Design Catalog for Low-Volume Roads Developed for South African Conditions

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The development of a design catalog for low-volume roads using granular base, subbase materials, and bituminous surfacings is described. The *S-N* design method was used for the development of the catalog. This is a mechanistic design method that is based on elastoplastic behavior, which implies inelasticity and nonlinearity of the material. It uses the principle of *S-N* curves, where *S* denotes a certain stress level and *N* denotes the number of stress repetitions to a failure condition to consider the accumulation of plastic strain (rutting) with each load cycle. The *S-N* design curves were developed from accurate measurements of elastic and plastic strains in granular layers under heavy vehicle simulator (HVS) testing of numerous pavements incorporating such layers. The method was verified by comparing the carrying capacities of 23 low-volume roads determined from field measurements of traffic and rut with the carrying capacities of the same roads calculated mechanistically with the *S-N* method based on pavement structures obtained through in situ and laboratory testing of materials taken from the roads and classified by the specification normally used for pavement materials in South Africa. Reasonable agreement was found between the carrying capacities determined from field measurements and those determined mechanistically with the *S-N* method. This agreement validated the use of the *S-N* method for the development of the catalog. The approach to the selection of materials for low-volume roads varies from other approaches since little relaxation of the materials classification used for high-volume roads is permitted. The "adjustment" for low-volume roads is made in the design catalog compiled with the *S-N* design method. The design catalog was compared with other catalogs, such as Transport Research Laboratory Road Note 31. It was generally found that pavement structures having fewer selected layers and constructed with lower-quality material are required by the low-volume road catalog described in this paper to get the same performance.

In South Africa the pavement structure is commonly selected from a catalog of suitable designs. The TRH 4 (*1*) catalog is widely used for rural roads and all traffic levels. However, TRH 4 is limited in its treatment of low-volume roads. It caters to the lowest traffic category of less than 200,000 equivalent 80-kN axles (E80s) (approximately 18 kips) per lane over the design life of the road. The next lowest traffic category catered to is 800,000 E80s per lane over the design life of the road. The recommended pavement structures are conservative for traffic volumes of less than 500,000, 100,000, or 400,000 E80s per lane. There is a need for a design catalog for traffic volumes of 800,000 E80s and less, divided into appropriate smaller categories. The development of such a catalog, which uses granular base and subbase materials and bituminous surfacings, is discussed in this paper.

The catalog was developed with a mechanistic design procedure that was verified by comparison of the analytically determined performance with the actual field performance of a number of low-volume roads. The approach to the selection of materials for low-volume roads differs from other approaches since little relaxation of the material classification used for high-volume roads specified in the TRH 14 (2) is permitted. The adjustment for low-volume roads has been made in the design catalog.

First, the specification of materials used in the catalog is addressed. The mechanistic design procedure and the method used for its verification are also discussed, leading to a discussion on the compilation of the catalog. In conclusion, the catalog is compared with other low-volume road catalogs, such as Road Note 31 (*3*).

Materials

The TRH 14 (*2*) classification system for granular materials (G1 to G10) is used, which is summarized in Table 1. G1 material results from the crushing of fresh, unweathered rock. G2 material is composed of crushed, unweathered rock, but material other than the parent rock may be present. G3 material is a slightly lower-quality crushed stone. G4 to G6 materials are referred to as natural gravel; the quality of the gravel declines gradually from G4 to G6. G7 to G10 are referred to as gravel-soil or subgrade materials. Pavement structures for low-volume roads generally use G4 or G5 material as base and G5 or G6 material as subbase constructed directly on subgrades of various strengths. Crushed stone (G3/G2) materials are used as bases in low-volume road pavement structures when the design traffic volume exceeds 400,000 E80s.

Design Procedure

Development

The principal failure mode of granular pavements is permanent deformation (rutting). The pavement structures proposed in the catalog were therefore designed so that the pavement was considered failed once a rut of 20-mm depth developed on the surface of the pavement.

