From reviewing these documents (as well as others deemed appropriate), it will normally be straightforward to derive a design suited to the particular needs.

5.7 Rehabilitation of Existing Roads

Various methods exist for determining needs for rehabilitation and strengthening of existing roads, and it is recommended that the SATCC Code of Practice for Pavement Rehabilitation[4] be used in the first instance. The catalogue in this guide may then be used, amongst others, to review the rehabilitation needs identified and help establish the most effective treatment.

5.8 Use of the Dynamic Cone Penetrometer (DCP)

The DCP is probably the single most effective testing device for road construction, being a simple, rapid and direct indicator of material condition that can be used from initial site survey through to construction control. Its use within the region is already established, and this section is intended only to highlight the main aspects of its effective usage.

During initial field survey the DCP can aid in determining the existing subgrade condition, in conjunction with normal indicator and CBR tests, and therefore in delineating uniform sections for design. Similarly, during construction the DCP can be used to monitor uniformity of layers, particularly in terms of in situ density. It can also be used as a design tool in its own right and a method has been developed for such application[5].

While the DCP is commonly used to estimate in situ CBRs from nominal penetration rates (mm/blow), this technique should only be used when correlations have been specifically developed for the DCP apparatus used. It is known that several different types of DCP are commonly used, having different cone types and dynamic energy input. If used with the wrong CBR correlations, incorrect estimates of CBR will be obtained. Since changes in moisture content will influence the rate of penetration for a given density, the Engineer must ensure that this factor is taken into account if the DCP is used for CBR estimation.

Alternatively, and especially for control monitoring, the penetration rate can be used in its own right as a compliance check. For example, the Engineer can determine an acceptable maximum DCP penetration rate directly from in situ measurements on areas (of subgrade or constructed granular layers) deemed to meet the required field strength and density requirement. The DCP can then be used as a process control tool to check that the field compaction is satisfactory to the specified depth. Where penetration rates exceed the acceptable specified maximum value, further compaction is indicated.

The DCP should not be used specifically, however, as the basis for determining construction acceptance (ie, for density or strength compliance with the specification requirements): this should still be undertaken using the appropriate standard test methods.

Consequently the use of the DCP during the whole construction process, from initial field survey through to rapid compliance checking, can significantly reduce the need for some of the more onerous testing and its use is strongly recommended.

6. SELECTION OF POSSIBLE PAVEMENT STRUCTURES

The design catalogue is given as Appendix C, and comprises two distinct sets of structures for nominally dry and nominally wet conditions (Charts D1 to D5, and W1 to W5 respectively). The set of structures deemed most appropriate should be as determined from Section 4. The charts are classified as follows (Table 6.1):

Table 6.1: Classification of structures in the design catalogue

Chart designation	Nominal pavement structure*	Comment
D1 & W1	Granular base and granular subbase combination	Normally gravel or crushed stone base; can be macadam if deemed appropriate and cost/riding quality are not an issue
D2 & W2	Granular base and cemented subbase combination	Base: as above. Subbase could include lime treated (to class T2, < 0.75 million ESAs) or bitumen emulsion treated (to class T4, up to 3 million ESAs)
D3 & W3	Cemented base and cemented subbase combination	Normally cemented base; bitumen emulsion treated base permissible to class T3 (up to 1.5 million ESAs)**. Subbase could include lime treated (to class T2, < 0.75 million ESAs) or bitumen emulsion treated (to class T4, up to 3 million ESAs)
D4 & W4	Bituminous base and granular subbase combination	Hot plant-mix asphalt base
D5 & W5	Bituminous base and cemented subbase combination	Base: as above. Subbase could include lime treated (to class T2, < 0.75 million ESAs) or bitumen emulsion treated (to class T4, up to 3 million ESAs)

* Surfacings include surface treatments and hot-mix asphalt

** Bitumen emulsion treated natural gravels, with residual bitumen contents up to 1.5 per cent, and including 1.0 per cent OPC, have given satisfactory performance to significantly higher trafficking levels in South Africa (Guidelines for the use of bitumen emulsion treated materials are currently in development by the CSIR, Pretoria, South Africa for the Southern African Bitumen Association (Sabita). These should be available by December 1998. See also Appendix A).

The appropriate design set(s) can then be accessed on the basis of design trafficking class (from Section 2) and design subgrade condition (from Section 3), and the designer can review the alternatives to finalise the selection (See Construction note below).

As noted in the introduction, the designer should regard the selected structure as being one of many possibilities that is likely to provide adequate service for the given design conditions. It is therefore recommended that, when possible, the suggested structure be reviewed in terms of the specific conditions and in light of established local (or other appropriate) practices. This might enable judicious refinement of the structure to optimise for prevailing conditions.

Before finalising the structural design, the Engineer should confirm that it provides the most cost-effective solution for the particular application. This will be based primarily on initial costs, but must also take into account probable future periodic maintenance needs (such as resealing during the design life) based on expected performance in the prevailing conditions.

While not addressed in this document, the designer should be aware that the most cost-effective, or economic, road would be defined as that which minimises the total cost of the facility during its life time. Factors that would be included in such an analysis are the initial construction cost, the maintenance costs, the road user costs, and any assumed residual value at the end of the design life.

For practical purposes, where details of this nature are unavailable, unreliable, or otherwise deemed unnecessary, it can be assumed that comparison of initial (construction) costs will provide a good basis for final selection for the structures in this guide.

Construction note
In some cases, the catalogue structures have base, subbase or capping layers of substantial thickness (more than 200 mm). Actual construction lift thicknesses should be defined by the Engineer, and it is recommended that compacted lift thicknesses greater than 200 mm or less than 100 mm should generally be avoided. The underlying principle, however, is that full uniform compaction is achieved within the layer and that a good key between individual lifts/layers is achieved.

