URBAN TRANSPORT GUIDELINES

Draft UTG2 STRUCTURAL DESIGN OF SEGMENTAL BLOCK PAVEMENTS FOR SOUTHERN AFRICA

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PREFACE

URBAN TRANSPORT GUIDELINES (UTG) is a series of documents written for practising transportation engineers and describe current recommended practice in selected aspects of urban transportation. They are based on South African experience and research and have the full support and approval of the Committee of Urban Transport Authorities.

To confirm their validity in practice, UTGs are circulated in draft form for a two-year period before receiving the final approval of CUTA. During this period, suggestions for improvement may be sent to:

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After final approval by CUTA, the revised document will be issued as a full UTG in both official languages.

SYNOPSIS

This document is intended as a complete guideline for the design of segmental block pavements in South Africa. The structural design method may be used for both concrete and fired-clay blocks. Segmental block pavements are classified into specific areas of use and a catalogue of designs suitable for each of these areas is given. The importance of materials, design loads, environment and drainage and compaction in relation to design are discussed, and various practical aspects are considered.

SINOPSIS

Hierdie dokument is bestem om 'n volledige riglyn vir die ontwerp van steenplaveisels in Suid-Afrika te wees. Die struktuurontwerpmetode kan vir sowel beton- as vuurkleiblokke gebruik word. Steenplaveisels word volgens spesifieke gebruiksareas geklassifiseer en 'n katalogus van ontwerpe wat vir elkeen van hierdie areas geskik is, word gegee. Die belangrikheid van materiale, ontwerplaste, omgewing, dreinering en verdigting met betrekking tot ontwerp word bespreek, en aan verskeie praktiese aspekte word oorweging geskenk.

KEYWORDS

Blocks, structural design, pavement layers

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This draft UTG was prepared for the Cuta Technical Committee on Pavement Design, Management and Stormwater by Dr J M Clifford of the National Institute for Transport and Road Research.

Broad acknowledgement to pioneering work in South Africa of Dr B Shackel and Mr L R Marais is made.

This document is intended as one part of a trilogy on segmental block paving. The other two parts are provided by the SABS Specification and by practical block-laying guidelines prepared by the CMA and BDA of South Africa.

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LIST OF FIGURES

1 INTRODUCTION

The procedures for the structural design of block pavements presented in this document are applicable to both industrial and normal roads. Industrial pavements, which include container stacking areas, can be designed for light, medium, heavy or very heavy duty. The design procedure includes the use of block paving for lightly trafficked or non-trafficked areas and covers, for example, footpaths, cycle tracks and pavements for civic uses. The procedures are based on a combination of existing methods, experience and the fundamental theories of structural design and material characteristics and behaviour. These recommendations do not necessarily exclude other design methods; indeed it is expected that as technology develops and the use of block pavements increases, many new procedures will be developed. For this purpose the catalogue of designs has been made loose-leaf to allow for updating as and when necessary.

The structural design of pavements concerns the protection of the subgrade (through the provision of pavement layers) to achieve, as cheaply as possible, a chosen level of service, with rehabilitation, over the analysis period. Factors such as time, traffic, materials, subgrade soils, environmental conditions and economics are taken into consideration.

2 THE DESIGN PROCESS

2.1 PHILOSOPHY

The design objective is to produce a structurally balanced pavement that will carry the traffic and other applied loads in the prevailing environment for the structural design period with high confidence at an acceptable level of service without major structural distress. Various means of rehabilitation are considered to bring a worn pavement back to an acceptable level of service.

2.2 THE DESIGN PROCEDURE

Figure 1 shows a flow diagram of the design process on which this document is based. Each of the eight sections of the flow diagram will be treated separately but all sections must be considered in order to produce a design.

A catalogue of designs based on current experience of block pavement construction and behaviour throughout southern Africa is included in this document. This catalogue is considered adequate for providing the basic design method but, special conditions may require a more detailed design by means of other methods.

It is fully expected that with use, current designs will be updated from time to time. These updates will be given in the catalogue of designs.

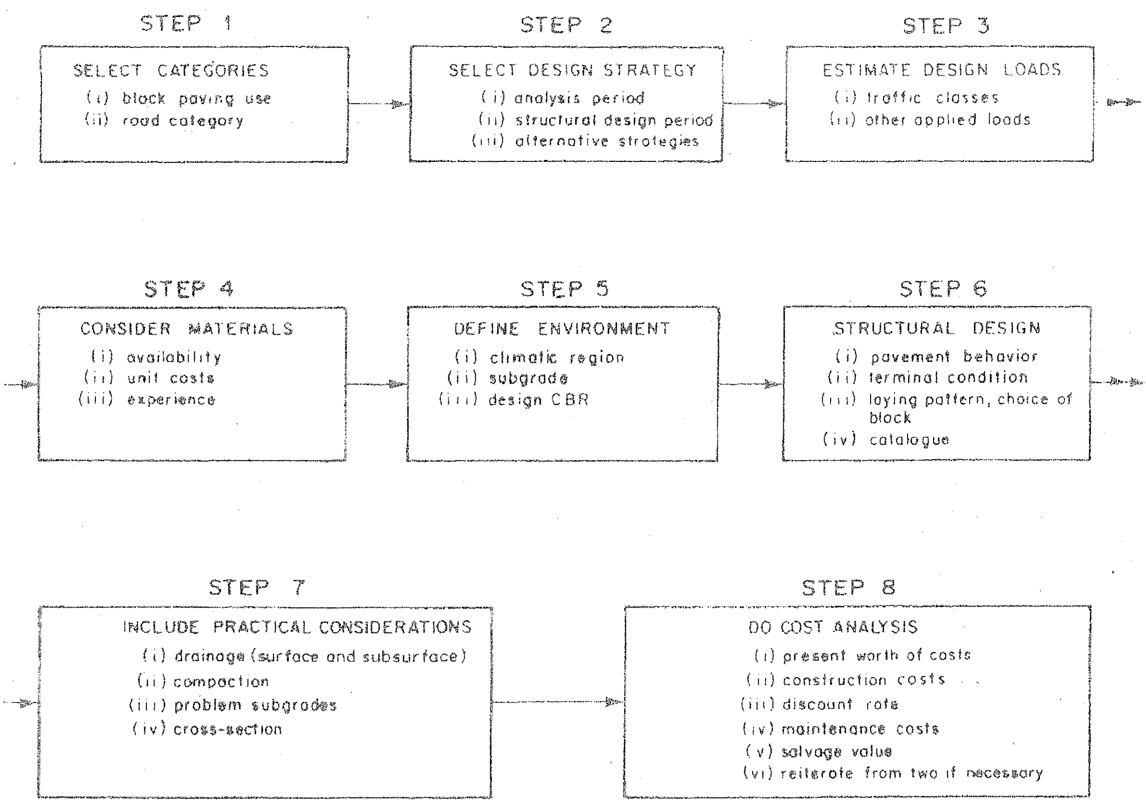


FIGURE 1

Structural design of segmental block pavements - flow diagram

3 SELECT CATEGORY (Design step 1)

3.1 SEGMENTAL PAVEMENT CATEGORIES

There are three main design categories, namely A, I and R. A is for architectural, I for industrial and R for road:

A - architectural (non-vehicle associated)
(i) footpaths;
(ii) slope protection and
(iii) utility (eg swimming pool surrounds).

I - industrial
(i) normal heavy vehicle parking;
(ii) medium industrial working area;
(iii) heavy industrial areas and
(iv) abnormally heavy industrial stacking areas.

R - roads
(i) parking areas and driveways;
(ii) service areas;
(iii) rural and
(iv) urban.

3.2 SUBDIVISION OF SEGMENTAL PAVEMENT CATEGORIES: R - ROADS (RURAL AND URBAN)

The design of segmental pavements for rural and urban roads (categories (iii) and (iv) above) can be classified into traffic categories used for the design of interurban and rural pavements detailed in TRH4 (1985), and in the Norms document (1985), and given in Figure 2.

3.3 INCLUSION OF THE IMPORTANCE, SERVICE LEVEL, TRAFFIC AND ROAD STANDARD OF ROAD CATEGORIES

The client will usually specify the required category of road. However, the designer should ascertain that the traffic volume, present and future wheel and axle loadings and other factors comply with Figure 2. The final decision will rest with the client.

The level of service that a user expects from a road is related to the function of the road, to the general standard of the facility and partly to the volume of traffic carried. For example, the user will expect a better riding quality on a dual-carriageway freeway than on a minor rural road. The design traffic is expressed in terms of total E80s over the structural design period, which is defined later in this document.

FIGURE 2

Definition of four divisions within Category R

	Road Category			
	UA	UB	UC	UD
General description	Primary and distributor roads		Local access roads	
Road class	1 and 2	3 and 4	5(a) and 5(b)	5(b) to 5(f)
Detailed description and function	Trunk roads and primary distributors (SAICE: Freeway and major arterial), also by-passes and certain rural main roads	District and local distributors (SAICE: Minor arterials and collectors), also industrial roads, CBD roads, goods loading areas and bus routes.	Residential access collectors, also car parks, no bus routes.	Local access roads: loops, access ways, access courts, access strips and culs-de-sac
Importance and service level	Very important High level of service	Important Moderate level of service	Less important Moderate to low level of service	Unimportant Low level of service
Total traffic over structural design period				
(a) If road carries construction traffic	$0,8 - 50 \times 10^6$ E80s/lane*	$0,05 - 3 \times 10^6$ E80s/lane	$< 0,2 \times 10^6$ E80s/lane	$< 0,2 \times 10^6$
(b) If road does not carry construction traffic	$0,8 - 50 \times 10^6$ E80s/lane*	$0,05 - 3 \times 10^6$ E80s/lane	$< 0,5 \times 10^6$ E80s/lane	$< 0,8 - 50 \times 10^6$

* or equivalent area

4 DESIGN STRATEGY (Design step 2)

4.1 ANALYSIS PERIOD, STRUCTURAL DESIGN PERIOD AND DESIGN STRATEGY

The analysis period is a convenient planning period during which full reconstruction of the pavement is undesirable. The structural design period is defined as the period during which it is predicted with a high degree of confidence that no structural maintenance will be required. In the case of a block pavement the occasional lifting of small areas of blocks to provide minor reinstatement is not considered as structural maintenance.

To fulfil the design objectives of selecting an optimum pavement design in terms of present worth of cost, it is necessary to consider the performance of the pavement during the analysis period. Figure 3 is a schematic representation of this design strategy.

It is important to note that any design procedure can only make an estimate of the timing and nature of the maintenance measures that may be needed. By nature estimates are only approximate but they provide a valuable guide for a design strategy. The actual maintenance should be determined by means of a proper evaluation of the maintenance required. The accuracy of the prediction could be improved by a pavement performance feedback system.

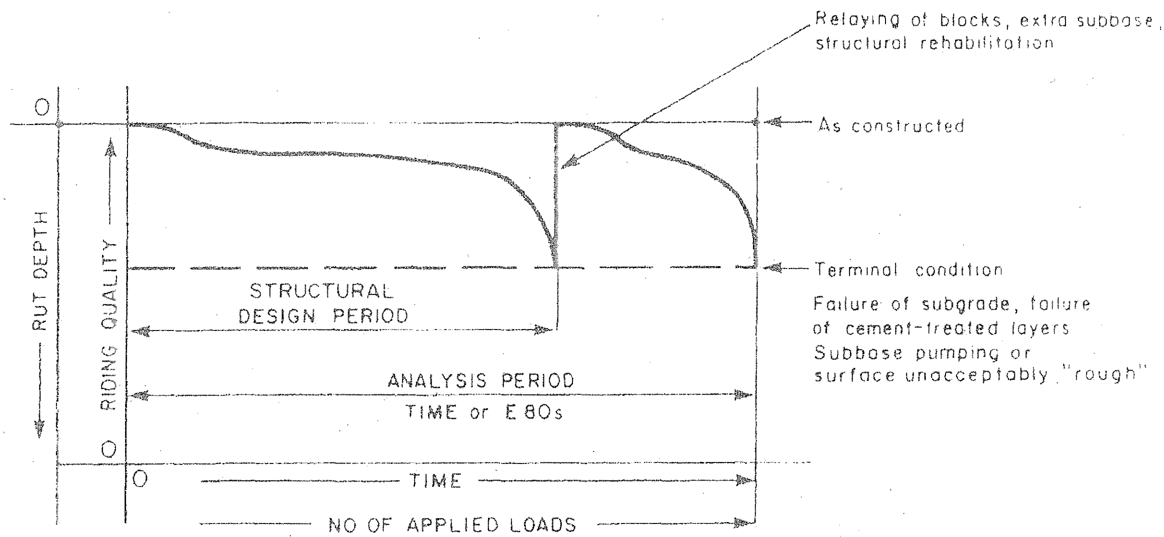


FIGURE 3

Design strategy for segmental block pavements

4.2 SELECTION OF ANALYSIS PERIOD

The analysis period is a realistic cost period. There may be a difference between the analysis period and the total period over which a facility will be used. The analysis period is often related to the geometric life. If the road alignment is fixed, a period of 30 years should be used. In the case of a short geometric life, in a changing traffic or loading situation, a short analysis period will be used. A short analysis period will also be used when the proposed pavement has a limited life (eg a mine road). The analysis period will influence the salvage value used in the design (step 8).

Figure 4 shows the possible ranges and recommended analysis periods for the various block-pavement categories. These values may be used in an economic analysis unless more detailed information is available.