The *S-N* design method for granular materials was used to mechanistically analyze the pavement structures proposed for the catalog. The method was developed by Wolff (*4*) and is based on the use of *S-N* curves

TABLE 1 Granular Materials as Specified in TRH 14 (*2*)

CODE	MATERIAL	ABBREVIATED SPECIFICATIONS
G1	Graded crushed stone	Dense-graded unweathered crushed stone; max. size 37,5 mm*; compacted to 86-88 % of bulk density; PI < 4
G2	Graded crushed stone	Dense-graded unweathered crushed stone; CBR** > 80 @ 98 % mod. AASHTO density; max. size 37,5 mm; compacted to 100-102 % mod. AASHTO density; PI < 6
G3	Graded crushed stone	Dense-graded stone and soil binder; CBR > 80 @ 98 % mod. AASHTO density; max. size 37,5 mm; compacted to 98 % mod. AASHTO density; PI < 6
G4	Natural gravel	CBR > 80 @ 98 % mod. AASHTO density; PI < 6; max. size 53 mm
G5	Natural gravel	CBR > 45 @ 95 % mod. AASHTO density; PI < 10; max. size 63 mm or 2/3 layer thickness; grading modulus > 1,5
G6	Natural gravel	CBR > 25 @ 93 % mod. AASHTO density; PI < 12; max. size 63 mm or 2/3 layer thickness; grading modulus > 1,2
G7	Gravel-soil	CBR > 15 @ 93 % mod. AASHTO density; PI < 12; max. size 2/3 layer thickness; grading modulus > 0,75
G8	Gravel-soil	CBR > 10 @ in-situ density
G9	Gravel-soil	CBR > 7 @ in-situ density
G10	Gravel-soil	CBR > 3 @ in-situ density

* *1 inch = 25,4 mm*

** *Soaked CBR*

where *S* denotes a certain stress level or stress state and *N* denotes the number of stress repetitions to a failure condition. The method provides a design procedure and design curves for G1 to G6 materials. G7 to G10 are considered subgrade materials, and a design procedure based on vertical compressive strain in the subgrade, such as the South African mechanistic design method (*5*) was used to ensure adequate subgrade performance.

Rutting or permanent deformation may be caused by the elastoplastic behavior of granular materials (*4*). Elastoplastic behavior implies nonlinearity and inelasticity of the material, which means that

> the stress-strain curve of a granular material will not be a straight line with a constant slope, but a curved line with a slope or resilient modulus M_r varying with the applied stress, and plastic strain takes place during each application of a stress much smaller than the yield stress of the material and that these strains accumulate with load or stress repetitions. On the removal of stress, the loading stress-strain curve will not be retraced, but a hysteresis loop will form indicating the permanent deformation that took place during the application of each cycle of stress (*4*).

Therefore, it is important to use computer analyses that take account of nonlinear material behavior. The permanent deformation developed during each load cycle must be considered in the development of a design procedure for granular materials. The principle of *S-N* curves was found to be ideally suited for this purpose. *S-N* curves were developed from accurate measurements of elastic and plastic strains in granular layers under heavy vehicle simulator (HVS) testing of pavement structures, which incorporated such layers.

To develop a transfer function for rutting using the *S-N* curve principle, failure must be defined as a specific terminal permanent strain in the pavement layer for which the transfer function is being developed. However, any terminal permanent strain for the specific layer can be considered. Measuring permanent strain development with load repetitions in each of the separate layers constituting the pavement was made possible through the use of the multidepth deflectometer (*6*) in HVS testing. Data regarding the permanent strain in each layer caused by load (or stress) repetitions of a number of different wheel loads on various pavement types are available from HVS testing. These data are best presented by the following function of permanent strain versus repetitions of a specific wheel load (*7*):

$$y = (mx + a)(1 - e^{-bx}) \tag{1}$$

where

y = permanent strain,
x = number of load repetitions,
a, b, m = constants, and
e = base of natural logarithm.

The function is shown in Figure 1, which also shows the function $y = ax^b$ commonly used for modeling permanent deformation versus load repetition data in repeated-load triaxial testing. The lack of fit of the function $y = ax^b$ when applied to a large number of load repetitions is clearly demonstrated in Figure 1. Equation 1 can be used to calculate the number of repetitions of a specific wheel load (inducing a certain amount of stress) necessary to obtain the permanent strain in a specific layer that corresponds to the chosen terminal permanent strain. The stress induced in the layer by the wheel load can be calculated using the material parameters backcalculated from multidepth deflectometer measurements of elastic deflections taken during HVS testing. One point on a curve resembling an *S-N* curve can then be obtained by plotting an invariant of the stress (such as the sum of the principal stresses, θ) on the vertical axis and the number of load repetitions to failure on the horizontal axis. Additional points on the curve are obtained by repeating the exercise for other wheel loads.