Both these factors have a marked effect on subsequent performance of the road, and every effort should be made to achieve the best compaction and bond. Local good practice for specific materials and compaction equipment should be followed where this is deemed appropriate. Monitoring and control checks should be instigated which provide confirmation of satisfactory layer construction.

7. REFERENCES

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APPENDIX A

MATERIALS

APPENDIX A: MATERIALS

A.1 Introduction

The specification of the materials to be used in the pavement are given in detail in the separate SATCC Standard Specifications for Road and Bridge Works document[6]. This Appendix is not intended to override any of the requirements given in that document, but is given in order to provide the pavement designer with certain insights that may not be readily apparent in the specification.

The information given here should therefore be regarded as general guidance, which might also provide a basis for considering the use of materials which may not otherwise fully comply with specification requirements.

This Appendix reviews the materials by class in the following sections: unbound, cemented and bituminous.

A.2 Unbound Materials

A.2.1 Granular Base Construction

A wide range of materials can be used for unbound bases. These include crushed rock or stone, naturally occurring as 'dug' gravels, and various combinations of crushing and screening, mechanical stabilisation or other modification. Their suitability for use depends primarily on the design traffic class of the pavement, and climate, but all base materials must have a particle size distribution and particle shape which provide high mechanical stability. In particular, they should contain sufficient fines (material passing the 0.425 mm sieve) to produce a dense material when compacted.

In circumstances where several types of base are suitable the final choice should take into account the expected level of future maintenance and the total cost over the expected life of the pavement. The use of locally available materials is encouraged, particularly at low traffic volumes (ie, categories T1 and T2).

In selecting and using natural gravels, their inherent variability must be taken into account in the selection process. This normally requires reasonably comprehensive characterisation testing to determine representative properties, and it is recommended that a statistical approach be applied in interpreting test results.

For lightly trafficked roads the specification requirements may be too stringent and reference should be made to specific case studies, preferably for roads under similar conditions, in deciding on suitability of materials which do not fully comply with specification requirements.

a) Graded Crushed Stone
Graded crushed stone can be derived from crushing fresh, quarried rock (used either as an all-in product, usually termed a crusher-run, or by screening and recombining to produce a desired particle size distribution), or from crushing and screening natural

granular material, rocks or boulders, to which may be added a proportion of natural fine aggregate.

After crushing, the material should be angular but not excessively flaky in order to promote good interlock and performance. If the amount of fine aggregate produced during crushing is insufficient, additional non-plastic sand may be used to make up the deficiency.

In constructing a crushed stone base, the aim should be to achieve maximum density and high stability under traffic. Aggregate durability is normally assessed by standard crushing tests but these are not as discriminating as durability mill testing, which is the preferred method.

The material is usually kept damp during transport and laying to reduce the likelihood of particle segregation. These materials are commonly dumped and spread by grader, rather than the more expensive option of using a paver, which demands greater construction skill to ensure that the completed surface is smooth with a tight finish. The Engineer should pay particular attention to this aspect to guarantee best performance. When properly constructed, however, crushed stone bases will have CBR values well in excess of 100 per cent[1].

b) Naturally-occurring Granular Materials

A wide range of materials including lateritic, calcareous and quartzitic gravels, river gravels and other transported gravels or granular materials resulting from the weathering of rocks have been used successfully for bases.

The over-riding requirement for the use of such materials is the achieval of the minimum design soaked CBR of 80 per cent at the probable in situ density and moisture content conditions, and the maintaining of this strength in service (long-term durability) without undesirable volume changes in the material. Some further discussion is given below, under the sub-section on potential problem materials below.

Guidance on material gradings which ought to meet the performance requirements is given in the form of grading limits in the specification, for various nominal maximum aggregate sizes. It must be noted that all grading analyses should be done on materials that have been compacted, since some material breakdown may occur during the process.

It should also be clearly understood that the gradings are for guidance and not compliance: material outside the grading limits which is deemed to meet the CBR strength and the long-term durability requirements should be deemed acceptable. In other words, the performance criteria are the critical parameter in selecting materials.

Where the required performance cannot be consistently achieved by a particular as-dug material, mixing of materials from different sources is permissible in order to achieve the

1 The CBR classification is used in this document as being the most widely adopted regional method for assessing unbound materials. Where other methods are used (such as the Texas Triaxial test), guidance may be needed on correlation for local materials. As a rule-of-thumb, however, local materials already regarded as "base" or "subbase" quality based on previous usage and performance ought to comply with the nominal CBR requirements in this document. The main criterion is then to ensure that a satisfactory degree of compaction is achieved in the field to minimise traffic-induced consolidation and premature rutting/failure.

required properties, which might include adding fine or coarse materials or combinations of the two.

Where blending of different materials is necessary, it has been found that a high proportion of coarser particles (more than 10 mm diameter) should have angular, irregular or crushed faces, since this aids in particle interlock and stability. By the same token, the amount of smooth, rounded, aggregate particles should be kept as low as possible, and preferably not more than 50 per cent of the coarse particle volume.

The fines should preferably be non plastic but should normally never exceed a PI of 6, or a linear shrinkage of 3. If difficulties are encountered in meeting these criteria, the addition of a low percentage of hydrated lime or cement could be tried.

(i) *Potential Problem Materials*

- Weathered materials of basic igneous origin, including basalts and dolerites and others (unsound materials).

  The state of decomposition or metamorphic alteration can lead to rapid and premature failure with moisture ingress, and affects their long term durability even when stabilised.

  Identifying these materials can be difficult with normal aggregate classification tests and other methods must be used (including petrographic analysis, and soundness tests such as soaking in ethylene glycol[2]).

  Where there is any doubt about a material's soundness or suitability, it is advisable to seek expert advice where local knowledge is insufficient.

- Marginal quality materials.