SEGMENTAL BLOCK PAVEMENT CATEGORY	RECOMMENDED ANALYSIS PERIOD (YEARS)		
	FIXED CONDITIONS	UNCERTAIN CONDITIONS	SUGGESTED RANGE
A - ARCHITECTURAL			
(i) FOOTPATHS	10	-	2 - 20
(ii) SLOPE PROTECTION	10	-	2 - 20
(iii) UTILITY	10	-	2 - 20
I - INDUSTRIAL			
(i) NORMAL HEAVY VEHICLE PARKING	20 - 30	10	10 - 40
(ii) MEDIUM INDUSTRIAL WORKING AREA	20 - 30	10	10 - 40
(iii) HEAVY INDUSTRIAL AREAS	20 - 30	10	10 - 40
(iv) ABNORMALLY HEAVY INDUSTRIAL STACKING AREA	20 - 30	10	10 - 40
R - ROADS			
(i) PARKING AREAS & DRIVEWAYS	10	-	2 - 20
(ii) SERVICE AREAS	5 - 20	5	5 - 30
(iii) RURAL *	30	20	15 - 30
(iv) URBAN *	30	20	15 - 30

NB* RESEARCH INDICATED THAT THE RECOMMENDED ANALYSIS PERIODS COULD BE REDUCED BY 50%, THE PERIODS GIVEN HERE ARE IN ACCORDANCE WITH TRH4

FIGURE 4

Analysis periods for various segmental block-pavement categories

5 DESIGN LOADS (Design step 3)

In the design of road and other pavements the cumulative damaging effect of all individually applied loads is expressed as the number of equivalent 80 kN single-axle loads (E80). TRH16 and TMH3 give details of the methods of calculating the E80s[18,19].

This is the number of 80 kN single-axle loads that would cause the same damage to the pavement as the actual spectrum of applied loads. For structural design, an estimate of the cumulative equivalent traffic over the structural design period is required. This cumulative equivalent traffic can be determined in two different ways:

(i) By estimation based on experience and by the use of nomograms (Figures 5 and 6).

(ii) Through detailed computation by estimation of initial and mean daily traffic, growth rates and lane or area distribution factors. Two publications, namely TRH16[19] and TMH3[18] are designed to assist in this detailed computation.

Unless more specific information is available, estimation of the cumulative equivalent traffic over the structural design period from tabulated values is recommended.

The cumulative equivalent traffic (total E80s over the design period) is grouped into six traffic classes, varying from ER for very light traffic to E4 for very heavy traffic. The class of equivalent traffic is a major factor in the selection of the actual pavement structure obtained from the catalogue of designs. The traffic classes are defined in Figure 7.

5.1 ESTIMATION OF EQUIVALENT TRAFFIC FROM NOMOGRAMS

To estimate the cumulative traffic over the structural design period, without involved computations, the designer can rate the pavement as E0 to E4 by using the nomograms given in Figures 5 and 6.

To determine the design class either an estimate of the initial daily equivalent traffic (E80s per lane or equivalent area) is required or the average daily equivalent traffic.

If the initial daily equivalent traffic is used a growth rate has to be applied. This is given in Figure 5. Its use should be based on specific information but for interurban road design a growth rate of 2 to 10 % has been determined and a value of 6 % is being used.

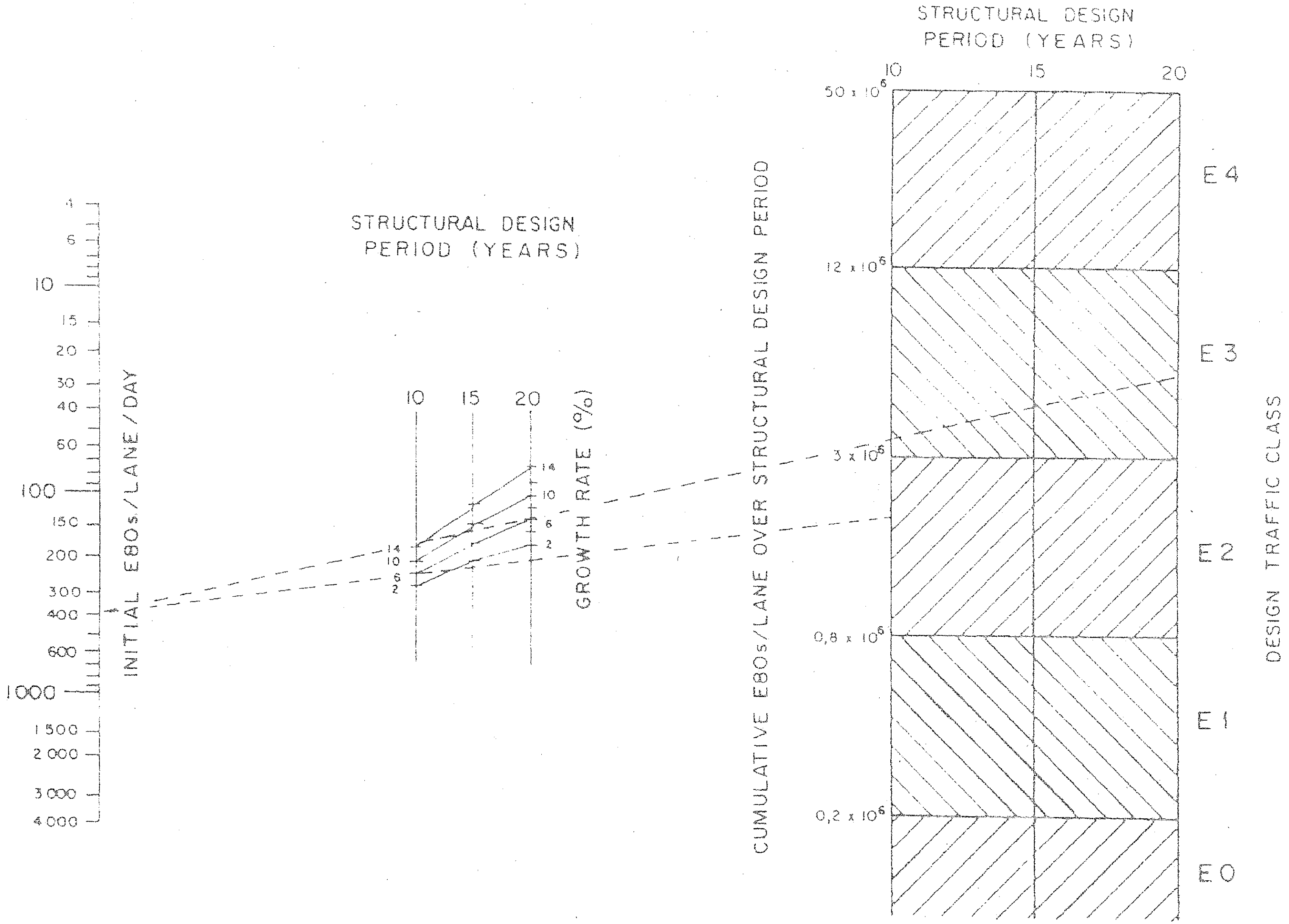


FIGURE 5[1]
Nomogram for determining design traffic class from the initial E80s/lane/day, the growth rate and the structural design period

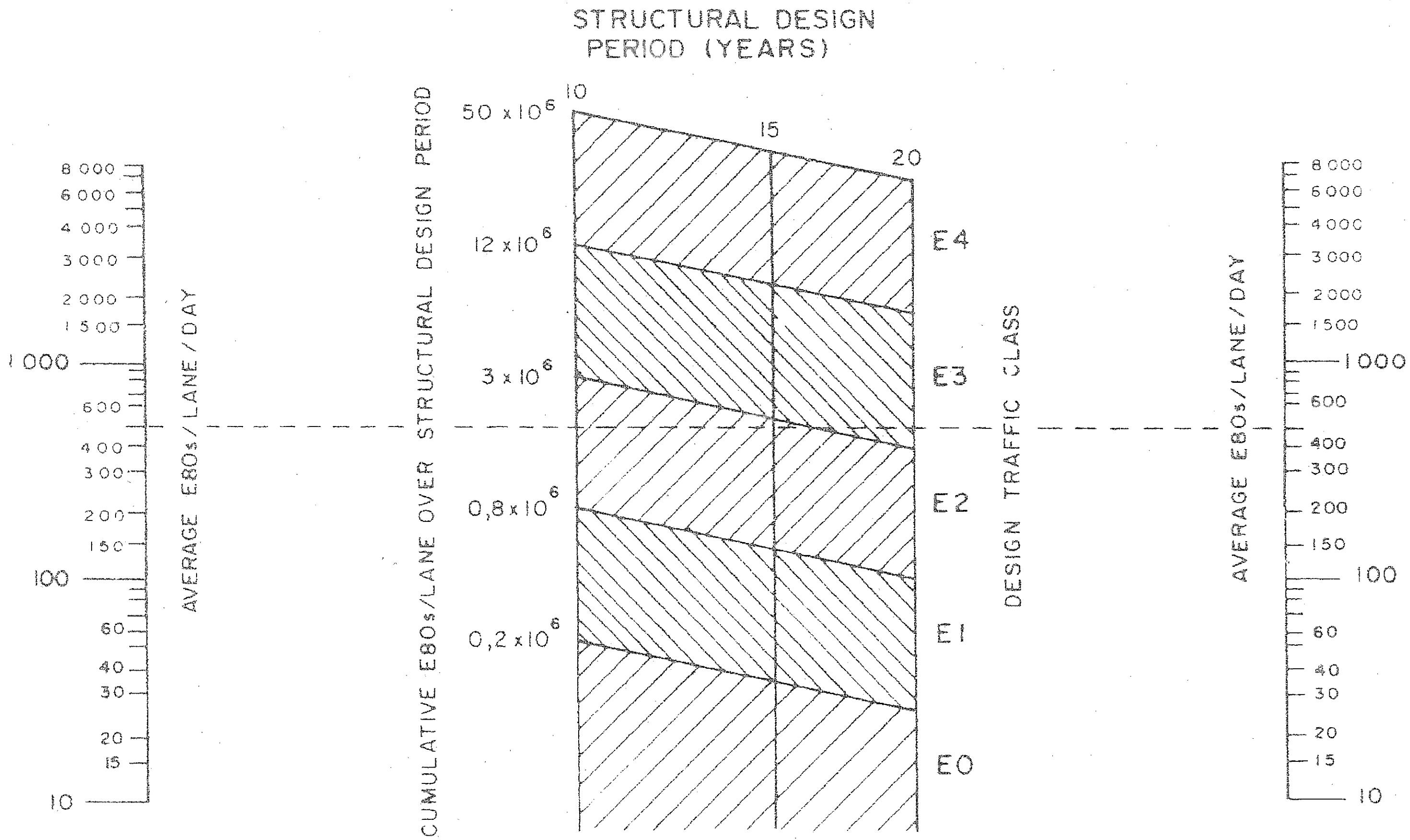


FIGURE 6[1]

Nomogram for determining design traffic class from the average E80s/lane/day, and the structural design period

TRAFFIC CLASS	CUMULATIVE EQUIVALENT TRAFFIC E80 / LANE OR ≡ AREA	DESCRIPTION	BLOCK PAVING CATEGORY
ER	$< 0{,}05 \times 10^6$	RESIDENTIAL ROADS	Rii
EO	$< 0{,}2 \times 10^6$	VERY LIGHTLY TRAFFICKED, FEW HEAVY VEHICLES	Rii Riii
E1	0,2 - 0,8 x 10	LIGHTLY TRAFFICKED, FEW HEAVY VEHICLES	Riii
E2	0,8 - 3 x 10	MEDIUM TRAFFIC VOLUME, FEW HEAVY VEHICLES	Rii, iii iii
E3	3 - 12 x 10	HIGH VOLUME, MANY HEAVY VEHICLES	Rii, iv Iiii
E4	12 - 15 x 10	VERY HIGH VOLUME, MANY, VERY HEAVY VEHICLES	Riv Iiii + iv

FIGURE 7

Classification of traffic for structural design purposes

5.2 DETAILED COMPUTATION OF EQUIVALENT TRAFFIC

Detailed computation of E80s involves:

(i) applied load equivalency;

(ii) actual surveys of loading conditions;

(iii) projection of loading data throughout the design period and

(iv) estimating the lane or area distribution.

5.3 APPLIED LOAD EQUIVALENCY (equivalent traffic)

The number of E80s is termed the equivalent traffic. A load-equivalency factor relates the number of repetitions of a given axle load to the equivalent number of E80s.

This equivalency factor is a function of:

(i) pavement composition;

(ii) material types;

(iii) definition of terminal conditions and

(iv) definition of terminal ridability.

Figure 6 gives average load-equivalency factors based on

$$F = \left(\frac{P}{80}\right)^n \quad \text{.......} \quad (1)$$

where F = the load equivalency factor

P = the axle or applied load

n = 4

The figure 4 is taken as the South African national average. The n value ranges from n = 2 for granular materials to n = 6 for cement-treated materials. These n values assume that the material is not saturated, is under 40 °C, or is not gap-graded etc.

Some pavements are sensitive to overloading. These include shallow-structured pavements with thin cemented bases. In such cases n is more than 4 but with less sensitive designs n is less than 4. In a case of doubt a sensitivity analysis is required using a spectrum of loading conditions and applying n in a range of 2,0 to 6,0. This is of particular importance in the case of abnormally high axle loading.

The equivalent traffic can be determined by multiplying the axle loads in each load group of the entire load spectrum by the relevant equivalency factor read from Figure 8.

