show that the life of the surfacing and water ingress into the pavement play an important part in the behaviour of some pavements. For this reason, planned maintenance of the surfacing is very important to ensure that these pavements perform satisfactorily. The service life of each type of surfacing will depend on the traffic and the type of base used. Table 8.15 gives guidelines regarding the service life that can be expected from various surfacing types. These values may be used for a more detailed analysis of future maintenance costs.

Typical maintenance measures that can be used for the purpose of cost analysis are given in Table 8.16. It should be noted that, since the costs are discounted to the present worth, the precise selection of the maintenance measure is not very important. Some maintenance measures are used more commonly on specific pavement types and this is reflected in Table 8.16. There are two types of maintenance:

- measures to improve the condition of the surfacing; and
- structural maintenance measures applied at the end of the structural design period.

The structural design period (SDP) has been defined as the period for which it is predicted with a high degree of confidence that no structural maintenance will be required. Therefore, typical structural maintenance will generally only be necessary at a later stage. If structural maintenance is done soon after the end of the structural design period, the distress encountered will only be moderate. When structural maintenance is done much later, the distress will generally be more severe. Figure 8.11 indicates the degree of distress to be expected at the time of rehabilitation for different structural design periods. Table 8.16 makes provision for both moderate and severe distress.

The typical maintenance measures given in Table 8.16 should be replaced by more accurate values, if specific knowledge about typical local conditions is available.

Street-user delay costs should also be considered, although no proper guide for their determination is readily available. The factors that determine overall street user costs are:

- running costs (fuel, tyres, vehicle maintenance and depreciation), which are largely related to the street alignment, but also to the riding quality (PSI);
- accident costs, which are related to street alignment, skid resistance and riding quality; and
- delay costs, which are related to the maintenance measures applied and the traffic situation on the streets. This is a difficult factor to assess as it may include aspects such as the provision of detours.

Table 8.15: Suggested typical ranges of period of service (without rejuvenators) of various surfacing types in the different street categories and base types (if used as specified in the catalogue)

BASE TYPE	SURFACING TYPE (≤ 50 mm THICKNESS)	TYPICAL RANGE OF SURFACING LIFE (YEARS) ROAD CATEGORY		
		A (ES3-ES100)	B (ES1-ES10)	C, D (ES0,003-ES3)
Granular	Bitumen sand or slurry seal	-	-	2 - 8
	Bitumen single surface treatment	6 - 8	6 - 10	8 - 11
	Bitumen double surface treatment	6 - 10	6 - 12	8 - 13
	Cape seal	8 - 10	10 - 12	8 - 18
	Continuously-graded asphalt	8 - 11		
	Gap-graded asphalt premix	8 - 13		
Bituminous	Bitumen sand or slurry seal	-	-	2 - 8
	Bitumen single surface treatment	6 - 8	6 - 10	8 - 11
	Bitumen double surface treatment	6 - 10	6 - 12	8 - 13
	Cape seal	-	8 - 15	8 - 18
	Continuously-graded asphalt	8 - 12	8 - 12	-
	Gap-graded asphalt premix	8 - 14	10 - 15	-
	Porous (drainage) asphalt premix	8 - 12	10 - 15	-
Cemented	Bitumen sand or slurry seal	**	-	-
	Bitumen single surface treatment	**	4 - 7	5 - 8
	Bitumen double surface treatment	**	5 - 8	5 - 9
	Cape seal	**	5 - 10	5 - 11
	Continuously-graded asphalt	**	5 - 10	-
	Gap-graded asphalt premix	**	6 - 12	-

- Surface type not normally used.

** Base type not used.

Real discount rate

When a “present-worth” analysis is done, a real discount rate must be selected to express future expenditure in terms of present-day values. This discount rate should correspond to the rate generally used in the public sector. Unless the client clearly indicates that he prefers some other rate, 8% is recommended for general use. A sensitivity analysis using rates of say 6,8 and 10% could be carried out to determine the importance of the value of the discount rate.

Salvage value

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

- Where the existing pavement is left in position and an overlay is constructed, the salvage value of the pavement would be the difference between the cost of constructing an overlay and the cost of constructing a new pavement to a standard equal to that of the existing pavement with the overlay. This is termed the “residual structural value”.