  There are many examples where as-dug gravels, which do not conform to normal specifications for bases, have been used successfully. Generally, their use should be confined to the lower traffic categories (ie, T1 and T2) unless local evidence indicates that they could perform satisfactorily at higher levels.

  The Engineer is advised to be duly cautious if some extrapolation of performance appears warranted, and to ensure that the basis of the good behaviour is reasonably understood. In most cases, the presence or absence of moisture will alter the in situ behaviour of such materials, which is why the CBR is normally assessed under soaked (worst-case) conditions.

c) Wet- and Dry-bound Macadams

This is a traditional form of construction, regarded as comparable in performance with a graded crushed stone, that has been used successfully in the tropics. Two nominal

2 Chemical soundness tests such as sodium and magnesium sulphate tests are not regarded as such good indicators as the technique of soaking in ethylene glycol

types are used: dry-bound and wet-bound. They are often constructed in a labour-intensive process whereby the large stones are arranged by hand.

The materials consist of nominal single-sized crushed stone and non-plastic fine aggregate filler (passing the 5.0 mm sieve). The fine material should preferably be well graded and consist of crushed rock fines or natural angular pit sand.

Both processes involve laying single-sized crushed stone (often of either 37.5 mm or 50 mm nominal size) in a series of layers to achieve the design thickness. Each layer of coarse aggregate should be shaped and compacted and then the fine aggregate spread onto the surface. The compacted thickness of each layer should not exceed twice the nominal stone size.

For dry-bound, the fines are vibrated into the voids to produce a dense layer. In wet-bound (waterbound macadam), the fines are rolled and washed into the surface to produce a dense material. Any loose material remaining is brushed off and final compaction carried out usually with a heavy smooth wheeled roller.

This sequence (large stone, compaction, void filling) is then repeated until the design thickness is achieved. Production economy can be obtained if layers consisting of 50 mm nominal size stone and layers of 37.5 mm nominal size stone are both used, to allow the required total thickness to be obtained more precisely and to make better overall use of the output from the crushing plant.

Aggregate hardness, durability, particle shape and in situ density should conform to those used for graded crushed stone.

Due to the method of construction for macadams, the finished surface may be relatively bumpy and achieving an acceptable riding quality may require an asphalt levelling course as well as surfacing. Generally it is more economical and "labour friendly" to use a properly specified crusher-run, which will provide a better finished riding surface.

The wet-bound operation should not be even considered where water sensitive, plastic materials are used in the subbase or subgrade, as it is practically impossible to prevent moisture ingress (or even saturation) during construction. If this method of base construction is used, it should therefore be undertaken on a stabilised subbase which will minimise the risk of damage to underlying layers.

A.2.2 Granular Subbase Construction

The subbase may fulfil several requirements apart from its load-spreading capability as part of the pavement structure, including forming a working platform for the construction of the upper pavement layers, and as a separation layer between subgrade and base. The choice of subbase material therefore depends on the design function of the layer as well as the anticipated moisture regime both in service and at construction.

A nominal minimum CBR of 30 per cent is required at 95 per cent modified AASHTO MDD (test method T-180). Where construction traffic loading or climate is severe during construction, the Engineer is advised to specify more stringent requirements. Broadly, the poorer the conditions, the lower should be the limits on PI and linear shrinkage, and the more the need for a well-graded better-quality material. Conversely for less severe conditions, particularly in drier areas, some relaxation of these requirements may be deemed justifiable.

In wet areas or if saturation of the layer is anticipated at any time during its life (for example, if used as a drainage layer, or if water might penetrate at some stage due to poor surface maintenance and a permeable base) the CBR must be determined from samples soaked in water for four days. In drier areas the Engineer may consider an unsoaked test, but it is strongly advised that the standard soaked test is adhered to whenever possible. This is because, even in nominally dry areas, there may still be some likelihood of wetting or saturation of the subbase during its life, the observed effect of which is to cause marked rapid deterioration of the road.

A.2.3 For Selected Layer Construction

In a number of cases, particularly for the poorer subgrade support conditions (class S1, S2 and S3), selected layers are required to provide sufficient cover on weak subgrades (see Appendix C design catalogue).

The requirements are more relaxed than for subbases, with the main criterion being a minimum CBR strength of 15 per cent at 93 per cent of the modified AASHTO MDD (test method T-180), at the highest anticipated moisture content in service. Estimation of this moisture content must take into account the functions of the overlying subbase layer and its expected moisture condition, and the moisture conditions in the subgrade. If either of these layers is likely to be saturated during the life of the road then the selected layer should also be assessed in this state.

Where possible, selected materials should be homogeneous and relatively insensitive to moisture change on bearing capacity (CBR strength).

A.3 Cemented Materials

This section provides guidance on the use of cemented materials as base and subbase layers in the pavement structure. In this document, the term cemented materials covers the main categories of treatment or stabilisation with Portland cement, treatment with lime, and treatment with bitumen emulsion.

For more complete discussion of these materials, RN31[1] is recommended as a source for cement and lime treatments. For bitumen emulsion treatment, the Southern African Bitumen Association (Sabita) of South Africa is currently developing guidelines for the use of these materials, which should be available by April 1998.

The use of other materials having natural cementing action (pozzolans), such as pulverised fuel ash (PFA), is not discussed specifically here, although some of the design considerations will be similar to the materials considered here. The Engineer is advised to draw on established local practice and specialist advice if the use of pozzolans might be warranted.

An overriding consideration in the use of cemented materials is that treatments will be applied in situ, with the main intention of enhancing the suitability for pavement construction of locally available materials, and avoiding the need to import other materials. This can usually lead to more cost-effective use of available materials but, as noted in the guidelines, the economic viability of possible alternative approaches should be assessed prior to finalising the pavement design.

Beneficial properties that will normally be sought or attained for these types of materials, compared with the untreated parent material, include:

- Increased strength or stability
- Increased layer stiffness and load-spreading capability
- Increased resistance to erosion
- Reduced sensitivity to moisture changes
- Reduced plasticity.