Repeating the procedure for other HVS tests with different pavement structures and wheel loads but the same material allows a distribution of points to be obtained. The function that fits the data points best is referred to as the *S-N* curve or transfer function for that material at a 50 percent confidence level. The procedure is shown schematically in Figure 2.

Figure 3 shows *S-N* graphs for a G5 material at a 50 percent confidence level. Similar graphs were developed for G1, G2, G4, and G6 materials. For the G5 material in Figure 3, graphs are provided for a number of failure conditions, which are defined as a certain permanent strain of the layer (e.g., 10,000 με). The stress state in the granular layer is denoted on the vertical axis by the

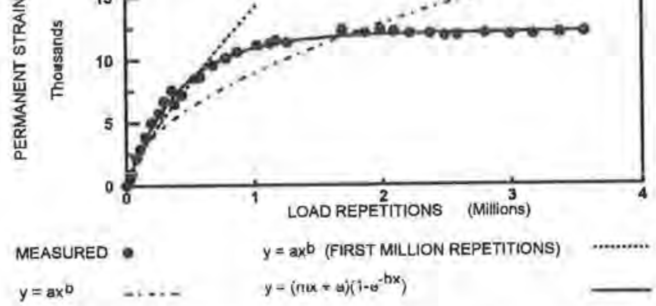

FIGURE 1 Different functions for modeling permanent strain development with load repetitions in granular materials.

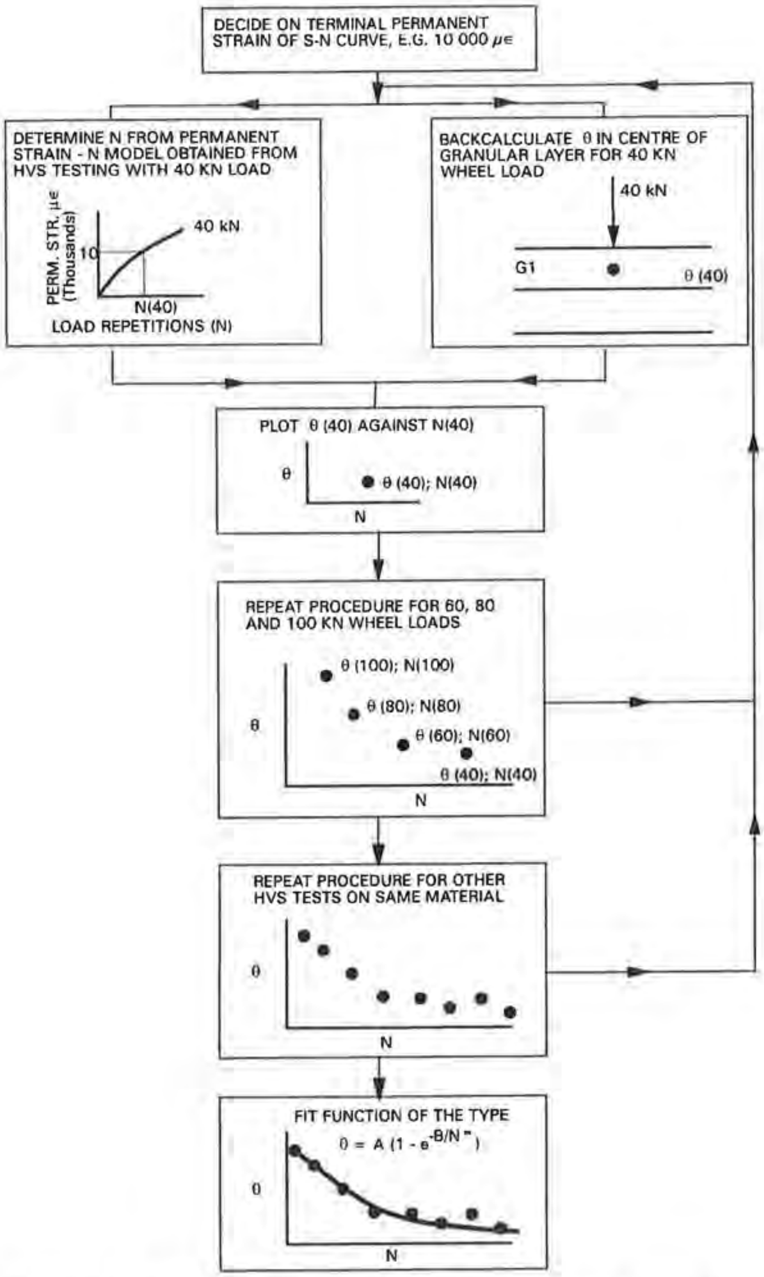

FIGURE 2 Procedure for development of *S-N* curves from HVS data.