- Where the material in the existing pavement is taken up and recycled for use in the construction of a new pavement, the salvage value of the recycled layers would be the difference between the cost of furnishing new materials and the cost of taking up and recycling the old materials. This salvage value is termed the “recycling value”.

- In some cases the procedure followed could be a combination of (a) and (b) above and the salvage value would have to be calculated accordingly.

Table 8.16: Typical future maintenance for cost analysis

BASE TYPE	TYPICAL MAINTENANCE MEASURES*			
	MEASURES TO IMPROVE THE SURFACING CONDITION**		STRUCTURAL MAINTENANCE	
	SURFACE TREATMENT ON ORIGINAL SURFACING	ASPHALT PREMIX	MODERATE DISTRESS	SEVERE DISTRESS
Granular	S1 (10 - 15 yrs) S1 (18 - 27 yrs)	S1 (12 - 20 yrs) S1 (21 - 30 yrs) or AG (13 - 22 yrs) AG (24 - 33 yrs)	30 - 40 AG, AC	>100 BS, BC or Granular overlay or Recycling of base
Bituminous		S1 (13 - 17 yrs) S1 (22 - 28 yrs) or AG (13 - 17 yrs) AG (26 - 34 yrs)	30 - 40 AG, AC	>100 BS, BC or Recycling of base
Concrete	Joints repair, surface texturing (15 yrs, 30 yrs) (equivalent cost of 20 mm PCC)		Further joint and surface repairs	Concrete granular or Bituminous overlay or Recycling
Cemented	S1 (8 - 13 yrs) S1 (16 - 24 yrs) S1 (23 - 30 yrs)	S1 (8 - 13 yrs) S1 (16 - 24 yrs) S1 (23 - 30 yrs)	Further surface treatments	Thick granular overlay or Recycling of base
Paving blocks	No maintenance measures		Re-levelling of blocks	Rebuild base, bedding sand and blocks
Cast-in-situ blocks	No maintenance measures		Remove and replace blocks with cast-in-situ blocks	Rebuild underlying layer and place cast-in-situ blocks

* S1 (10 yrs) represents a single surface treatment at 10 years and 40 AG (20 yrs) represents a 40 mm thick bitumen surfacing at 20 years.

** Refer to Table 8.15 for typical lifetimes of different surfacing types.

The salvage values of individual layers of the pavement may differ considerably, from estimates as high as 75% to possibly as low as 10%. The residual salvage value of gravel and asphalt layers is generally high, whereas that of concrete pavements can be high or low, depending on the condition of the pavement and the method of rehabilitation. The salvage value of the whole pavement would be the sum of the salvage values of the individual layers. In the absence of better information, a salvage value of 30% of initial construction cost is recommended.

Optimisation of life-cycle costs

In Table 8.2 a description of the street and its drainage is given, with their LOS values. In the matrix the combined LOS value is given. The final LOS value is determined mostly by the LOS of the drainage.

The main purpose of the determination of a representative LOS for a street is to illustrate the associated life-cycle costs. This identification can enable authorities and decision makers to select a design which will be affordable and upgradable. The costs associated with a typical street are made up of design and construction costs, maintenance costs and street-user costs. Construction costs are high for high LOS values and low for low LOS values. Maintenance costs, on the contrary, are low for high LOS values and high for low LOS values.

This concept is illustrated in Figure 8.12 with typical, present worth-of-cost versus LOS values. The combined cost curve has a typical minimum value between the highest and lowest LOS values. Street-user costs are low for high LOS streets and high for low LOS streets.