Potential problems or pitfalls with these types of material, of which the Engineer should be aware in their application, include:

- Propensity to cracking, through traffic loading or environmental conditions (thermal and shrinkage stresses), particularly with cement treatment.
- Degradation of the cementing action due to carbonation (carbon dioxide), specifically fr cement and lime treatment.
- Requirement for greater levels of skill and control during construction (compared with untreated materials) to achieve satisfactory results.

Results from pavements using bitumen emulsion treated materials indicate that this type of material is immune to the first two potential problems, but it is more expensive and requires greater levels of skill and control during construction (compared with cement stabilised materials) to achieve satisfactory results.

Construction of satisfactory cemented layers is largely dependent on producing well-mixed homogeneous materials. This, therefore, means that in situ plant mixing is recommended for the best control and results. However, this may be impractical for certain applications and lime treatment is usually only practical by mix-in-place methods. The underlying need to produce a homogeneous mix should, nevertheless, remain the principal requirement.

A.3.1 Treatment or Stabilisation with Portland Cement

While a range of materials can be treated with cement, the use of high cement contents (say 5 per cent or more) should tend to be avoided both for economic and for performance considerations. In particular higher cement contents can lead to greater cracking potential, which may detract from the overall performance of a pavement.

For this reason it is now common practice to set both upper and lower bounds on the strength of these materials to minimise the detrimental effects of cracking, on the basis that the formation of closer-spaced, narrower cracks (which occur with lower strength material) is more desirable than wider-spaced, wide cracks (which occur for stronger cemented materials).

The latter causes much greater loss of structural integrity of the layer, as well as greater susceptibility to reflection cracking through overlying layers, and the potential for undesirable moisture ingress to the pavement.

As a guide, material suitable for cement treatment will normally have a low Plasticity Index (less than 10), with a reasonably uniform grading. Materials with higher PIs can first be treated with lime (modified), prior to cement treatment. Direct treatment with cement of materials with higher PIs is unlikely to be satisfactory.

Laboratory trial mixes should be made, where such treatment appears to have potential, for a range of cement contents (typically 2, 4 and 6 per cent by weight) at mix moisture contents appropriate to field mixing and to a dry density which reflects probable field compaction.

Seven days moist curing at 25°C should be allowed, where specimens are either wax-sealed or wrapped in plastic cling-film then sealed in plastic bags, and kept out of direct sunlight, to represent on site conditions. This allows the strength gain that should be achieved in practice during site curing.

Strength testing, however, should be after a further four hours soaking of the specimens (again at 25°C) with specimens tested direct from the waterbath to represent worst case operational conditions. In dry regions, where the possibility of saturation of the layer is deemed negligible, it may be more realistic to allow some drying out prior to testing (say 24 hours at 25°C, kept out of direct sunlight).

Strength results should be plotted against cement contents in order to determine the design cement content. A reasonably well-defined relationship between strength and cement content should be obtained, and it is advisable to plot the average strength of each set of specimens as well as the individual results to view the overall correlation. In the case that unexplainable or anomalous results obscure the picture, further testing should be undertaken.

Depending on the layer application, the design cement content should ensure that the strength from the above process should be between 0.75 and 1.5 MPa, or be between 1.5 to 3 MPA, based on specimens of nominal height to width/diameter ratios of 1:1. Generally, this should be based on the average strength relationship and the cement content to achieve the mid-range values (ie, target strengths of 1.1 MPa and 2.2 MPa respectively).

Where specimens of height to width/diameter ratios of 2:1 are used, the corresponding ranges should be 0.6 to 1.2 MPa and 1.2 to 2.4 MPA.

The catalogue (Appendix C) indicates the specific strength range which should be used, depending on the layer application, and for some designs includes a requirement for a 3 to 5 MPA UCS. This should be determined from the same process. Corresponding strength bounds for specimens of height to width/ diameter ratios of 2:1 are 2.4 to 4 MPa respectively.

Long-term durability of the material will normally be satisfactory if the parent material is sound. It should be checked, however, if any doubt at all exists about the mixture and a wet-dry brushing test has been found to be a suitable method.

A.3.2 Treatment with Lime

Addition of lime has been found very effective on many materials with high PIs, normally greater than 10, which will not respond so well to cement treatment. It may be used in order to lower the PI of materials otherwise within specification limits, as a pre-treatment (for the same purpose) of materials that might then be treated with cement or bitumen emulsion to produce a suitable road building material, or as a strengthening agent like cement.

In certain regions lime is produced on a small scale, in local batch kilns, while in others it may be commercially available on a large-scale. The quality control of the products is likely to differ considerably as well, so the Engineer must firstly confirm that both production rate and quality are satisfactory for the need identified. Two main categories of lime can be produced: hydrated and unhydrated (quick) lime. Use of quicklime is strongly cautioned against due to health risks, and its use for roadbuilding is already banned in a number of countries.

Compared with cement, the strength and stiffness gains are less marked and the cementitious reaction is slower so that (depending on the parent material) measurable changes can take place over a number of years. By the same token the initial effect of lime addition, particularly to wet soils, is rapid and the chemical reaction leads to increases in strength and trafficability of such materials.

Lime treatment can be used for both base and subbase construction, adopting the same strength limits for cemented material (as given above), and there are many examples of its successful use throughout the sub-continent.

In selecting design lime content for subbase usage, the same procedure used for Portland cement addition as outlined above should be followed with the major difference in the curing time allowed. For lime, this should be 11 days moist curing instead of 7 days. Testing should then be conducted after a further 4 hours soaking as indicated for the cemented material.

It should be noted that for strength control during construction, the curing regime above is impractical, and the Engineer should determine 7 day minimum strength limits for this purpose.