5.4 STATIC MASS MONITORING PROCEDURES

The static axle loads of a representative sample of vehicles can be determined by means of permanent weigh-bridges or portable scales (mass meters). The axle loads can be classified into convenient axle-load groups. Additionally, visual surveys of all passing traffic can be carried out and the traffic can be divided into apparent axle loading groups. By this means an estimation of the number of repetitions of a given load can be made. These figures can easily be translated to equivalent load by using Figure 8.

5.5 PROJECTION OF THE TRAFFIC DATA OVER THE STRUCTURAL DESIGN PERIOD

The present average daily equivalent traffic (daily E80s) may be projected into the future by the use of tables given in, for example, Draft TRH4[1].

SINGLE-AXLE LOAD P(kN)	80 kN EQUIVALENCY FACTOR F FROM $F_A = \left(\frac{P}{80}\right)^x$ WHERE:		
	x = 2	x = 4	x = 6
75 - 84	1,00	1,00	1,00
85 - 94	1,3	1,6	2,0
95 - 104	1,6	2,4	3,0
105 - 114	1,9	3,6	6,8
115 - 124	2,2	5,0	11,4
125 - 134	2,6	7,0	18,4
135 - 144	3,1	9,4	28,7
145 - 154	3,5	12,4	43,4
155 - 164	4	16	64
165 - 174	4,5	20,4	92
175 - 184	5,1	25,6	130
185 - 194	5,6	31,8	180
195 - 204	6,3	39	244
>205	7,6	57	435

WHERE F_A = LOAD-EQUIVALENCY FACTORS (AXLE LOADS)

p = SINGLE-AXLE LOAD

x = SEE TEXT

FIGURE 8

80 kN single-axle equivalency factors for various values of x

6 MATERIALS (Design step 4)

The selection of materials for the pavement design is based on a combination of availability, economics and previous experience. These factors need to be evaluated during the design in order to select the materials that suit the requirements best.

Generally the design procedure uses the standard material specifications defined in Draft TRH14[3] ("Standards for road construction materials"). The classification of the materials is given in Figure 9. The material codes listed in this table are used extensively in the catalogue of designs. Only abbreviated specifications are given and TRH14 should be used for more details. Waste materials (eg blast-furnace slags) and pedogenic materials have not been classified because of their varying quality. If these materials are to be used they should be classified under the appropriate material codes[3].

The materials are classified according to their fundamental behaviour into various categories with different classes according to their strength characteristics.

6.1 DESCRIPTION OF MAJOR MATERIAL TYPES

Granular materials and soils show stress-dependent behaviour, and under repeated stresses, deformation can occur through shear and/or densification.

Cemented materials are elastic, possess tensile strength and usually crack under repeated flexure. These materials also crack because of shrinkage and drying. Through the application of an upper strength limit specification, such shrinkage cracks can be minimized. Because of the possibility of excessive shrinkage cracking of C1 materials they may not be suitable for segmental paving. A C2 material may be all that is required. C3 and C4 materials can be used as replacements for granular layers in subbases. They can be treated with either cement or lime, depending on the properties of the natural materials.

Symbol	Code	Material	Abbreviated specifications
	G1	Graded crushed stone	Dense-graded unweathered crushed stone; Max size 37,5 mm 86–88 % of apparent density; fine PI $\not>$ 4
	G2	Graded crushed stone	Dense-graded unweathered crushed stone; max size 37,5 mm 100–102 % mod AASHTO; fines PI $\not>$ 6
	G3	Graded crushed stone	Dense-graded stone + soil binder; max size 37,5 mm; minimum 98 % mod AASHTO; fines PI $\not>$ 6
	G4	Natural gravel	CBR $\not<$ 80; PI $\not>$ 6
	G5	Natural gravel	CBR $\not<$ 45, PI $\not>$ 10 max size 63 mm
	G6	Natural gravel	CBR $\not<$ 25, Max size $\not> \frac{2}{3}$ layer thickness
	G7	Gravel-soil	CBR $\not<$ 15; Max size $\not> \frac{2}{3}$ layer thickness
	G8	Gravel-soil	CBR $\not<$ 10; at in-situ density
	G9	Gravel-soil	CBR $\not<$ 7 at in-situ density
	G10	Gravel-soil	CBR $\not<$ 3 at in-situ density
	C1	Cemented crushed stone or gravel	UCS 6 to 12 MPa at 100 % mod AASHTO; Spec at least G2 before treatment; Dense-graded
	C2	Cemented crushed stone or gravel	UCS 3 to 6 MPa at 100 % mod AASHTO; Spec generally G2 or G4 before treatment; Dense-graded
	C3	Cemented natural gravel	UCS 1,5 to 3,0 MPa at 100 % mod AASHTO; Max size 63 mm
	C4	Cemented natural gravel	UCS 0,75 to 1,5 MPa at 100 % mod AASHTO; Max size 63 mm
	S-A	Interlocking paving blocks (type S-A)	Geometrical interlock on all vertical faces (possible to lay in herringbone bond) Wet crushing strength $\not<$ 25 MPa
	S-B	Interlocking paving blocks (type S-B)	Geometrical interlock on same vertical faces (not possible to lay in herringbone bond) Wet crushing strength $\not<$ 25 MPa
	S-C	Non-interlocking paving blocks (type S-C)	No geometrical interlock. Wet crushing strength, average $\not<$ 25 MPa, single units $\not<$ 20 MPa see 9.6
	SND	Bedding-sand	For use with concrete, clay or other blocks

NOTE: Code S-C refers to all non-interlocking blocks whether made from fired clay, concrete or another material. S-C would include square, rectangular, circular or other non-interlocking shapes

FIGURE 9

Definition of material symbols used in the catalogue

7 ENVIRONMENT

The climatic conditions, particulary moisture and temperature, under which the pavement will function as well as the underlying subgrade conditions, define the environment. The environment must be taken into account in the design of pavement structures.

7.1 CLIMATIC REGIONS AND THE DESIGN OF PAVEMENTS

The climate will largely determine the weathering of natural rocks, the durability of weathered, natural road building materials and, depending on drainage conditions, also the stability of untreated materials in the pavement. The climate may also influence the equilibrium moisture content. The designer should always consider the climatic conditions and avoid using materials known locally to display excessive water-susceptibility or temperature-sensitivity in adverse conditions. It is also possible to accommodate climatic conditions by either adjusting CBR values or by weighting the equivalent traffic, but not by both. A suggested weighting system for equivalent traffic is given in TRH4 (1985).

Southern Africa can be divided into three climatic regions:

(i) a large dry region;

(ii) a moderate region and

(iii) a small wet region.

Figure 10 shows a map of southern Africa with the different climatic regions indicated. These are macroclimates and it should be noted that different microclimates could exist within these regions.

7.2 CLIMATE AND SUBGRADE CBR

The design parameters for the subgrade is the soaked California Bearing Ratio (CBR) at a representative expected final in situ density for structural design purposes. When a material is classified according to the CBR, this implies that not more than 5 % of measured values of such a material will fall below the classified value. Research is being conducted on subgrade CBR and means of reducing its variability to enable a greater confidence level to be incorporated in the pavement design. It is expected that reduction in base and subbase thicknesses will result, when the studies to define the subgrade's potential more accurately are completed.

A proper preliminary soil survey should always be conducted. In the design it is current practice to use soaked CBR values and the use of these soaked values, especially in dry regions, is overconservative[4]. It is therefore suggested that the design CBR of a material be increased from soaked CBR to approach the in situ CBR, for example in the large dry areas of southern Africa.

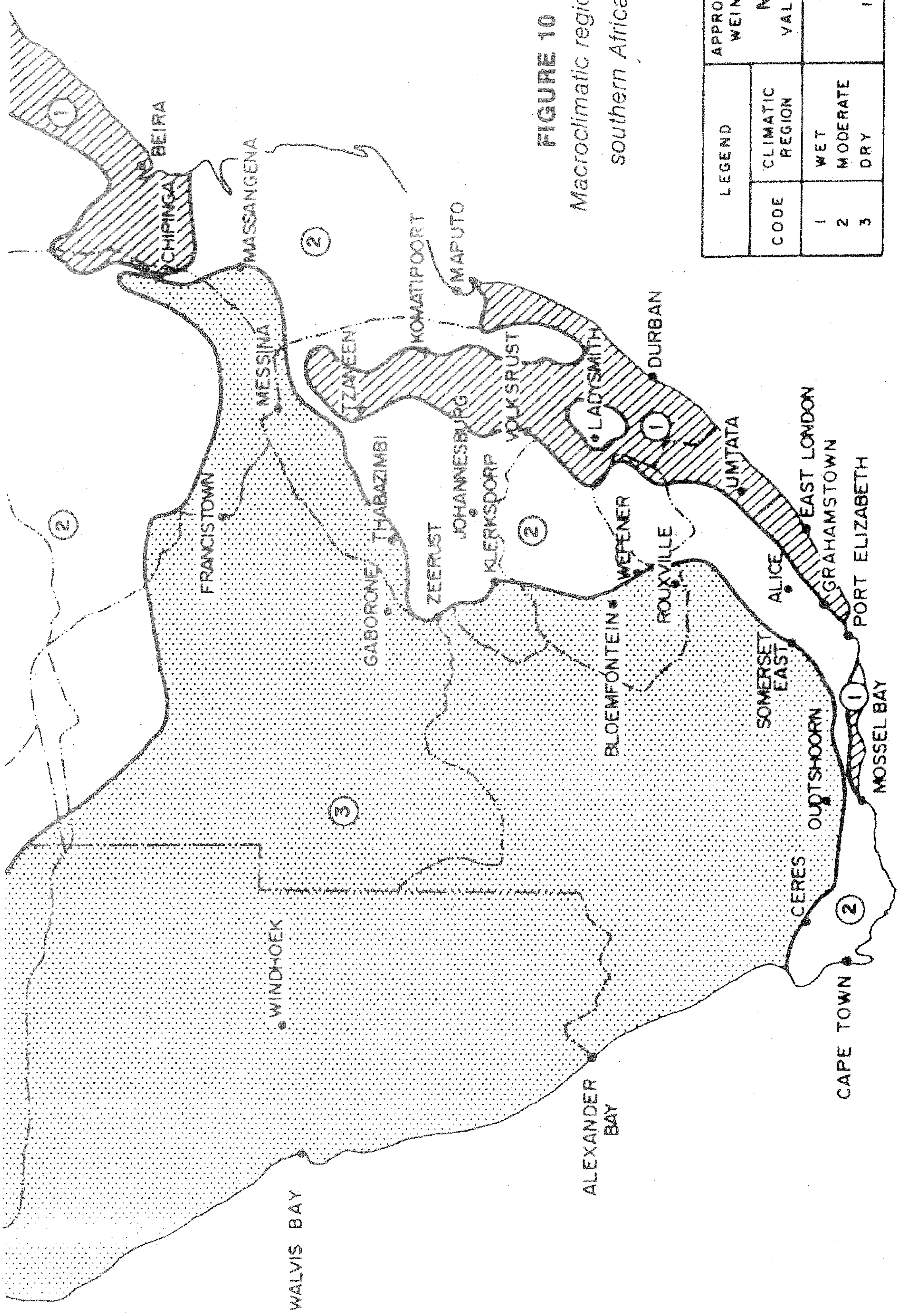


FIGURE 10

Macroclimatic regions of southern Africa

LEGEND		
CODE	CLIMATIC REGION	APPROXIMATE WEINERT N VALUES
1	WET	2
2	MODERATE	5
3	DRY	10

7.3 MATERIAL DEPTH

The term "material depth" is used to denote the depth below the finished level of the road 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.

Figure 11 specifies the material depths used for determining the design CBR of the subgrade for the different block paving and road categories.

7.4 DELINEATION OF SUBGRADE AREAS

A segmental block paving project should be subdivided into significant subgrade areas. A too fine delineation 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 at the site - or major soil boundaries - so that it is appropriate to define a design CBR for each unit.

The designer should differentiate between very localized good or poor soils and more general subgrade areas. Localized soils should be treated separately from the rest of the pavement design. Normally, localized poor soils will be removed and be replaced by suitable material.

SEGMENTAL BLOCK PAVING CATEGORY	ROAD CATEGORY	MATERIAL DEPTH (mm)
Low speed S1	-	300 - 600
Civic uses S2	-	300 - 600
Heavily loaded S3	-	800 - 2 500
Urban roads S4	-	800 - 1000
Higher speed S5	-	800 - 1200
-	A	1000 - 1200
-	B	800 - 1000
-	C	800
Special pavements S6	-	INVESTIGATE

FIGURE 11

Material depths to be used for determining the design CBR of the subgrade

7.5 DESIGN CBR OF SUBGRADE

For construction purposes the design subgrade CBR is limited to five groups in the structural design method as shown in Figure 12.

The CBR is normally determined after samples have been soaked for four days and may be adjusted according to Section 7.2. Special measures are necessary if a material with a CBR of 3 is encountered within the material depth. These include treatment (chemical or mechanical), stabilization, modification (chemical), removal and replacement with a better material or the addition of extra cover. After the special treatment, the material will be classified under one of the remaining four subgrade groups.

7.6 DESIGN CBR ON FILL

When the block pavement is on fill, the designer must use 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. TRH9 should be consulted when a material with a CBR of 3 is used in the fill.