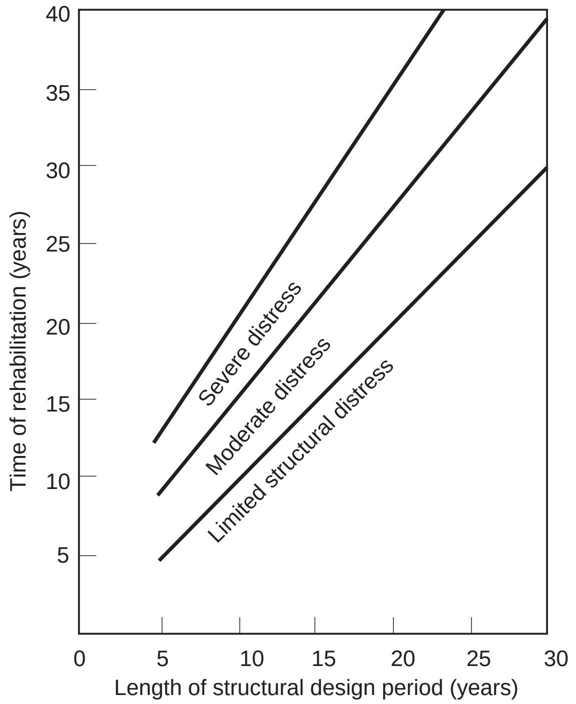

Figure 8.11: Degree of structural distress to be expected at the time of rehabilitation for different structural design periods

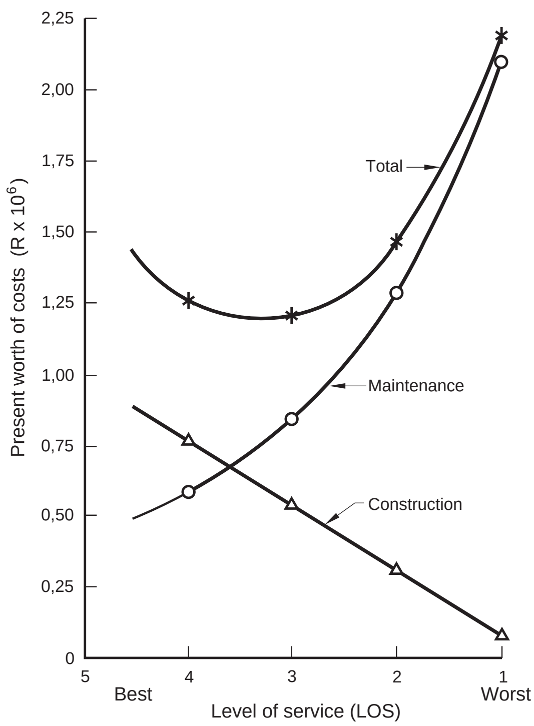

Figure 8.12: Typical cost versus level of service curve values

DISCUSSION ON THE DESIGN PROCEDURES FOR DIFFERENT STREET TYPES

At this stage the designer should have gathered enough information on the street(s) to be designed, to be able to decide which design procedure to follow - as illustrated in Figure 8.1. If an existing network is to be upgraded, the information contained in the street profiles may be used to determine paving priorities at this stage. With a background knowledge of the basic concepts from the previous section, it is now possible to go into the detailed structural design of the street pavements.

PAVED ARTERIAL AND ACCESS STREETS

The design process

The portion of the flow diagram in Figure 8.1 that refers to the design of paved arterial and access routes is enlarged upon in Figure 8.13, and divided into 8 sections. Each section will be treated separately but all sections have to be considered as a whole before a design can be produced.

The first five sections represent the basic inputs to pavement design, namely street category, design strategy, design traffic, material availability and environment. The sixth section explains how, with these as inputs, the designer can then use an appropriate design method to obtain possible pavement structures. Information on certain practical considerations in the design of streets follows in the seventh section. In the final section the analysis of alternative designs on a life-cycle cost basis, in the light of construction costs and maintenance costs, is considered.

A simplified flow diagram for the structural design of residential streets (Category UC and UD only) is suggested in Figure 8.14.

Street category

The street category will have been identified during the process of compiling the street profile, and will most likely be UA, UB or UC. The section on characteristics of streets may be consulted for a discussion on street categories in general.

Design strategy

Select an appropriate analysis and structural design period for the street under consideration. The section on street standards provides guidelines on typical analysis and design periods and lists other factors that need to be considered.