A.3.3 Treatment with Bitumen Emulsion

As indicated in the introductory comments, treatment with bitumen emulsion has been proven to be very effective for a range of materials, leading to significant improvements in strength and durability. It can be used for both base and subbase layers.

The approach adopted successfully in South Africa is the use of a 60 per cent anionic stable grade emulsion, applied at typically 1 to 3 per cent by weight (corresponding residual bitumen contents, 0.6 to 1.8 per cent), combined with the addition of 1 per cent ordinary Portland cement.

The exact nature of the reaction is still unclear, but it is conjectured that the emulsion initially aids compaction (leading to higher density and strength than the untreated material), the cement then helps the emulsion to break, and the combined effect of the bitumen and cement contributes to a long-term strength gain.

It is clear, however, that this type of treatment can generally enhance the roadbuilding characteristics of natural gravels and in situ material, thus allowing the use of lower quality parent material which would otherwise not meet specification requirements. Guidance and details on the approach is given in the Sabita guide[6].

As indicated in Section 6 of the guide, the use of this type of treated material is currently recommended only up to certain traffic levels, simply because the technique has only a relatively short track record. There are, however, a good number of sections in South Africa which have been in service more than 10 years (and some more than 20), in some instances carrying substantial traffic, and no failures have been reported.

The Engineer is therefore advised to use due discretion, and is encouraged to consider the inclusion of trial sections in order to establish a performance record in a particular region.

A.4 Bituminous Materials

For this discussion, the term bituminous materials covers asphalt base and surfacing materials, and surface dressings. This section is intended to highlight some of the more important considerations in their application, without going into specific detail, because it is assumed that

such materials will already form part of established road construction techniques in the region. More complete details of these types of materials can be found in RN31[1] or other local guides. The guidance on all types of seal applications given in Technical Recommendations for Highways, TRH3[8] is strongly recommended.

Prime and tack coats are not specifically discussed here, but their correct use is implicitly assumed in bituminous layer applications.

The use of tar as a binder is not specifically excluded in the following discussion, but its use is not encouraged due to acknowledged health hazards as a cancer-causing agent. It is strongly urged that all member States endeavour to phase out the use of tar and substitute an oil-based bituminous binder.

A.4.1 Asphalt Premix Base and Surfacings

Asphalt premixes are plant-produced bituminous mixes using good quality aggregates, hot mixed, transported to the site, and laid and compacted while still hot. Minimum practical thicknesses, depending on the aggregate size, can be as low as 25 mm or so. For the designs in this guide, the minimum asphalt premix surfacing thickness is 40 mm.

The mixes must be designed to provide high deformation (rutting) resistance, high fatigue resistance, good load spreading (high stiffness), and good durability while being sufficiently workable during construction to allow satisfactory compaction.

In particular, the load spreading/deformation resistance requirements (necessitating a high stiffness) can conflict with the need for fatigue resistance (usually necessitating more flexibility). Thus the design of suitable asphalt premixes should be regarded as a specialist function, whereby the asphalt producer should be given a performance-related specification to meet, using his particular expertise to ensure mix compliance.

Commonly used bituminous premixes include asphalt concretes, bitumen macadams, rolled asphalts, and mastic asphalts. These have been developed over the years from different backgrounds, essentially to make use of local aggregates and to provide similar desirable performance characteristics, but differ in composition and design approach. Where possible, therefore, the Engineer should make use of local knowledge of satisfactory performing materials and be guided by the asphalt producer.

Primary practical considerations for asphalt premixes include:

- Bitumen content } influencing long-term
- Air voids } durability
- Marshall stability and flow criteria influencing performance

and the exact requirements will differ depending on the application as either base or surfacing. Factors which will influence selection of specific parameter values include design trafficking level, operating temperature, incidence of overloading, channelisation of traffic, and gradient/terrain.

Clearly the harsher the operating environment, particularly related to the abovementioned factors, the more stringent the specification required. The Engineer should therefore draw on specialist advice for the particular application in defining the asphalt premix specification.

Particular attention should be paid to the sealing of any cracks which may develop during the life of the road in order to prevent premature distress, usually from ingress of water to the underlying layers.

A.4.2 Surface Dressings

Surface dressings (or surface treatments or seals) are produced in situ, generally using either penetration grade bitumens, cutbacks, or bitumen emulsions as the binding and sealing agent. Bitumen-rubber binder (in which natural and/or synthetic rubber from old vehicle tyres, mainly, is blended with a bitumen binder) has also been used successfully to provide a resilient, durable, binding agent with greater resistance to deformations and cracking. Its use may be appropriate on more heavily trafficked roads where vehicle overloading is significant, or where there are high deflections.

Hard, durable, single-sized aggregate chippings are normally used to provide a non-skid running surface. More recently, graded aggregate seals (Otta seals) have been shown to be highly successful under light traffic, and result in more cost-effective use of material with a more "forgiving" construction requirement.

Bitumen binders (penetration grades, cutbacks, bitumen-rubbers and polymer modified binders) are normally applied hot, and emulsions may be applied cold, although low water content emulsions (sometimes used on more heavily trafficked roads) can also be gently heated to aid application. The underlying requirement is that the binder, on application, should be sufficiently fluid to spread evenly and have good adhesion with the stones. The other requirement, particularly for remedial sealing, is for the binder to then revert to its harder, stiffer (ambient condition) viscosity within a reasonable time so that trafficking can start as soon as possible.

It is generally advised to use a cutback bitumen, of medium to rapid curing, as this will normally fulfil the requirements indicated above satisfactorily. It should be noted that it is not advisable to use cutback bitumen under hot ambient conditions. The Engineer should, in any case, draw on established local practice for the particular conditions of application.

There are a number of different variations of surface dressings, with single surface treatments (or spray-and-chip) being the cheapest and simplest, ranging through double seals and more sophisticated treatments such as slurry and Cape seals. The Cape seal is a combination of a surface dressing with a slurry seal on top which has been found effective where a surface dressing alone may deteriorate too quickly under heavier trafficking.