sum of the principal stresses θ as calculated in the center of the layer. Figure 3, for example, indicates that 1.0×10^5 repetitions of a load that causes a stress state θ of 250 kPa (1 psi = 6.9 kPa) in a 150-mm-thick granular layer will cause a permanent strain of 10,000 με in the layer. A permanent strain of 10,000 με in a 150-mm-thick layer is equivalent to a permanent deformation or rut of 1.5 mm. This illustrates how *S-N* curves can be used to calculate the rut in a granular pavement layer when it is subjected to repetition of a standard wheel load. The surface rut in a granular pavement structure is then calculated by adding the permanent strains in each layer.

Verification

The *S-N* design method was verified by comparing the performance of low-volume road pavements with granular bases and subbases as determined from measure-

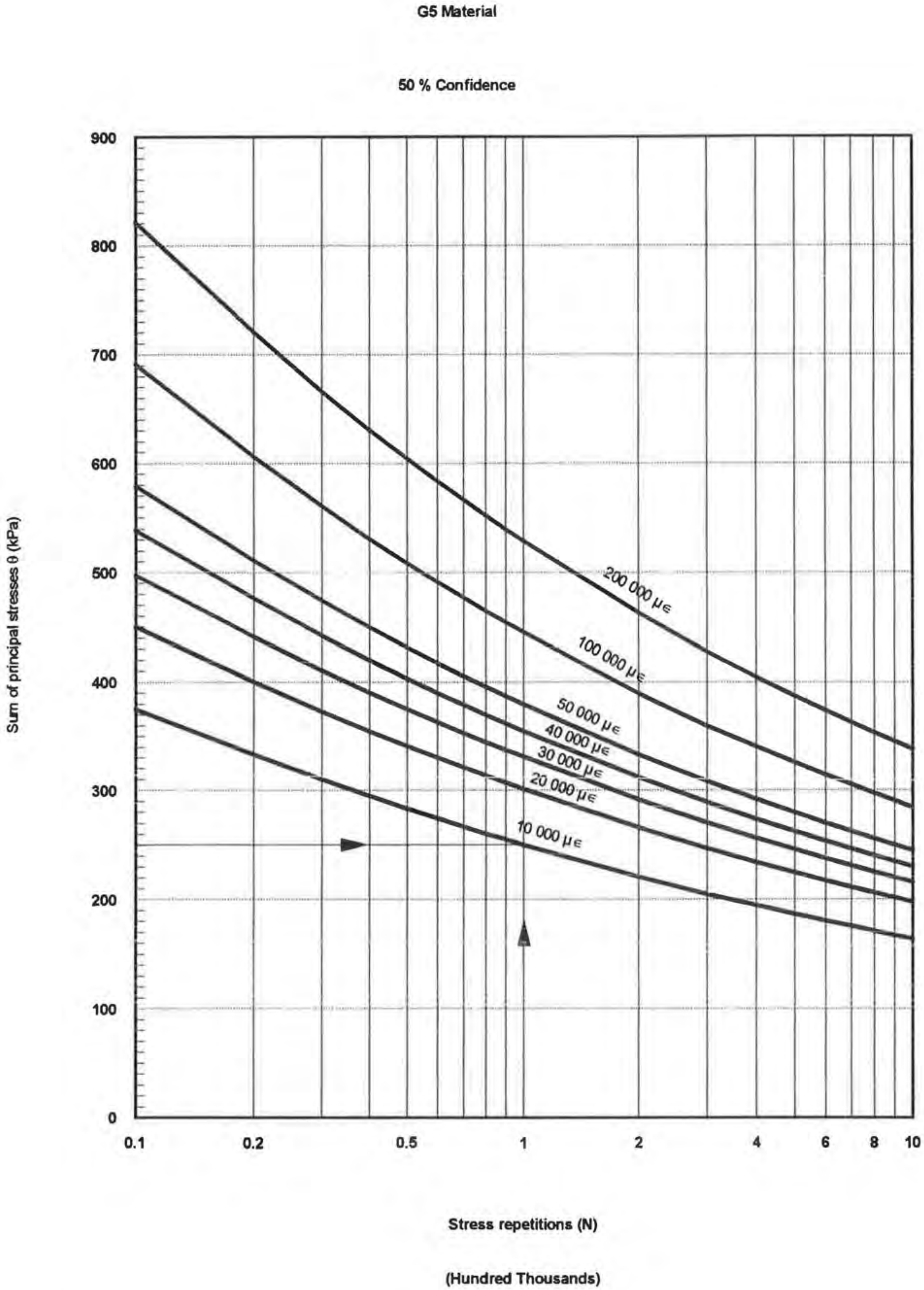

FIGURE 3 *S-N* graph for G5 material at 50 percent confidence level.