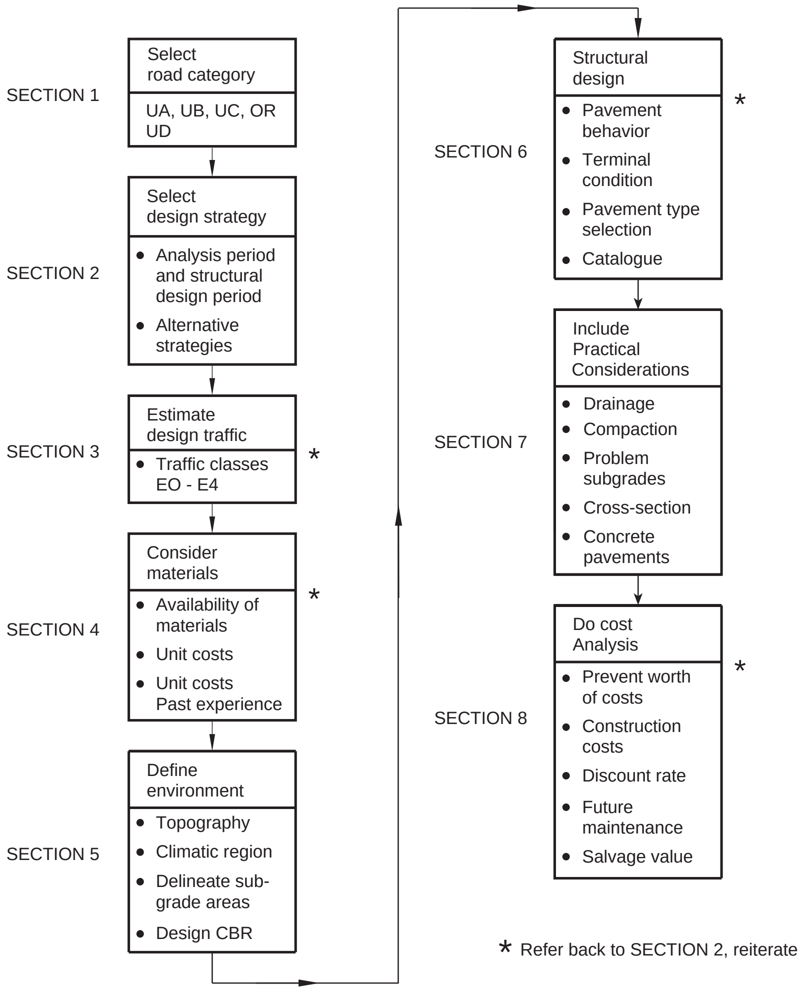

Figure 8.13: Structural design flow diagram (mainly for category UA and UB streets)

Design bearing capacity

Calculate the cumulative equivalent traffic for the particular street, according to the procedure outlined in the section on design strategy. Based on the cumulative equivalent traffic, an appropriate pavement class or design bearing-capacity interval may then be selected from Table 8.5.

Materials

Most of the materials for the selected, subbase and base layers of the pavement structures applicable to arterial and access streets will usually have to be imported. Possible material sources and the availability and cost of different types of material should be established. The availability of material combined with the expected behaviour of the major types of material and pavement, as discussed in the section on materials, will determine the final selection of the appropriate materials and pavements for particular needs.

Environment

The two most important environmental factors to consider are the climatic region and the design of the subgrade on which the street will be constructed. These are discussed in the section on environment.

Structural design

The actual structural design has two aspects - the selection of appropriate pavement types and an appropriate design method for the particular street.

<u>Pavement selection</u>

The behaviour of different pavement types has been dealt with. Certain types may not be suitable for some street categories, traffic classes or climatic regions. A number of alternative types should, however, be selected. The most cost-effective design will then be identified in the economic analysis.

Pavement structures with thin, rigid or stiff layers at the top (shallow structures) are generally more sensitive to overloading than deep structures. If many overloaded vehicles can be expected, shallow structures should be avoided.