Single surface treatments can be extremely effective when used to reseal existing surfaced pavements, while double surface treatments should be used on new construction. Where traffic loading conditions are particularly severe, the use of a bitumen-rubber premix with a single surface treatment has been found particularly effective and long-lived.

Common characteristics of all properly constructed new surface dressings are their ability to keep out moisture, together with their inability to rectify inherent riding quality/ roughness deficiencies from the underlying layer. In other words, surface dressings cannot be used to remedy riding quality problems.

Practical considerations in the use of surface dressings include:

- Aggregates must be clean
- Aggregates must be sufficiently strong and durable

- Aggregates must bond with the selected binder. Use of pre-coating may assist the bonding process
- Binders must be applied uniformly to the specified application rate
- Stones must be well shaped (not flaky or elongated) and nominally single-sized
- Rubber-tyred rollers are preferred for good stone embedment without crushing

The Engineer is advised to use TRH3[8] for detailed guidance on all aspects of seal selection, design and construction including:

- Factors influencing the performance of surfacing seals
- Pre-design investigations
- Selection of appropriate surfacings
- Criteria for determination of the choice of binder
- Surface preparation/pre-treatment
- Design and construction of seals
- Recommended material specification

as well as process and acceptance control, maintenance planning and budgeting, construction of seal work using labour-intensive methods, life expectancy of seals, relative cost of surfacings, selection of type of reseal and stone spread rates.

Surface dressings will deteriorate under both the effects of trafficking and time (aging of the binder), and should be expected to require remedial action within the design life of the road. Deterioration will normally take the form of loss of the sealing ability through cracking, and/or the loss of texture through stone loss or smoothing as stone gets pushed in.

Normal remedial action would be application of a new seal, as part of a periodic maintenance programme, and this should be considered a standard requirement which should be taken into account when selecting the pavement structure. Failure to maintain surface dressings is likely, therefore, to lead to a reduced pavement life.

APPENDIX B

DRAINAGE AND SHOULDERS

APPENDIX B: DRAINAGE AND SHOULDERS

B.1 Introduction

The long-term satisfactory performance of a road is influenced by both drainage and the shoulders. Provision of suitable drainage clearly has a direct effect on the likelihood of any of the pavement layers being adversely affected by water and moisture ingress. Shoulders contribute both to the effective drainage of surface water away from the structure, and to the lateral support provided to the structure preventing the layer materials from deteriorating during trafficking.

This Appendix provides some guidance on both these factors in ensuring satisfactory performance of a road during its life. The pavement designer is nevertheless advised to take full cognisance of the detailed guidance on drainage aspects given in the South African TRH15[9] document, as well as any local guides on these aspects.

B.2 Drainage

Water can enter the road as a result of rain penetrating the surface or as a result of the infiltration of ground water. The road surface must be constructed with a camber so that it sheds rainwater quickly and the top of the subgrade or improved subgrade must be raised above the level of the local water table to prevent it being soaked by ground water. The road designs in this guide are based on the assumption that side drains and culverts associated with the road are properly designed, maintained, and function correctly.

Drainage within the pavement layers themselves is an essential element of structural design because the strength of the subgrade used for design purposes is based on the moisture content during the most likely adverse conditions. Since it is impossible to guarantee that road surfaces will remain waterproof throughout their lives, it is critical to ensure that water is able to drain away quickly from within the pavement.

Crossfall is needed on all roads to assist the shedding of water into the side drains. A suitable value for paved roads is about 3 per cent for the carriageway, with a slope of about 4-6 per cent for the shoulders. An increased crossfall for the carriageway (for example, 4 per cent) is desirable if the quality of the final shaping of the road surface is likely to be low for any reason.

There is evidence that there are also benefits obtained by using steeper crossfalls for layers at successive depths in the pavement.

Thus ideally the top of the subbase should have a crossfall of 3-4 per cent (the minimum being the same as the carriageway) and the top of the subgrade should be 4-5 per cent. These crossfalls not only improve the drainage performance of the various layers but also provide a slightly greater thickness of material at the edge of the pavement where the structure is more vulnerable to damage (note: the design thickness should be that at the centre line of the pavement).

When permeable base materials are used particular attention must be given to the drainage of this layer. Ideally, the base and subbase should extend right across the shoulders to the drainage ditches. Under no circumstances should a 'trench' type of cross-section be used in which the pavement layers are confined between continuous impervious shoulders. This will undoubtedly lead to a swimming pool effect whereby water is trapped within the pavement layers, and these rapidly deteriorate under trafficking.

If it is not feasible to extend the base and subbase material across the shoulder, a continuous drainage layer of pervious material (typically 75 to 100 mm thickness) can be laid under the shoulder such that the bottom of the drainage layer is at the level of the top of the subbase. This is very effective and highly recommended.

Alternatively, drainage channels at 3 to 5 m intervals should be cut through the shoulder to a depth of 50 mm below subbase level. These channels should be back-filled with material of base quality but which is more permeable than the base itself, and should be given a fall of 1 in 10 to the side ditch. This is not as effective as the foregoing, but should be used if neither of the other methods can be incorporated.

If the subgrade itself is permeable and can drain freely, it is preferable that vertical drainage can take place. This can be achieved by ensuring that each layer of the pavement is more permeable than the layer above, but is not always feasible.

The most important point, therefore, is that the road structure is designed to allow outflow of water from the layers and that no inadvertently built in barriers prevent free draining. Full consideration of the permeabilities of the various construction materials should be made in order to devise the best drainage method.

B.3 Shoulders

Shoulders are an essential element of the structural design of a road and are especially important when unbound materials are used in the pavement. For this type of construction it is recommended that shoulders should ideally be at least 2.0 m wide.