ments with performance predicted with the design method. Paige-Green compiled a data base (*8–16*) on the performance of 23 low-volume roads located in the provinces of the Orange Free State and the Transvaal in South Africa. The pavement compositions of the low-volume roads were determined from test pits, in situ density measurements, laboratory tests, and dynamic cone penetrometer (DCP) soundings. The tests were conducted in the outer and inner wheel paths as well as center of the road. The data were used to classify the pavement materials according to TRH 14 (2) standards. The pavement structures were analyzed with the *S-N* method to determine the number of standard wheel load repetitions (E80s) that would cause a 20-mm rut.

Paige-Green also measured ruts in the outer and inner wheel paths at the test positions and estimated the traffic volumes. The traffic was estimated from traffic counts conducted by the road authority. Results of these traffic counts are normally presented as average daily traffic (ADT) and percentage of heavy vehicles.

Studies on traffic composition on rural roads by the Transvaal Provincial Administration (TPA) indicated that a factor of 0.97 should be used to convert the number of heavy vehicles to E80s. The cumulative number of E80s over the pavement to the date of testing was determined from the following equation:

$$\text{E80s} = (\text{ADT}/2 \times \%\ \text{heavy vehicles} \times 0.97) * 365 * \text{age (years)}$$

The ADT was divided by 2 to get the traffic per lane (or per direction).

The data are summarized in Table 2. The number of E80s necessary to form a 20-mm rut was calculated from Paige-Green's data by linear extrapolation of the measured rut and traffic data. These data are also given in Table 2 and provide a conservative estimate of the carrying capacity of the pavement because the rate of permanent strain (rut) development with load applications (traffic) is not a constant (linear). Instead, it diminishes until it eventually approaches a constant value. The number of load repetitions where the rate of permanent strain approaches a constant value depends on the stress associated with the applied load, material type, and initial compaction of the pavement layer (*4*).

The number of E80s required to produce a 20-mm rut in the low-volume roads that were investigated was thus estimated from field measurements and also determined mechanistically with the *S-N* method and two other design methods that are currently used in South Africa. A comparison of the carrying capacities determined from the field measurements with those determined from the other design methods is shown in Figure 4. The *S-N* method predicts carrying capacities that are relatively close to the carrying capacities estimated from field measurements. The DCP method (*17*) predicts higher carrying capacities than those estimated from the field measurements. The factor of safety (FOS) method (*18,19*) gives the least consistent prediction of carrying capacity. It also has the poorest correlation with the carrying capacities estimated from field measurements compared with the other two design methods, perhaps because the FOS method is based on linear elastic theory.

A further comparison between carrying capacities determined from field measurements and mechanistically with the *S-N* method is shown in Figure 5. The *S-N* method predicts carrying capacities that are more conservative than the carrying capacities estimated from field measurements for the different pavement structures. The *S-N* method for the development of the catalog provides the best estimates of carrying capacity, and the carrying capacities calculated are slightly conservative.

Compilation of Catalog

The *S-N* method was used to compile the proposed design catalog for pavements with granular bases and subbases and bituminous surfacings for low-volume roads in moderate to dry and wet regions (Table 3). Traffic loading refers to the standard South African design axle, an 80-kN axle composed of two 40-kN double wheel assemblies (20 kN per tire at 520 kPa tire pressure). The designs are based on a failure criterion of 20 mm permanent deformation.

Elastic deflections on the surface of the proposed structures are important when deciding on the type of surfacing seal to be used. The design of the surfacing seals should receive careful attention since elastic deflections may be higher than normal (*20*). If maintenance is expected to be low, a 25-mm asphalt wearing course is recommended. The flexible low-volume road pavement structures cause relatively high horizontal tensile strains at the bottom of the thin asphalt wearing course, which leads to short fatigue lives for the asphalt. The asphalt fatigue lives were calculated and found to be adequate for the low traffic volumes.