7.7 DESIGN CBR IN CUT

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

SUBGRADE CBR (%)
< 3
3 - 7
7 - 15
15 - 25
> 25

FIGURE 12

Subgrade CBR groups used for the structural design

8 STRUCTURAL DESIGN AND BLOCK PAVEMENT CATALOGUE (Design step 6)

The designer may use a number of design procedures, such as a mechanistic design method[6, 7], a structural design method[8], design curves or the catalogue of designs given in this document. Whatever the method used, factors such as segmental block pavement category, design strategy, applied loads, materials available, and environment must be taken into account. Some estimation of future maintenance measures is necessary before a comparison of different structures can be made on the basis of present worth of costs. Special construction considerations which might influence either the pavement structure or the pavement costs, are discussed in design step 7.

This document is mainly aimed at using the catalogue of designs. It is however, likely that the best results will be obtained if the catalogue is used together with relevant local experience.

8.1 BEHAVIOUR OF DIFFERENT PAVEMENT MATERIALS USED WITH BLOCK PAVEMENTS

The behaviour of a segmental block pavement and the type of distress which will become the most critical, vary with the materials used in the subbase layer or layers. The behaviour of these materials will normally determine the type of maintenance expected and may also influence the pavement type selection. A brief description of the typical behaviour of these material types follows:

8.1.1 Untreated granular subbases

The mode of distress for pavements with untreated subbases is usually deformation arising from shear or densification of the untreated materials. The deformation may manifest itself either by excessive rutting in the wheel paths or by longitudinal roughness (ie differential settlement and differential rutting). Granular materials are often susceptible to water and excessive deformation can occur should water ingress through the surface.

8.1.2 Treated subbases (eg cemented or lime-treated)

Treated subbases improve the load carrying capacity of the segmental block pavement. Treated subbases are designed so that, at some stage the subbase will crack under loading. The cracking may propagate until eventually the layer exhibits properties similar to those of a good quality natural granular material. Little rutting or longitudinal deformation is likely for some time and this increases somewhat when the subbase has cracked extensively. It is, however, likely that some cracking into irregular blocks of subbase material will be evident very early in the life of over-treated bases; this is caused by the mechanisms of drying shrinkage and thermal stresses in the treated layers. Load-induced cracking will cause these irregular blocks to break up into smaller ones. The ingress of water through any poorly sealed joints in the block paving may cause the irregular blocks of subbase material to rock, resulting with time in the pumping of fines from the lower layers. Rutting or roughness will generally be low up to this stage but are likely to increase as the extent of the cracking increases.

Block pavements consisting of treated subbases on granular subbases can be sensitive to overloading. When both the subbase and a lower subbase are treated, the pavement will be less sensitive to overloading.

8.2 POSSIBLE CONDITIONS AT THE END OF THE STRUCTURAL DESIGN PERIOD

There is no design method available to predict the exact condition of a segmental block pavement 10 to 20 years in the future. However, as shown in the previous paragraph, certain kinds of distress can be expected in certain segmental block pavements and account must be taken of such distress. Figure 13 shows terminal conditions of rut depth and cracking considered acceptable for the various categories.

POSSIBLE CONDITION AT END OF STRUCTURAL DESIGN PERIOD	SEGMENTAL BLOCK-PAVING CATEGORY										
	Ai	Aii	Aiii	Ii	Iii	Iiii	Iiv	Ri	Rii	Riii	Riv
rut depth (mm)	50	50	50	50	30	30	40	50	30	40	30
Length or area of pavement exceeding stated rut depth (%)	60	60	60	50	30	50	50	60	50	50	15-30
Type of distress Granular subbase	Deformation by shear or densification, excessive rutting, longitudinal roughness										
Type of distress Cemented subbase	Breaking up of subbase, rocking of subbase blocks, pumping of fines										

NOTE : A STANDARD TEST FOR NEWLY CONSTRUCTED BLOCK PAVEMENTS SUGGESTS 10 mm MAXIMUM DEFORMATION UNDER A 3 m LONG STRAIGHT EDGE. THIS COULD BE USED FOR MEASURING TERMINAL RUT DEPTHS

FIGURE 13

Possible condition at end of structural design period for the segmental block-paving categories

8.3 THE CATALOGUE DESIGN METHOD

Before the catalogue is used, all the factors noted in design steps 1 through 5 should be considered. By making sure of the segmental block paving category, design strategy, design equivalent traffic and material availability, the designer can choose a segmental block pavement structure. It should be noted that these designs are considered to be of adequate capacity 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 segmental block pavement structures.

8.4 SELECTED LAYERS BELOW THE SEGMENTAL BLOCK PAVING

The catalogue assumes that all subgrades are brought to equal support standards. Design step 5 limits the design CBR of the subgrade to four groups (Figure 12). For block pavements the in situ subgrade soil should be prepared, and ripped and recompacted if needed. On top of this prepared layer, one or two selected layers may be required. The required selected subgrade layers will vary according to the design CBR of the subgrade. Figure 14 shows the preparation of the subgrade and required selected layers for the different subgrade design CBRs.

DESIGN CBR OF SUBGRADE (%)	< 3	3 - 7	7 - 15	15 - 25	> 25
ADD SELECTED LAYERS UPPER LOWER	NOT APPLICABLE	150 mm G7 (150 mm G9)*	150 mm G9	— —	— —
TREATMENT OF IN SITU SUBGRADE	SPECIAL TREATMENT REQUIRED	RIP AND RECOMPACT TO 150 mm G10	RIP AND RECOMPACT TO 150 mm G9	RIP AND RECOMPACT TO 150 mm G7	USE AS SUBBASE ON BASE LAYERS **

* IF THE IN SITU SUBGRADE IS EXPECTED TO BE VERY WET OR IN WET CLIMATIC REGIONS (FIGURE 2.1) AN ADDITIONAL 150 mm LAYER OF G9 MAY BE REQUIRED

**COMPACTED TO THE APPROPRIATE DENSITY. SEE FIGURE 16.

FIGURE 14

Preparation of subgrade and required selected layers for the different subgrade design CBRs

8.5 DEFINITION OF TERMS USED IN BLOCK PAVEMENTS

Figure 15 shows the various layers possible in a block pavement and defines the terms used. It must be noted that whereas the blocks themselves form the surfacing of the road, their structural properties are similar to those of a road base - hence they are known as the base layer.

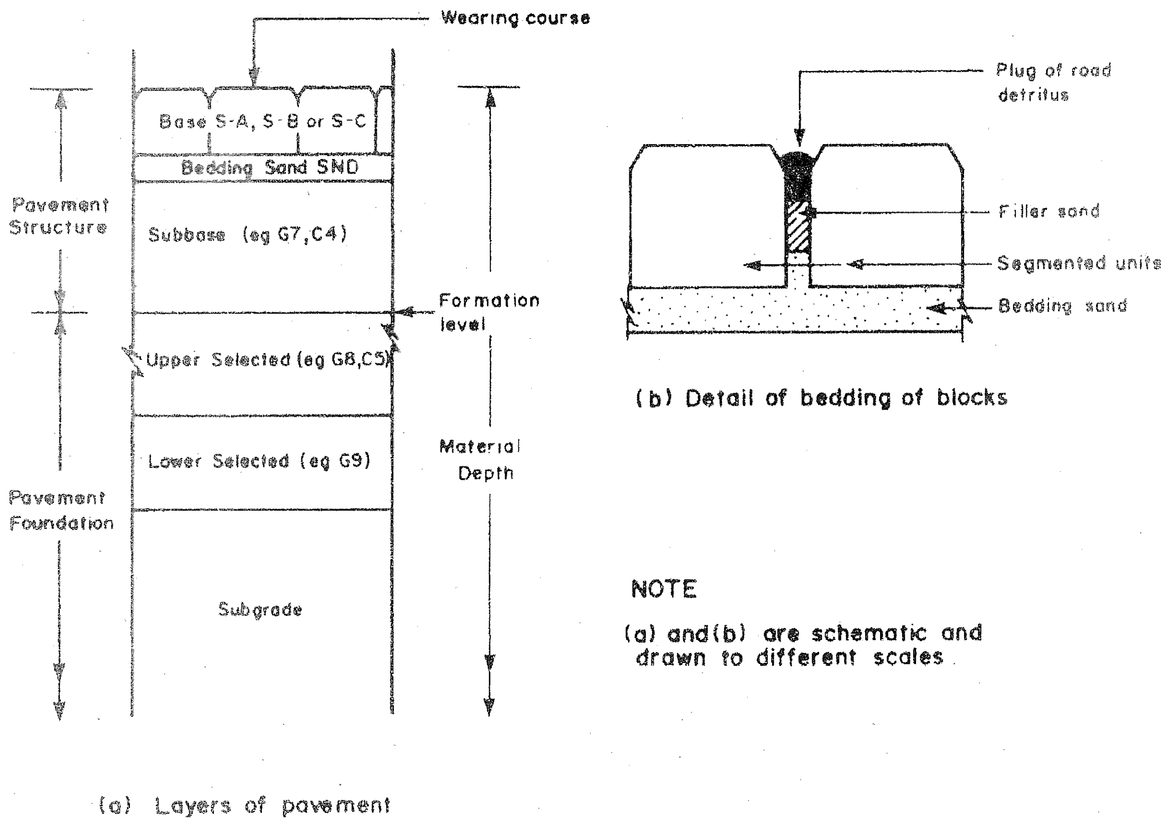


FIGURE 15

Terminology used with segmental block paving

8.6 CATALOGUE OF DESIGNS FOR SEGMENTAL BLOCK: CATEGORY A (ARCHITECTURAL)

Figure 22 shows designs suitable for the A category (Architectural).

8.7 CATALOGUE OF DESIGNS FOR SEGMENTAL PAVING: CATEGORY I (INDUSTRIAL)

Figure 23 shows designs suitable for the I category (Industrial).

8.8 CATALOGUE OF DESIGNS FOR SEGMENTAL PAVING: CATEGORY R (ROADS)

Figures 24 and 25 show designs suitable for the R categories (Roads) with Figure 24 containing designs suitable for moderate or dry conditions and Figure 25 designs suitable for wet conditions.

9 PRACTICAL CONSIDERATIONS (DESIGN STEP 7)

SABS 1200 MJ - 1984 is the specification for segmental block paving. It is valuable to consult this document and to consider the notes given in this section as well.

9.1 DRAINAGE AND COMPACTION

Experience has shown that inadequate drainage is probably responsible for more pavement distress in southern Africa than inadequate structural or material design. Drainage design is discussed in detail in TRH 15[16]. The basic philosophy is to provide effective drainage at least to the material depth so that the pavement structure is prevented from becoming saturated. Consequently, effective drainage is essential to good pavement performance, and it is pre-supposed in the structural design procedure.

Drainage design is an extensive subject and detailed discussion of it is beyond the scope of this document.

Both the discharge of surface run-off and the control of subsurface water need to be considered. Surface run-off is generally readily controlled, but subsurface drainage is important. Certain in situ materials that are highly permeable, eg some Kalahari sands and Cape Flats sands, are free-draining and little extra drainage is required. Impermeable materials may trap moisture and cause the pavement layers to become saturated, with an associated loss in strength. These will require deeper subsurface drainage. Particular attention needs to be paid to cuttings, high-perched water tables, vleis etc.

The design procedures assume that the material properties specified are achieved in the field.

Figure 16 gives the minimum compaction standards required for the various layers of the pavement structure. It should be noted that below subbase level, the standards are independent of the material type used.

PAVEMENT LAYER	COMPACTED DENSITY
SUBBASE (UPPER AND LOWER)	95 % MOD. AASHTO
SELECTED SUBGRADE (COHESIVE)	93 % MOD AASHTO
SELECTED SUBGRADE (NON COHESIVE)	100 % MOD AASHTO
SUBGRADE	
(WITHIN 200 mm OF SELECTED SUBGRADE)	90 % MOD AASHTO
(WITHIN MATERIAL DEPTH)	85 % MOD. AASHTO
FILL	90 % MOD AASHTO

FIGURE 16

Compaction requirements for construction of pavement layers

9.2 SUBGRADE BELOW MATERIAL DEPTH

Certain special problems may arise in the subgrade which require individual treatment. The design procedure assumes that these have been taken into account separately. The main problems that need to be considered are:

(i) the excessive volume changes that occur in some soils as a result of moisture change, eg expansive soils and soils with collapsible structures;
(ii) flaws in structural support, eg sinkholes, mining subsidence and slope stability;
(iii) the non-uniform support that results from wide variations in soil types or states;
(iv) the presence of soluble salts which, under favourable conditions, may migrate upwards and cause cracking, the disintegration of cemented bases and loss of density fo untreated bases and
(v) the excessive deflection and rebound of highly resilient soils during and after the passage of a load, eg ash, micaceous and diatomaceous soils.