For bound bases, shoulder widths can be reduced if required, and in some situations where construction widths may be limited (for example, mountainous areas), this may influence the selection of pavement structure.

Where there is a large volume of non-motorised traffic, shoulder width should be increased to a minimum of 3.0 m in order to maintain safe unimpeded flow of motorised traffic.

In order to exclude water from the road, the top of the shoulders should be impermeable and a surface treatment or other impermeable seal is recommended. Sealed shoulders prevent ingress of water at the edge of the pavement, which is an area particularly vulnerable to structural damage. In wet regions, sealing of shoulders (even if these are only one metre width) should be regarded as essential.

In selecting the shoulder seal type, single seals are not generally recommended since they tend to require traffic moulding to perform well: without such action they can deteriorate fairly quickly and become permeable. Preferable are two layer treatments (for example, double surface

treatments, Cape seals) or asphalt premix since these should provide a more durable, better performing, surfacing.

Unsurfaced shoulders are not generally recommended because they require considerable maintenance if satisfactory performance is to be guaranteed. They may be appropriate in dry regions, but seals should be applied in general.

Where the base and subbase cannot be extended to form the shoulders, the shoulder material should be selected using the same criteria as for a gravel-surfaced road or a subbase to carry construction traffic. Thus the material should be strong enough to carry occasional vehicles and should be as cohesive as possible without being too weak when wet.

For sealed shoulders on grades, base-quality shoulder material must be used to avoid early failures from heavy vehicles running on the shoulder if adequate provision (such as passing lanes) cannot be made in the geometric design.

It is also very desirable if at least the outer edge of the shoulder is able to support the growth of grasses which help to bind the surface and prevent erosion. On rural roads where shoulders rarely need to carry traffic, excellent shoulder performance can be obtained if the whole of the shoulder is grassed.

In these circumstances it is necessary for the grass to be cut regularly to prevent the level of the shoulder building up above the level of the carriageway-shoulder interface where it can penetrate the road structure and cause structural weakening.

APPENDIX C

DESIGN CATALOGUE

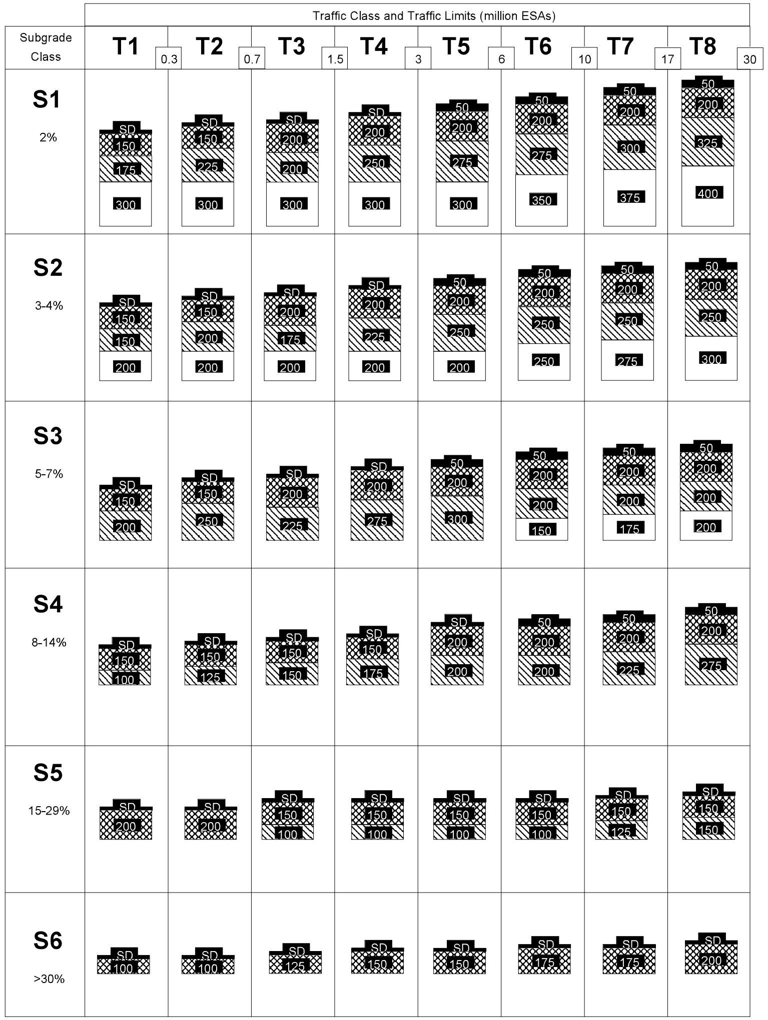
APPENDIX C: DESIGN CATALOGUE

C.1 Introduction

The following catalogues are provided:

- Chart D1 - Granular base/granular subbase in dry regions
- Chart D2 - Granular base/cemented subbase in dry regions
- Chart D3 - Cemented base/cemented subbase in dry regions
- Chart D4 - Bituminous base/granular subbase in dry regions
- Chart D5 - Bituminous base/cemented subbase in dry regions
- Chart W1 - Granular base/granular subbase in wet regions
- Chart W2 - Granular base/cemented subbase in wet regions
- Chart W3 - Cemented base/cemented subbase in wet regions
- Chart W4 - Bituminous base/granular subbase in wet regions
- Chart W5 - Bituminous base/cemented subbase in wet regions

CHART D1 : Granular base / granular subbase — Dry Regions



KEY :-
- Surface dressing or hot mix asphalt as indicated
- Granular Base (Soaked CBR > 80%)
- Granular Subbase (Soaked CBR > 30%)
- Selected layer (Soaked CBR > 15%)

See Appendix A and the Specifications for details

Note : 50mm hot mix asphalt layer can be reduced to 40mm where local experience shows this to be adequate