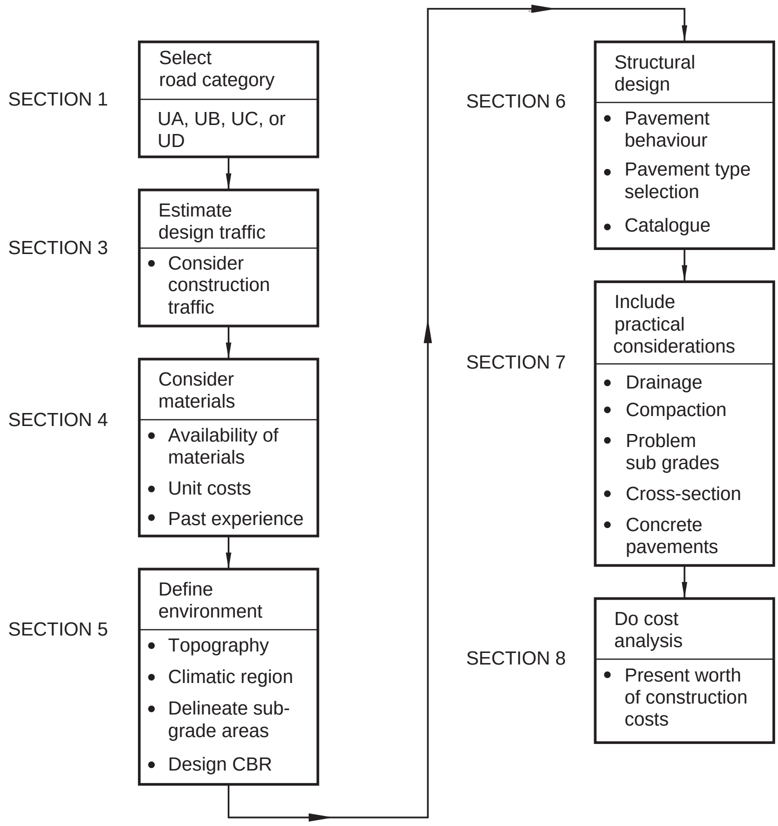

Figure 8.14: Simplified design flow diagram for residential streets (category UC and UD)

Figure 8.3 indicates that the more rigid structures deteriorate rapidly once distress sets in, whereas the more flexible pavements generally deteriorate more slowly. Signs of distress are often more visible on rigid pavements.

Pavement structures consisting of water-susceptible materials may be undesirable for wet climatic regions, unless special provision is made for drainage.

Table 8.17 shows recommended pavement types (base and subbase) for different street categories and traffic classes. Reasons why certain pavement types are not recommended are also stated briefly.

Possible condition at end of structural design period:

There is no design method available to predict the exact condition of a length of street 10 to 20 years in the future. However, certain modes of distress can be expected in certain pavement types and account must be taken of such distress. Table 8.18 shows acceptable terminal conditions of rut depth and cracking for the various street categories and pavement types. Figure 8.15 demonstrates that the rut depth values in Table 8.18 actually represent ranges of failure conditions.

Although the net depth conditions may be classified as terminal, there may be instances where the rutting has occurred primarily in the subgrade and the structural layers are still integral. In these cases the rutting may be rectified - using, for example, a thick slurry - and the street may continue to provide an acceptable level of service.

<u>Design method selection</u>

The designer may use a number of design procedures, such as the mechanistic design method, the AASHTO structural number method, the CBR cover curves or the catalogue of designs given in Appendix A. A brief overview of a selected number of design methods is given in the section on structural design methods above. Whatever the strategy used, traffic, available materials and environment must be taken into account. Some estimation of future maintenance measures is necessary before a comparison can be made on the basis of present worth of costs. Special construction considerations that might influence either the pavement structure or the pavement costs are discussed below in the section dealing with practical considerations.

This document includes the application of the catalogue design method, which is given in detail in Appendix A. However, the best results will probably be obtained if the catalogue is used together with some other design method. The

Table 8.17: Suggested pavement types for different road categories and traffic classes

PAVEMENT TYPE		STREET CATEGORY AND PAVEMENT CLASS (DESIGN BEARING CAPACITY)*										ABBREVIATED REASON WHY THE LISTED PAVEMENT TYPES ARE NOT RECOMMENDED FOR THE GIVEN STREET CATEGORY AND TRAFFIC LOADING
BASE	SUBBASE	UA			UB		UC			UD		
		ES 30	ES 10	ES 3	ES 3	ES 1	ES 1	ES 0,3	ES 0,1	ES 0,1	ES 0,03	
Granular	Granular	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	Uncertain behaviour
	Cemented	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	
Asphalt hot-mix	Granular	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	
	Cemented	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	
Concrete	Granular	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Extra thickness required to prevent fatigue cracking
	Cemented	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Too expensive, too difficult to trench
Cemented	Granular	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	Fatigue cracking, pumping and rocking of blocks
	Cemented	✗	✗	✗	✓	✓	✓	✓	✗	✗	✗	Shrinkage cracks unacceptable
Paving blocks	Granular	✗	✗	✗	✓	✓	✓	✗	✗	✗	✗	Not recommended at high speeds
	Cemented	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	
Bituminous cold-mix	Granular	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	
	Cemented	✗	✓	✓	✓	✓	✓	✗	✗	✗	✗	
Macadams	Granular	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	
	Cemented	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Cast-in-situ blocks		✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	Not recommended at high speeds