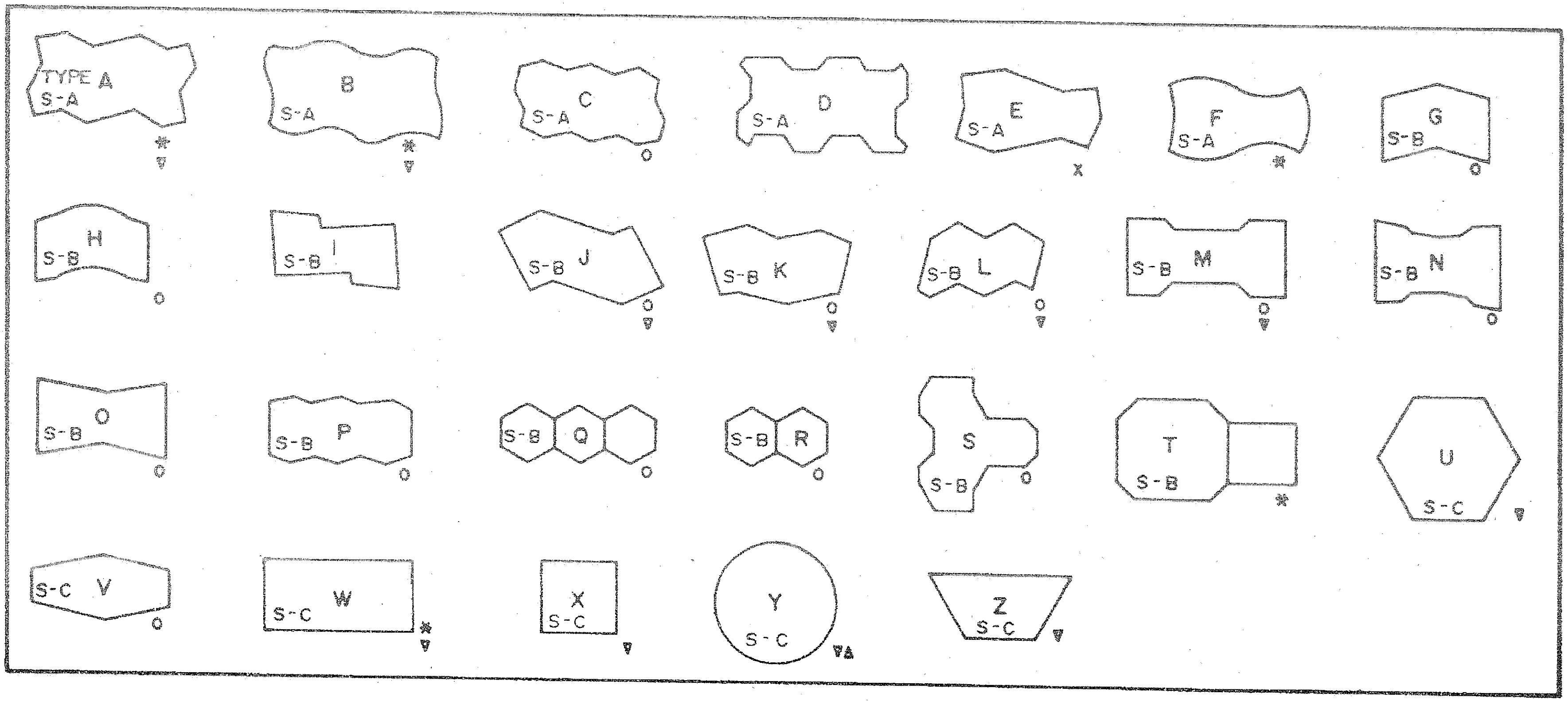
Acceptable guidelines should be followed to deal with these problems.

9.3 THE EFFECT OF THE SHAPE OF THE PAVING BLOCKS

A major advantage of segmental paving blocks over earlier forms of small-element paving such as cobblestones is that, in general, they can be laid by unskilled labourers. However, in order to realize this objective, it is essential that the shape of the blocks be such that, once a laying pattern has been established, each block can be located unambiguously with respect to its neighbours. In other words, the block shapes should be self-locating. Inspection of the shapes shown in Figure 17 reveals that blocks A through T all fulfil this requirement. Within this group, shapes A through F provide positive location along both the long and short sides of the block. Blocks U through Z, including the widely used rectangular shape, W, are not self-locating and may require more time to locate.

The second factor affecting the efficiency of block laying is the degree to which blocks must be rotated during laying in order to achieve bond. Certain shapes (eg G, H and K) must be rotated through 180° during laying even when working in stretcher bond. Furthermore, shapes I and J must be turned upside down for every second course. This has the advantage that an otherwise reject block with a poor finish may be laid the other way up. Not only does this impede laying but it precludes the use of a chamfer on these shapes of block. Moreover, repairs to pavements laid in these shapes can be unsightly because the tops and bottoms of the blocks stain and weather to different degrees and maintenance crews seldom bother to re-use the blocks in their original orientations.

The third factor affecting block laying is the degree to which the joint spacings between blocks can be controlled. During block manufacture wear of the mould will lead to gradual changes in block dimensions. Where the block has straight sides the increases



o Suitable for stretcher bond only   * Suitable for variety of bonds including herringbone   ▿ Currently available in southern Africa (1981)
▵ Special jointing may be necessary (eg weak cement mortar)   S-A Interlocking paving blocks - geometrical interlock along all vertical faces [possible to lay in herringbone bond]   S-B interlocking paving blocks - geometrical interlock along some vertical faces [not possible to lay herringbone bond]   S-C Non-interlocking paving blocks - no geometrical interlock along vertical faces

FIGURE 17

Principal examples of paving block shapes in dimension can be easily accommodated within the joint spacings since the faces of adjacent blocks will remain parallel irrespective of mould wear. However, where the block has curved sides (eg block shape F) the effects of mould wear are to alter the radii of curvature of the sides of the block.

The versatility of a paving block system largely relates to the number of bonds that can be achieved for a particular shape of block. Most of the blocks shown in Figure 17 can only be laid in stretcher bond which can lead to less than optimal performance of the pavements under very heavy traffic. So far as block laying is concerned, where pavements can only be laid in stretcher bond it is necessary to break bond at every intersection (see Figure 18 for types of laying bond). If the blocks can be laid in herringbone pattern it becomes possible to follow any form of road alignment using just the standard size and shape of block without ever needing to break bond even at intersections. This is shown schematically in Figure 19. For this reason block shapes permitting herringbone bonding are to be preferred to shapes that only permit block laying in stretcher bond.

Positive geometrical interlock may be said to exist when the geometries of two neighbouring blocks so interact as to prevent the movement of the axes of the blocks parallel to one another. In this respect those blocks which provide geometrical interlock along all vertical faces may exhibit better performance than blocks which provide geometrical interlock on some faces[10].

9.4 THE EFFECT OF THE BLOCK MATERIAL

Blocks can be manufactured from either a cementitious material (eg lime, cement, blast-furnace slag) or from a fired material (eg clay). There will be differences between blocks made from cementitious or fired materials in the following areas: tolerance, porosity, surface wear, durability, brittleness, moisture, expansion and shrinkage. It is possible to attain fine tolerances with cementitious materials which is an important factor in maintaining specified joint widths. The South African Bureau of Standards are preparing specifications to cover many of these factors and strict compliance is recommended for optimum performance.

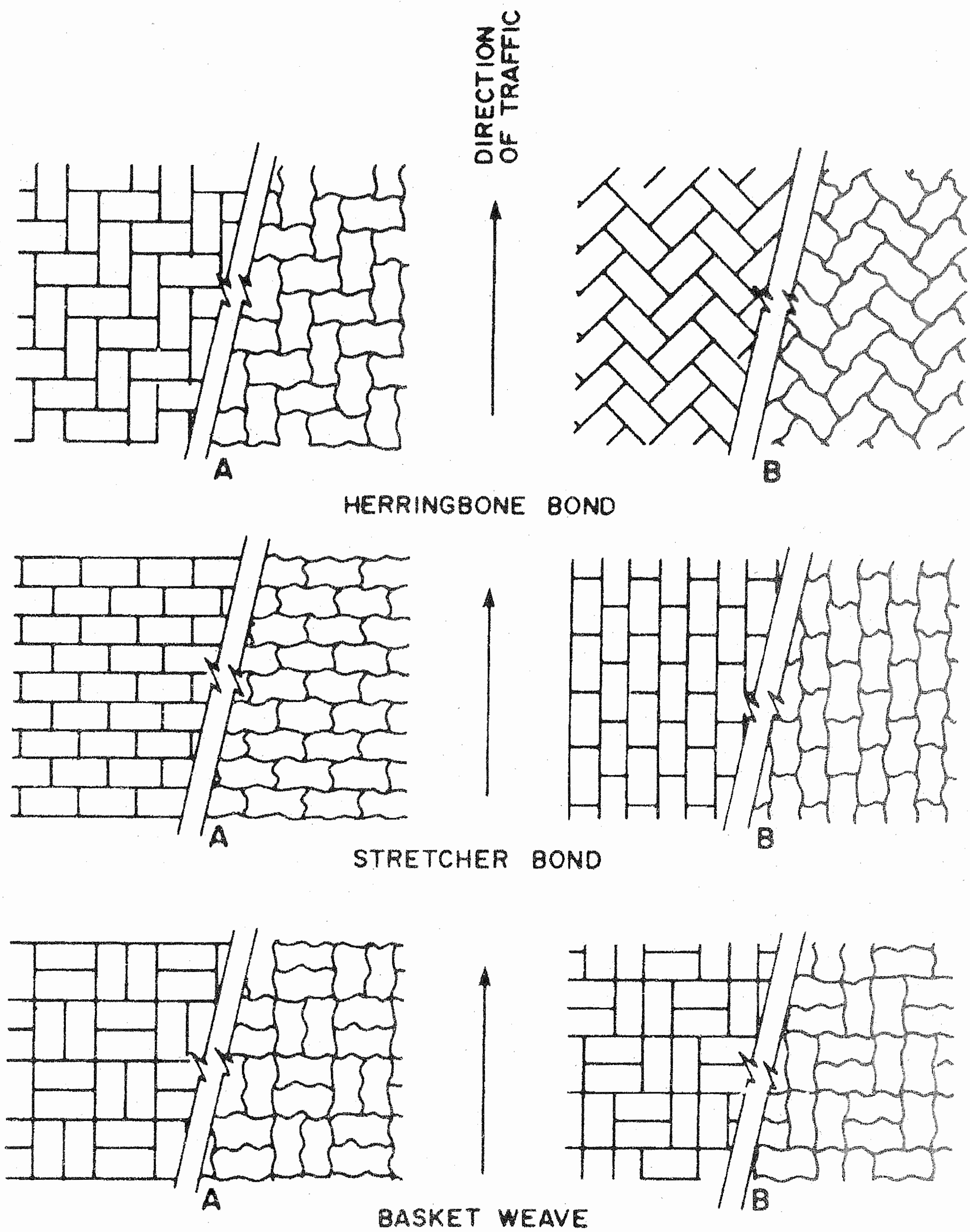


FIGURE 18
Types of laying bond

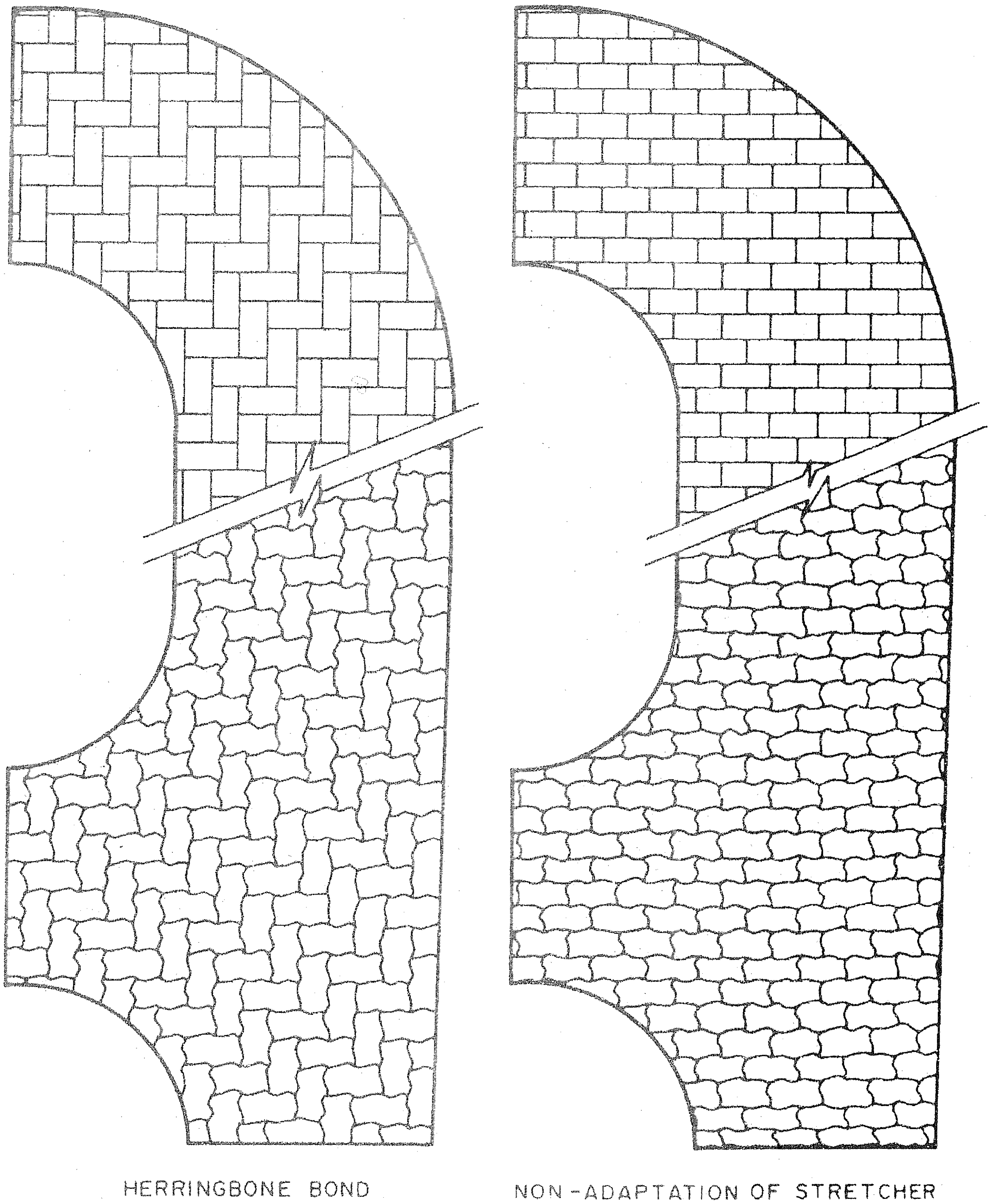


FIGURE 19

Adaptation of herringbone bond to changes in alignment by comparison with stretcher bond

9.5 THE EFFECT OF SIZE AND BLOCK THICKNESS

A limited investigation into the effects of changing the size of blocks shape A through F of Figure 17 has been made[9]. The approximate sizes of the blocks studied were 220 mm x 100 mm and 176 mm x 88 mm corresponding to approximately 40 and 50 blocks per square metre of pavement respectively. The comparison, although limited in scope, showed that changes in the size of the block have no effect on the performance of block pavements under traffic.