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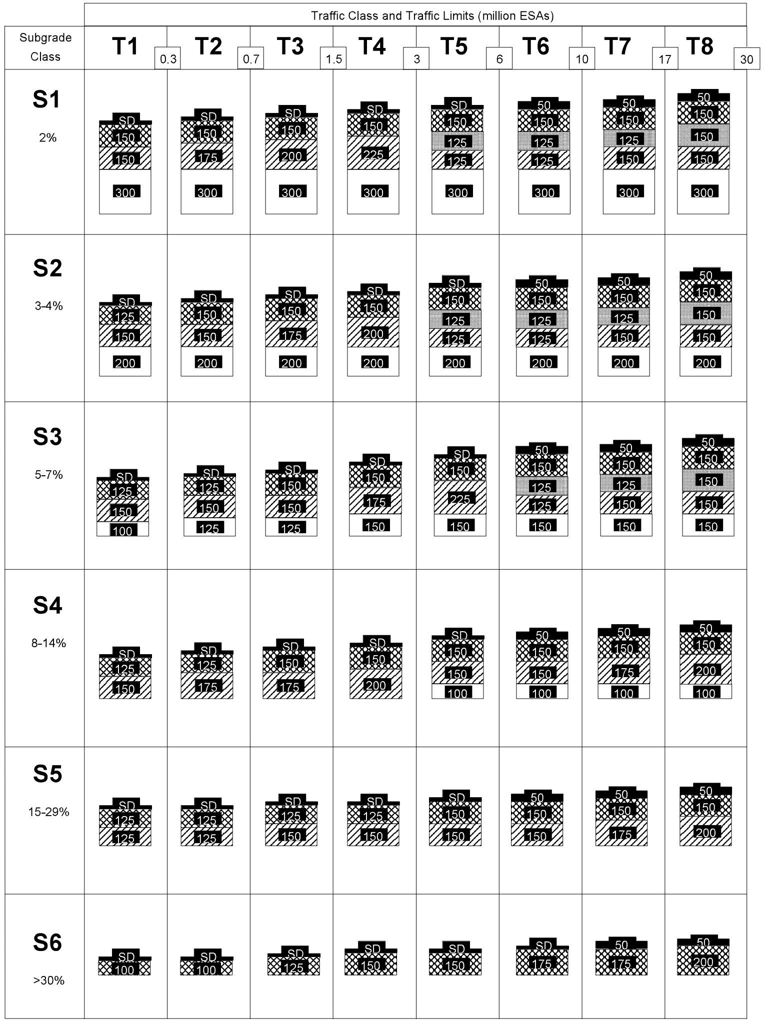
CHART D2 : Granular base / Cemented subbase — Dry Regions



KEY :-
- Surface dressing or hot mix asphalt as indicated
- Granular Base (Soaked CBR > 80%)
- Cemented Upper Subbase (7 day UCS 3 - 5 MPa)
- Cemented Subbase (7 day UCS 1.5 - 3 MPa)
- Selected layer (Soaked CBR > 15%)

See Appendix A and the Specifications for details

Note : 50mm hot mix asphalt layer can be reduced to 40mm where local experience shows this to be adequate

SATCC Code of Practice for the Design of Road Pavements/C2

CHART D3 : Cemented base / Cemented subbase — Dry Regions

Traffic Class and Traffic Limits (million ESAs)

Subgrade Class	T1	0.3 T2	0.7 T3	1.5 T4	3 T5	6 T6	10 T7	17 T8 30
S1 2%	SD 150 150 350	SD 150 175 350	SD 175 175 350	SD 200 200 350	SD 200 225 350	SD 200 250 350		
S2 3-4%	SD 150 150 225	SD 150 175 225	SD 175 175 225	SD 175 200 225	SD 200 225 225	SD 200 250 225		
S3 5-7%	SD 150 150 125	SD 150 150 125	SD 150 175 125	SD 175 200 125	SD 200 200 125	SD 200 225 125		
S4 8-14%	SD 150 150	SD 150 150	SD 150 175	SD 150 150 100	SD 150 150 150	SD 150 150 200		
S5 15-29%	SD 150 100	SD 150 100	SD 150 125	SD 150 150	SD 150 175	SD 150 200		
S6 >30%	SD 150	SD 150	SD 150	SD 175	SD 175	SD 200		

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KEY :-
- Surface dressing
- Cemented Base (7 day UCS 1.5 - 3 MPa)
- Cemented Subbase (7 day UCS 0.75 - 1.5 MPa)
- Selected layer (Soaked CBR > 15%)

See Appendix A and the Specifications for details

SATCC Code of Practice for the Design of Road Pavements/C3

CHART D4 : Bituminous base / Granular subbase — Dry Regions

Traffic Class and Traffic Limits (million ESAs)

Subgrade Class	T1	0.3 T2	0.7 T3	1.5 T4	3 T5	6 T6	10 T7	17 T8 30
S1 2%					SD 125 200 350	SD 150 200 350	50 175 200 350	50 200 200 350
S2 3-4%					SD 125 200 200	SD 150 200 200	50 150 200 200	50 175 200 200
S3 5-7%					SD 100 200 100	SD 125 200 100	50 125 200 100	50 150 200 100
S4 8-14%					SD 100 200	SD 125 200	50 125 200	50 150 200
S5 15-29%					SD 100 150	SD 100 150	50 125 150	50 150 150
S6 >30%					SD 125	SD 150	50 150	50 175

bit-gr1.drw

KEY :-
- Surface dressing or hot mix asphalt as indicated
- Bituminous Base
- Granular Subbase (Soaked CBR > 30%)
- Selected layer (Soaked CBR > 15%)

See Appendix A and the Specifications for details

Note : 50mm hot mix asphalt layer can be reduced to 40mm where local experience shows this to be adequate

SATCC Code of Practice for the Design of Road Pavements/C4