See Table 8.6 for definition of pavement classes.

Table 8.18: Possible condition at end of structural design period for various street categories and pavement types

POSSIBLE CONDITION AT END OF STRUCTURAL DESIGN PERIOD	ROAD CATEGORY			
	UA	UB	UC	UD
Rut depth Length of road exceeding stated rut depth (refer to Figure 8.15)	20 mm 10 %	20 mm 15 %	20 mm 25 %	20 mm 40 %
Type of cracking				
Granular base	Crocodile cracking, surface loss, pumping of fines			
Bituminous base	Crocodile cracking, pumping of fines			
Concrete pavement	Slab cracking, spalling at joints, pumping of fines			
Cemented base	Block cracking, rocking blocks, pumping of fines			
Proportion of road on which stated types of cracking occur	10%	15%	25%	40%

catalogue method can serve as a useful starting point, even if other design methods are used.

<u>The application of the catalogue design method</u>

General:
It should be noted that these designs are considered adequate to carry the total design equivalent traffic over the structural design period. Construction constraints on practical layer thicknesses and increments in thicknesses are met. It is assumed that the requirements of the material standards are met. The catalogue may not be applicable when special conditions arise; other methods should then be used, but the catalogue can still act as a guide. The catalogue does not necessarily exclude other possible pavement structures.

Selected layers:
The catalogue assumes that all subgrades are brought to equal support standards. The design CBR of the subgrade is limited to four groups (Table 8.12). Normally, the in situ subgrade soil will be prepared or ripped and recompacted to a depth of 150 mm. On top of this prepared layer, one or two selected layers may be added. The required selected subgrade layers will vary, according to the design CBR of the subgrade. Table 8.19 shows the preparation of the subgrade and required selected layers for the different subgrade design CBRs.

Interpolation between traffic classes:
The pavement structures in the catalogue are considered adequate to carry the total design traffic, according to the upper value of the traffic classes defined in Table 8.5. The total design traffic may be predicted with more accuracy than is implied by the traffic classes. In such a case the designer may use a simple linear interpolation technique. In many designs the only difference between the structures for the various classes of traffic is a change in the layer thickness. In these cases the designer may use linear interpolation. However, there is often a change in material quality, as well as in thickness. Simple interpolation is then inadequate and the designer will have to use other design methods.

Surfacings:
Urban and residential streets carry both traffic and stormwater runoff. The traffic often consists of either large volumes of lightly loaded vehicles (e.g. on CBD streets) or virtually no vehicular traffic (e.g. on residential streets and culs-de-sac). In both cases, however, a high-quality surfacing is required. Such surfacing is also necessary because the street acts as a water channel.

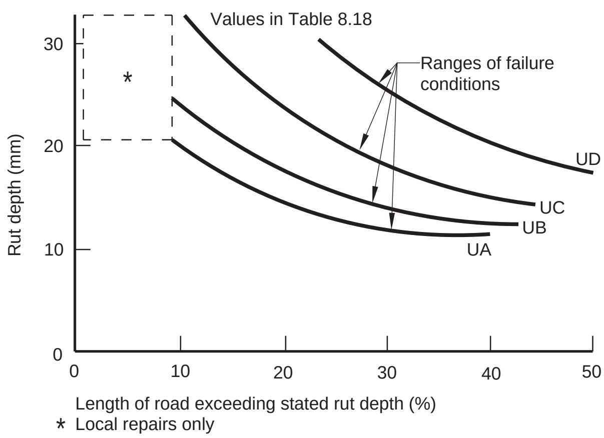

Figure 8.15: Ranges of terminal rut depth conditions for different street categories