In some recent studies it was determined[9] that an increase in the thickness of the paving blocks led to a reduction in the rutting deformations, surface deflections and subgrade stresses. These improvements in performance were found to be independent of the thickness of the subbase or the magnitude of the wheel load and were a non-linear function of block thickness. In this respect, a change in block thickness from 60 to 80 mm was more beneficial to performance than a change from 80 to 100 mm. It should be noted that, at the higher of the two wheel loads studied (36 kN), block thickness was the principal arbiter of pavement performance in respect of deformation and deflection, whereas at the lower wheel load (24 kN) both base and block thickness significantly influenced the pavement response. Irrespective of the wheel load, it was found that changes in block thickness had a bigger effect on performance than corresponding alterations in the thickness of the subbase course.

The mechanisms by which the blocks deformed are of interest. Generally no damage (ie cracking, spalling or rupture) of the individual blocks was observed. Pavement deformation therefore resulted from the movement of the intact blocks relative to one another. These movements were of two types, viz rotation about joint lines and faulting along joints.

Significant faulting normally occurred only where blocks were laid in stretcher bond with the long axes of the blocks parallel to the direction of trafficking or where there were significant variations in the thicknesses of adjacent blocks.

9.6 SKID RESISTANCE AND RIDING QUALITY

For segmental blocks to be used for higher speed roads some degree of surface roughness is necessary. The results of an extensive investigation[17] showed that some bricks and some of the concrete units with smooth surfaces which were evaluated did not provide adequate skid resistance. The normally available 25 MPa wet compressive strength units made with angular particles are suitable. Suitable riding quality requires strict adherance to the surface levels especially between individual blocks. Non-chamfered units generally provide better riding quality than chamfered units.

9.7 THE EFFECT OF BLOCK STRENGTH

Following studies on the effects of varying the compressive strengths of the paving blocks for a variety of shapes it was reported[10] that the load-associated performance of the block pavement was independent of the wet or dry compressive strengths or the flexural strengths within the range studied (25 to 55 MPa wet compressive strength). The Concrete Masonry Association provides a standard specification of 25 MPa characteristic wet compressive strength for their products.

Two strengths of block are recommended, 25 MPa wet compressive strength and 35 MPa wet compressive strength. The stronger blocks are for use where excessive abrasion or wear is expected. (In the case of durable aggregates[3] higher wet compressive strengths may be required. The shape and strength of aggregates used are significant in determining the suitability of blocks in terms of abrasion and wear.)

9.8 BLOCK LAYING

Blocks can be laid mechanically or by hand. Providing the constraints referred to in Section 9.3 above are observed the method of block laying has no effect on the design of the segmental block pavement.

9.9 LAYING TOLERANCES AND GEOMETRICS

Geometric design should follow practices for other pavements. Variable road widths, curves and junctions do not present problems in practice, since the blocks are small and can easily be cut and placed to suit the geometry of the pavement. Specially shaped blocks are also available.

Whereas the benefits of good drainage are generally appreciated, drainage still remains one of the most neglected aspects of pavement design.

Good surface drainage is therefore of prime importance to ensure non-saturation of subbase layers. In practice the cross-fall for block pavements should be a minimum of 1 % on large industrial areas where the terrain is very flat. The desirable minimum of 2 % should however be established wherever possible. Special considerations for wide areas of industrial paving should be given to ensure adequate cross-fall of the surface. Cambered cross-sections are also satisfactory.

9.10 EDGE RESTRAINT

Edge restraint is required along the edges of a block pavement to prevent the outward migration of blocks, which would result in the opening of joints and loss of bond between the blocks. Edge restraint can be provided by conventional kerbing. The aesthetic appearance may be improved with precast or natural stone kerbing as a contrast to the blocks themselves. In large industrial or civic areas intermediate restraint measures may sometimes be necessary.

9.11 "LOCK-UP" AND "INTERLOCK"

A phenomenon known as "lock-up" occurs with segmental paving blocks some time after laying. The joints between the blocks seal better due to the action of trafficking and weathering causing contraction and expansion of blocks and the addition of road detritus into the joints. It is also possible that with time a degree of individual settlement of the block within its sandbedding layer occurs. It is said that individual, shaped blocks "interlock" and a segmental pavement "locks up"[9,10]. This has been found to be similar to the "initial settling-in improvements" found with all pavements and noted especially during accelerated testing.

9.12 THE BEDDING-SAND LAYER

The bedding sand is only included in block paving as a construction expedient. Although a substantial attenuation of the stresses applied to a block pavement occurs within the sand[9,10], much of the deformation (rutting) in a pavement has been shown to originate in the bedding layer. Three factors have been determined to have an important influence on the response of block pavements to traffic. These are:

(i) thickness of the sand layer;
(ii) grading and angularity of the sand and
(iii) the moisture content of the sand during compaction and in service.

It has been reported[9] that a reduction in the loose thickness of the bedding sand from the traditional European specification of 50 mm to between 25 and 30 mm was beneficial to the deformation (rutting) behaviour of block pavements. An almost fourfold reduction in deformation was observed. Experience gained in more than 50 Heavy Vehicle Simulator (HVS) trafficking tests on prototype block pavements in South Africa has confirmed[10] that there is no necessity to employ bedding sand thicknesses greater than 25 to 30 mm in the loose (initial) condition which yields a compacted thickness typically close to 20 mm (a 5 to 10 mm surcharge is therefore considered adequate).

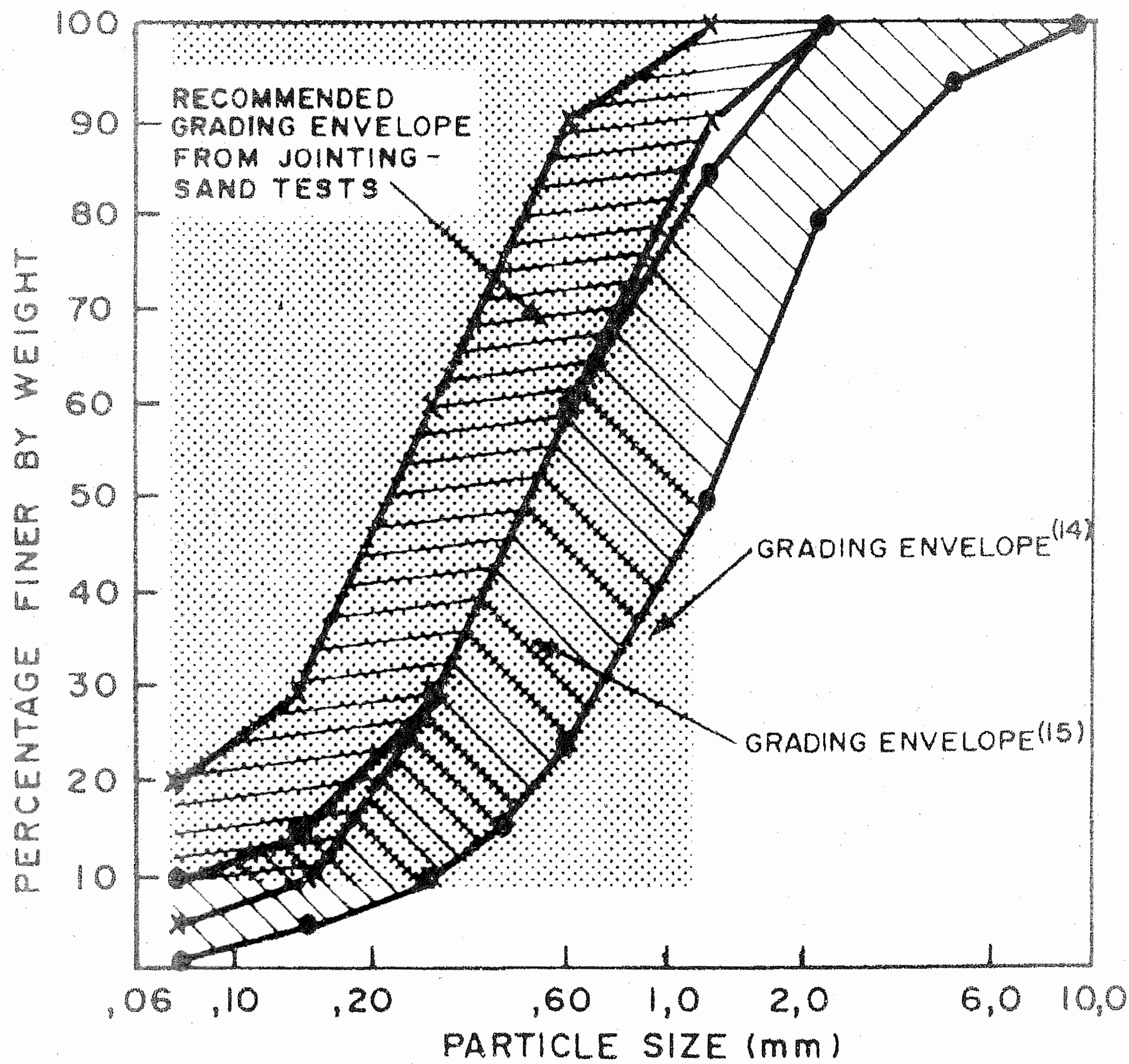
Unacceptable levels of performance have been observed where the proportion of silt and clay material smaller than 75 µm in the sand exceeds about 15 %. In sands with silt and clay contents between 20 and 30 %, substantial deformations (up to 50 % of the bedding sand thickness[10]) have been observed, especially where the sands were wet.

A recommended grading envelope for bedding sand is given in Figure 20.

Experience gained in South Africa has shown that adequate compaction of the sand bedding can be achieved at moisture contents typically lying within the range from 4 to 8 %, with a value of 6 % representing a satisfactory target value.

For sands of which the grading complies with the limits set out in Figure 20, the effects of water content appear to have little influence on the behaviour of the pavement under traffic. This has been confirmed by running HVS trafficking tests whilst maintaining the sand in a soaked condition. Generally this has had little effect on the rate of deformation, nor has pumping been observed. However, where the bedding sand contains a significant proportion of clay, greater than (say) 15 %, the addition of water to the bedding sand has been found to produce substantial increases in deformation accompanied by pumping. For this reason, the use of sands containing plastic fines should be avoided in the bedding layer.

Experimental evidence confirms that such sands are nevertheless suitable for jointing-sands (see Section 9.13) both in respect of their mechanical properties and as a means fo inhibiting the ingress of water into the joints.



(a) ENVELOPES OF JOINTING-SAND

FIGURE 20

Bedding and jointing-sand

SIEVE SIZE	% PASSING
9,52 mm	0
4,75 mm	95 - 100
2,36 mm	80 - 100
1,18 mm	50 - 85
600 μm	25 - 60
300 μm	10 - 30
150 μm	5 - 15
75 μm	0 - 10

(b) RECOMMENDED GRADING FOR THE BEDDING-SAND [15]

FIGURE 20 (cont'd)
Bedding and jointing-sand

9.13 COMPACTION OF BLOCKS INTO BEDDING-SAND AND SEALING OF JOINTS

After the blocks have been laid it is necessary to compact them into the bedding-sand. Normally two cycles of compaction are applied. The first cycle compacts the bedding-sand and causes this material to rise up the joints by amounts of between 5 mm and 25 mm (see Figure 21). A finer jointing-sand is then brushed into the joints.

The jointing-sand should pass a 1,18 mm sieve and have at least 10 % (but preferably 15 %) of material smaller than 75 μm. The complete grading envelope is shown in Figure 20. Mine sand has been found to be suitable for this purpose, but consideration should be given to the probability of staining of the blocks by certain chemicals within the sand. Once the joints are filled a further cycle of compaction is applied to bring the pavement to its final state. Each compaction cycle should involve at least two passes of the compactor. A vibrating plate compactor has been found to be the most suitable for this compaction work.

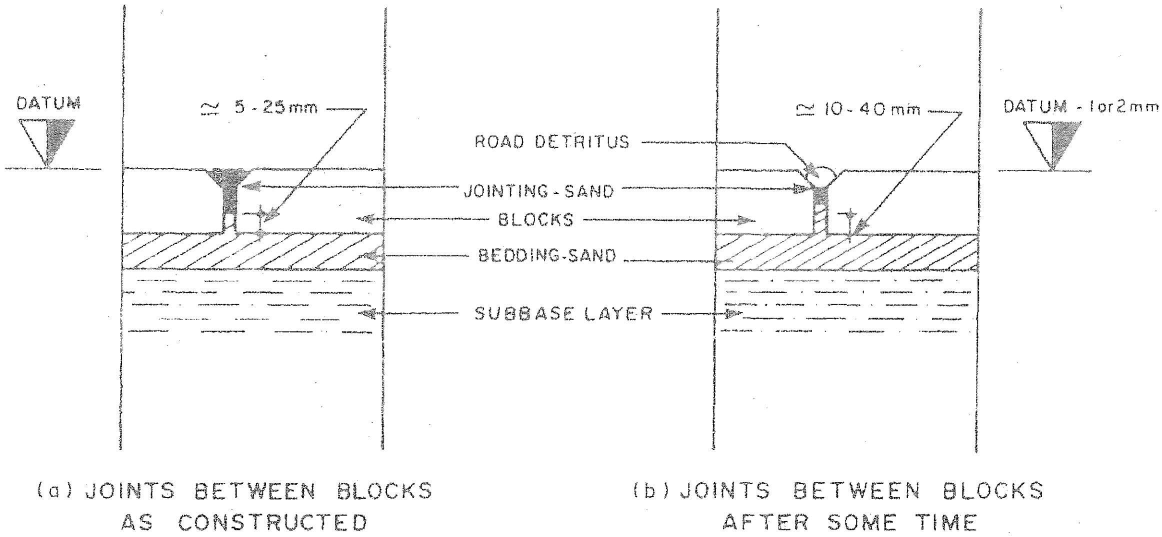


FIGURE 21

Changes occurring with the material in the joints of segmental paving as constructed and after some time

9.14 TIME EFFECTS OF SEALING OF JOINTS

Figure 21a shows a segmented block pavement when first opened to traffic. With the passage of time and the additional compaction caused by trafficking the joints will be as shown in Figure 21b. The cumulative compactive effect of traffic will cause the blocks to bed further into the bedding-sand and displace some of the jointing-sand vertically upwards. The action of passing vehicles removes some of the jointing-sand and it becomes part of the road detritus. This detritus, which includes dust, particles of rubber from tyres and other particles, forms an upper plug over the jointing sand assisting the sealing of the blocks.

9.15 STEEP GRADES

It has been stated above that the minimal falls to the surface of block pavements is customarily 1 %. This allows water to drain across the pavement reducing ingress by absorption or through the joints and eliminates ponding. Due to the ease of where blocks are used on steep grades the joints between the blocks become the drainage paths for rain water. In such circumstances the pattern of the blocks is an important consideration. If their alignment is such that the long joints are in the direction of the grade the joints will rapidly wash out.

9.16 RE-USE OF BLOCKS

An advantage of blocks is that they can be re-used. They can be taken up for repairs to failed areas of subbase or for the installation of services. Re-laying is straightforward. The blocks on either side of an opening may however creep. To avoid this the opening must either be jacked apart or the blocks restrained from creep by other means. Failure to do this could result in wider joints around the opening which could allow water ingress and subsequent saturation of subbase material. Difficulty would also be experienced in relocating blocks on completion of the repair.

9.17 MAINTENANCE

Little maintenance work is normally required with segmental block paving except to ensure that joints are kept full of sand, the treatment of weeds and the correcting of levels of surfacing should there be bad initial construction.

Various measures to deal with weeds growing within the joints of lightly trafficked areas are in current use. These include spraying with herbicides at regular intervals after checking that no environmental or ecological problems will be caused, or providing a polyethelene sheet below the bedding-sand during construction. The latter measure is not effective for three main reasons. Seeds germinate in the road detritus within the joints rather than under the blocks themselves, sheeting may induce sliding of the blocks on steep slopes and polyethelene sheeting could also result in the entrapment of water which is an undesirable condition in any pavement. Mine sand which has a high cyanide content can be used as bedding sand where its presence is not an environmental problem.

Poor surface levels are corrected by removing the area of blocks affected, levelling the subbase, compacting the subbase (often with hand rammers) and replacing the blocks.

Fired clay or concrete paving blocks meeting the specification appropriate to the intended usage, or in the absence of a suitable specification, products recommended by the manufacturer, ought to be used to ensure that products of adequate durability and abrasion-resistant characteristics are used. However, if the recommended minimum strength parameter of 25 MPa is achieved bricks may compare favourably with blocks in the long term.

10 COST ANALYSIS (DESIGN STEP 8)

Alternative pavement designs should be compared on a cost basis. The cost analysis should be regarded as an aid to decision-making. Although it is a very important factor, it does not necessarily include all the factors leading to a decision and should therefore not override all other considerations. The main economic factors which determine the cost of a facility are the analysis period, the structural design period, the construction cost, the maintenance costs, the salvage value at the end of the analysis period and the real discount rate.

The construction cost should be estimated from current contract rates for similar projects. Maintenance costs should include the cost of maintaining adequate surface levels and minor structural maintenance (eg re-laying small sections). The salvage value of the pavement at the end of the analysis period can make a contribution towards the next pavement. However, geometric factors such as minor improvements to the vertical and horizontal alignment, and possible relocation of drainage facilities, make the estimation of the salvage value very difficult. It should be noted that maintenance costs and salvage values are estimated in their current values and their future inflated costs are not te be taken account of.

10.1 PRESENT WORTH

The total cost of a project over the analysis period 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:

$$PWOC = C + M_1(1+r)^{-x_1} + \ldots\ldots M_i(1+r)^{-x_i} + \ldots\ldots - S(1+r)^{-z} \quad \ldots (2)$$

where PWOC = present worth of costs

C = present cost of initial construction

M = cost of the ith maintenance measure expressed in terms of current costs

r = real discount rate

x_i = number of years from the present to the ith maintenance measure, within the analysis period (where x_i = 1 to z)

z = analysis period

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

If the difference in present worth of costs between two designs is 10 % or less, it is assumed to be insignificant, and the present worth of costs of the two designs is taken to be the same.

A simple computer program can be designed for the easy calculation of the present worth of costs.

10.2 CONSTRUCTION COSTS (C)

A checklist of unit costs can be maintained and can be used to calculate the equivalent construction cost per square metre.

Factors which should be considered include: the availability of natural or local commercial materials, their expected trends in costs, the conservation of aggregates in certain areas and practical aspects, such as the speed of construction and the need to foster the development of alternative pavement technologies.

10.3 REAL DISCOUNT RATE (r)

Present worth analysis requires the selection of a real discount rate to express future expenditure in terms of present-day values. This discount rate should correspond to the rate generally used in the public sector. This currently ranges between 8 % and 12 % and is recommended at 10 %[13] in real terms (ie after compensating for the effect of inflation) in the public sector. Unless the client clearly indicates that he prefers some other rate, 10 % is recommended for general use. A sensitivity analysis could determine the importance of the value of the discount rate. The choice of a real discount rate should, however, be discussed with the client.

10.4 FUTURE MAINTENANCE (M_i)

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 reasonable comparison is made.

There are two types of maintenance measure:

(i) measures to improve the condition of the surfacing and

(ii) structural maintenance measures, applied at the end of the structural design period.

The structural design period (SDP) is the period during which it is predicted with a high degree of confidence that no structural maintenance will be required. If structural maintenance is done soon after the end of the structural design period, the distress encountered should only be moderate. When structural maintenance is done much later the distress will generally be more severe.

User-delay costs should also be considered and include the provision of alternative areas of activity whilst maintenance is being performed and the increased wear and tear to plant using the facility due to poorer riding quality.

10.5 SALVAGE VALUE (s)

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

(i) Where the existing pavement is left in position and an improvement is made, the salvage value of the pavement would be the saving in the cost of this improvement as opposed to constructing a new pavement to a standard equal to that of the existing pavement with the improvements. This can be termed the residual structural value.

(ii) Where the material in the existing pavement is taken up and recycled for use (blocks and subbase layers) in the construction of a new pavement, the salvage value of the recycled layers would be the difference in cost between furnishing new materials and the cost of taking up and recycling the old materials. This salvage value could be termed the recycling value.

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

The salvage values of individual layers of the pavement may differ considerably, from estimates as high as 95 % to possibly as low as 10 %. The residual salvage value of gravel and asphalt layers is generally high, whereas that of treated materials can be low. For block pavements the salvage value of the concrete blocks alone could be as high as 95 %[15].

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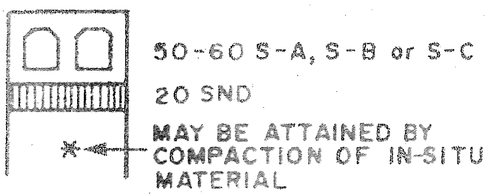
CATALOGUE OF DESIGNS

A - ARCHITECTURAL (NON-VEHICLE-ASSOCIATED)

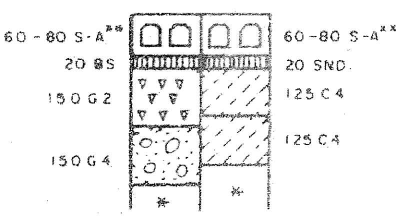


SUBDIVISIONS (i) FOOTPATH
(ii) SLOPE PROTECTION
(iii) UTILITY (eg. SWIMMING POOL SURROUNDS)

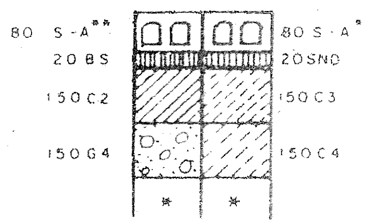
FIGURE 22
Catalogue of block-paving designs for TRH4

I - INDUSTRIAL

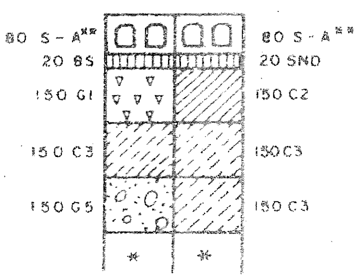
(i) 3-12 X 10⁶ E80s/LANE OR ≡ AREA



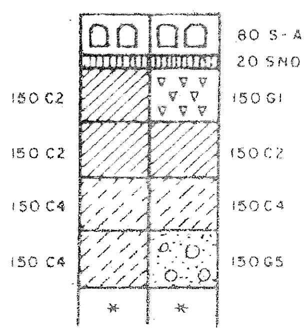
(ii) 12-50 X 10⁶ E80s/LANE OR ≡ AREA



(iii) 50-100 X 10 E80s/LANE OR ≡ AREA

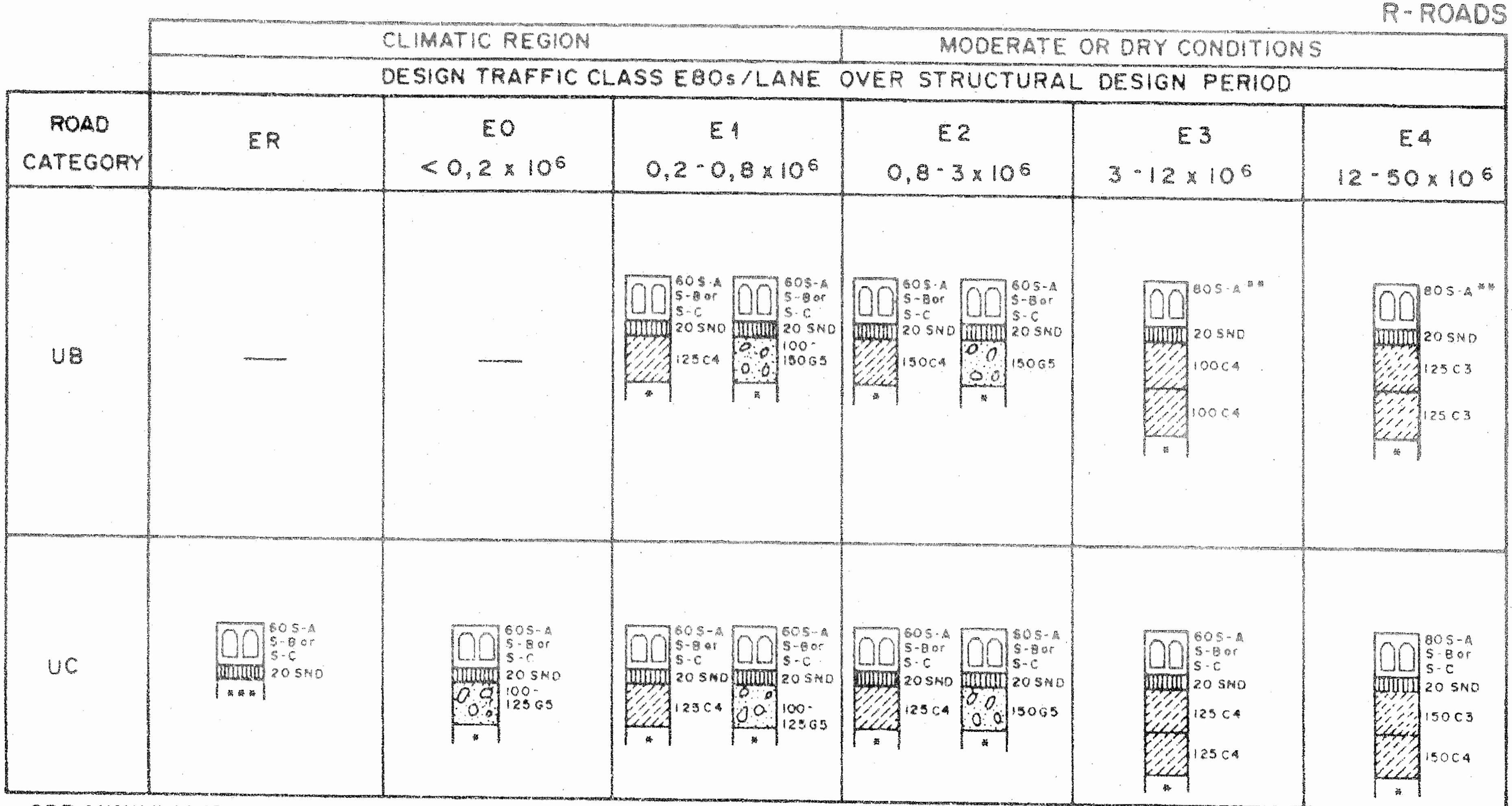


(iv) 100 X 10 E80s/LANE OR ≡ AREA



NOTE:
* CBR MINIMUM 15 %
** S-B OR S-C MAY BE SUITABLE IN SOME CASES

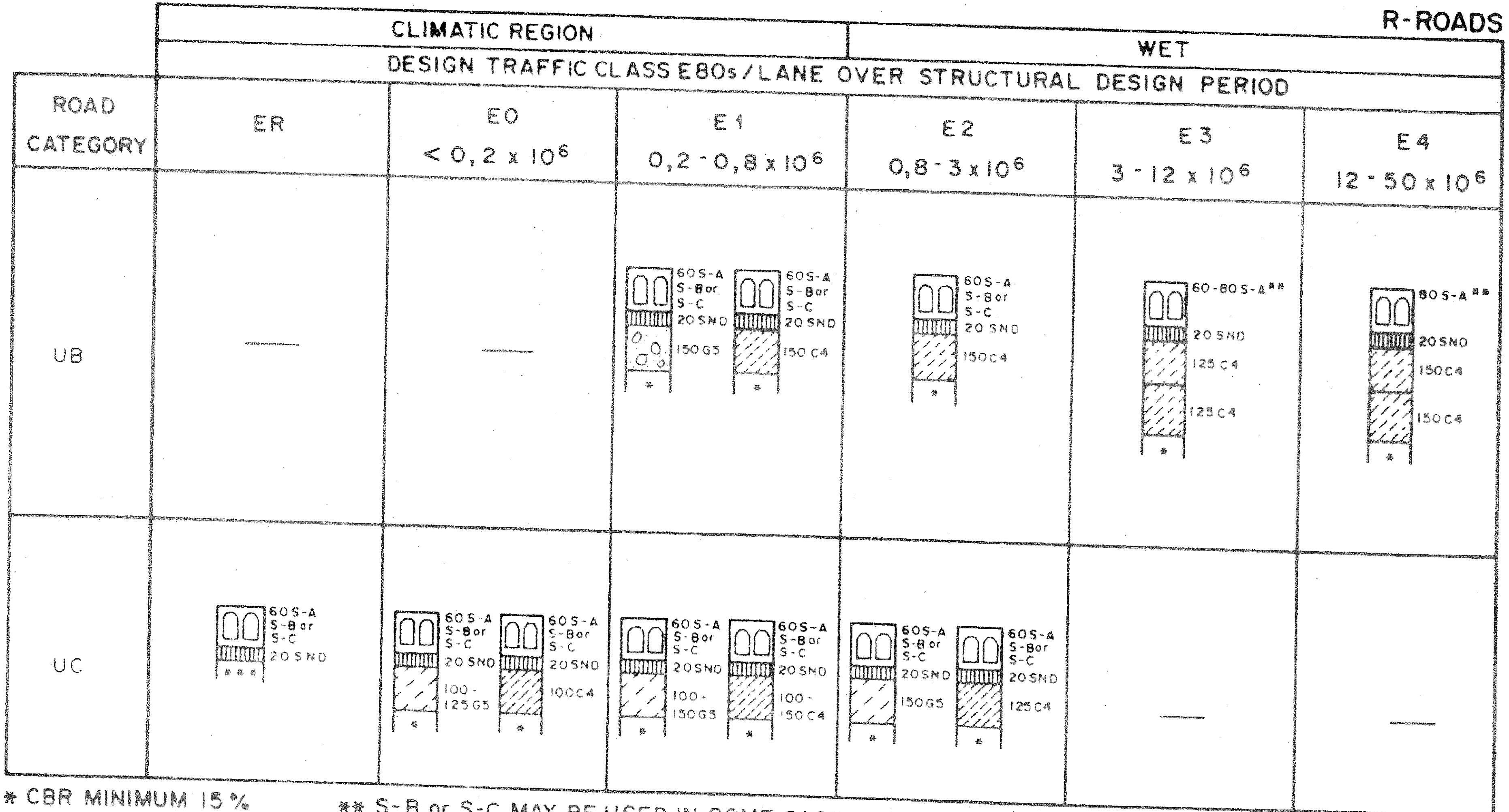
FIGURE 23
Catalogue of block-paving designs for TRH4



* CBR MINIMUM 15% ** S-B or S-C MAY BE USED IN SOME CASES *** CBR MINIMUM 10%

FIGURE 24

Standard designs for block pavements for TRH4



* CBR MINIMUM 15 % ** S-B or S-C MAY BE USED IN SOME CASES *** CBR MINIMUM 10 %

FIGURE 25

Standard designs for block pavements for TRH4

APPENDIX B

EXAMPLE OF DESIGN OF SEGMENTAL BLOCK PAVEMENTS

B.1 OBJECTIVE

An industrial concern wishes to use blocks to improve its yard. The yard is used (i) for stacking of heavy containers and stock; (ii) for servicing heavy vehicles; (iii) for parking staff cars and (iv) for a rest area for the staff. It is proposed to improve the rest area to provide gardens and paths for use by staff during their lunch period. A 0,5 km long main access road to the industrial yard is also to be block-paved. A suggested layout is shown in Figure 26.

B.2 PROCEDURE

The yard area is initially zoned into the various categories according to use (refer to Section 3.1).

(i) The stacking and stock area is category I(ii).
(ii) The service area for heavy vehicles is category I.
(iii) The parking area for staff cars is category R(i).
(iv) The paths in the rest area is category R(ii).
(v) The access road is category R(iv).
(vi) Special areas within the above where pigmented segment are provided to identify: individual parking bays, pedestrian crossings, rumble strips, edge restrictions and so forth.

The design of category R roads includes aspects of its importance, service level, traffic and road standard (Section 3.3 and Figure 2). From Figure 2 it can be seen that the main access road would be considered as road category UB and this classification allows consulting engineers to compare costs of block paving with asphalt or concrete construction for the same category.

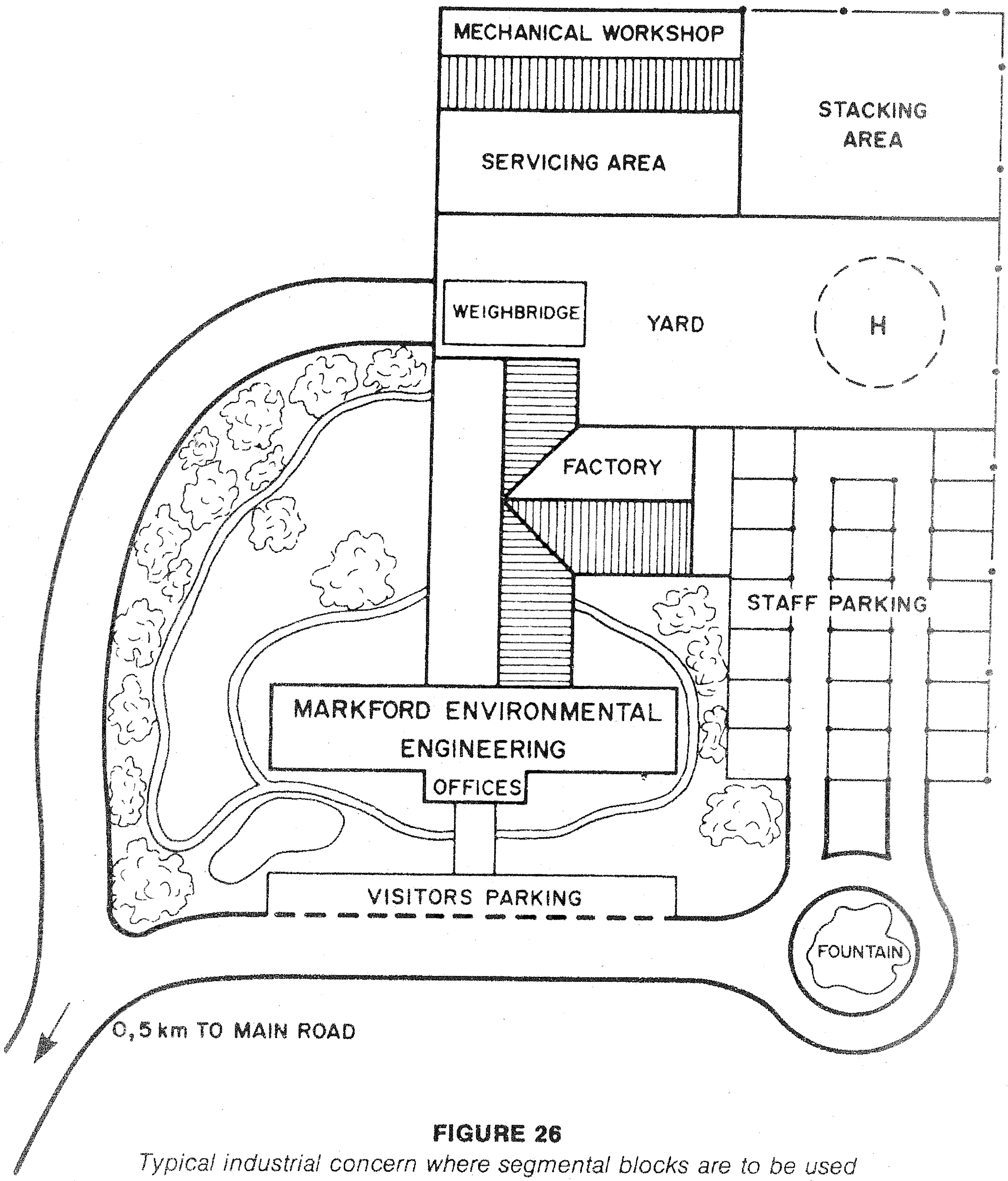


FIGURE 26

Typical industrial concern where segmental blocks are to be used

B.3 DESIGN STRATEGY (Refer to Section 4)

Reference to Figure 4 for R(iv) category B road shows three recommended analysis periods viz 30, 20 and 15 to 30 years. For an industrial access road however, a period of only 10 years may be the correct analysis period. The choice of analysis period affects the costing (design step 8).

B.4 DESIGN LOADS (Refer to Section 5)

Reference to Figure 7 shows that the access road carries E2 traffic. To categorize the stacking area and the vehicle servicing area requires analysis based on available information and its application to the nomograms in Figures 5 and 6. Figures 24 and 25 show several designs suitable for industrial stacking and working areas in wet or dry conditions which may be used with reasonable confidence without detailed checking of specific loading. However, as industrial paving use varies considerably it is strongly recommended that equivalent loads be calculated for greater confidence levels in the design (refer to Figure 8).

B.5 MATERIALS (Refer to Section 6)

The final choice of design requires the materials to be available and the expected distress mode from their use to be acceptable (refer to Section 8).

B.6 ENVIRONMENT (Refer to Section 7)

The environment refers to both climate and the conditions of the subgrade. Successful block pavements (and all pavements) require adequate drainage and sufficient compaction of the various layers. The catalogue of designs assume these measures have been taken into account. Southern Africa is divided (Figure 10) into three macroclimatic conditions. Minimum design standards are possible in the large dry area where saturation of subgrade materials is unlikely but note must be taken of the possible effects of saturated foundations in other areas.

It is important to consider material below the pavement to sufficient depth in accordance with Figure 11.

The subgrade CBR (soaked) must be checked. If this is less than 15, special provision must be made.

The standards required are shown in Figure 12.

B.7 TERMINAL CONDITIONS OF BLOCK PAVING CATEGORIES

The catalogue assumes expected terminal conditions in accordance with Figure 13. If these are too severe, additional strength will need to be provided either by increasing the thickness of the subbase layers or by designing the pavement for additional load-carrying capacity.

B.8 PRACTICAL CONSIDERATIONS (Refer to Section 9)

The key to all successful pavement design is good drainage and compaction. Once the design has been made it is possible to choose from a variety of block shapes available (see Figure 17). Block paving must be contained between kerbing. For the most severe loading, especially where slewing loads are expected, the use of S-A and S-B blocks is preferred.

B.9 USE OF THE CATALOGUE (Refer to Figures 11-27)

When the aforementioned factors have been considered the use of the catalogue for the choice of designs can be made.

(i) The stacking and stock area is category I (see Figure 23). Designs in I(iii) are suitable. The choice of cement treatment or granular base is made from local experience or preference.

(ii) The service area for heavy vehicles is category I (see Figure 23). The designs in I(ii) are both suitable.

(iii) The parking area for staff cars is category R(i) (see Figures 24 and 25). A suitable design should be chosen depending on the strength of the subgrade or made-up ground.

(iv) The paths in the rest area are category R(ii) (see Figures 24 and 25). The design chosen requires care to ensure uniform support under the blocks. Made-up ground or other potentially weaker areas should be improved to a support CBR of 15 %.

(v) The access road is category S4 (see Figure 25). Any of the designs are suitable.

B.10 ECONOMIC CALCULATIONS (Refer to Section 10)

A cost analysis should be made in accordance with Section 10. The final choice of design is therefore not based on any single consideration but on all the factors involved, including: costs, availability of materials, local experience and expertise with blocks, aesthetics and customer needs and preferences.