A layer thickness of 150 mm was used for G4 to G6 materials because the material is usually obtained from borrow pits, and the difference in cost between a 100- and 150-mm layer is not excessive. If the material chosen has a more significant cost, such as crushed stone does, the use of a thinner layer was considered. However, layers less than 125 mm were considered impractical from a construction viewpoint.

The nonlinear elastic material characteristics for granular materials (G2 to G6) used in compilation of

TABLE 2 Summary of Data from Field Measurements on Low-Volume Roads (8–16)

ROAD NO.	PAVEMENT STRUCTURE	AGE (years)	N*	BASE PARENT MATERIAL	CUMM. TRAFFIC (E80's)	RUT (mm)	ESTIMATED TRAFFIC TO 20 mm RUT (E80's)
D514	125 G4**/200 G6/G8	6	2	Granite	$9,1x10^4$	11	$1,7x10^5$
D736	200 G6/100 G6/G7	6	2	Shale	$2,2x10^4$	4	$1,1x10^5$
D466-E	200 G5/200 G6/150 G6/G6	7	2	Laterite	$1,2x10^5$	8	$1,8x10^5$
D466-W	185 G5/100 G6/G8	7	2	Laterite	$1,6x10^5$	6	$3,0x10^5$
D390	175 G6/100 G6/G8	8	2	Laterite	$5,9x10^4$	16	$5,2x10^5$
D2485	200 G6/200 G6/G5	8	4	Shale	$1,5x10^4$	6	$7,4x10^4$
D804-8	200 G6/200 G6/G7	4	5	Andesite	$1,5x10^4$	11	$4,9x10^4$
D804-11	200 G5/200 G5/G5	4	5	Andesite	$1,5x10^4$	12	$2,7x10^4$
D804-19	200 G6/200 G6/G6	4	5	Calcrete	$1,2x10^4$	2	$2,5x10^4$
S191	150 G4/150 G5/150 G6/G6	9	3	Dolerite	$6,2x10^4$	14	$1,2x10^5$
S65-6	175 G4/175 G5/G7	11	3	Dolerite	$6,1x10^4$	8	$8,9x10^4$
S65-57	120 G4/200 G6/G6	11	3	Dolerite	$4,7x10^4$	6	$1,5x10^5$
S63	150 G4/200 G5/G5	10	3	Dolerite	$2,7x10^4$	7	$1,6x10^5$
P13/2	125 G4/150 G5/100 G6/G7	30	3	Dolerite	$1,9x10^5$	12	$7,8x10^4$
D467	150 G5/200 G6/G6	7	2,8	Norite	$6,4x10^4$	8	$3,0x10^5$
D540	200 G6/200 G6/G6	5	2,8	Laterite	$2,2x10^4$	10	$1,6x10^5$
D410-5	200 G5/200 G5/G5	3	5	Chert wad	$7,4x10^3$	8	$4,4x10^4$
D410-1	200 G5/200 G6/G5	7	5	Chert wad	$3,9x10^4$	5	$1,9x10^4$
P172-2	150 G4/200 G5/G6	7	5	Shale	$6,1x10^4$	6	$1,6x10^5$
D132	200 G5/150 G5/G7	4	5	Shale	$1,5x10^4$	7	$2,0x10^5$
D804	200 G4/200 G4/G5	7	5	Andesite	$3,5x10^4$	5	$4,2x10^4$
D404	140 G4/150 G6/G8	8	5	Shale	$9,8x10^3$	6	$1,4x10^5$
D421	125 G4/150 G5/200 G6/G7	4	1,8	Shale	$2,2x10^4$	12	$3,2x10^4$

* *Weinert climate factor N where N = (12* Evaporation in January/Mean Annual Precipitation)* (Weinert, H.H. *Basic Igneous Rocks in Road Foundations.* Research Report 218. National Institute for Road Research, CSIR, Pretoria, South Africa, 1964.)

** *Notation - 125 mm layer of G4 quality material. Bottom layer indicates in-situ material.*

the catalog were obtained from backcalculation of elastic deflections measured with the multidepth deflectometer (4). The resilient moduli for subgrade materials (G7 to G10) were taken from the South African mechanistic design method (5). The subgrade materials were considered to be linear elastic. The pavement structures for the moderate to dry regions were determined by using the resilient modulus values proposed by the South African mechanistic design method (5) for dry material. The pavement structures for the wet regions were determined by using the resilient modulus values proposed by the South African mechanistic design

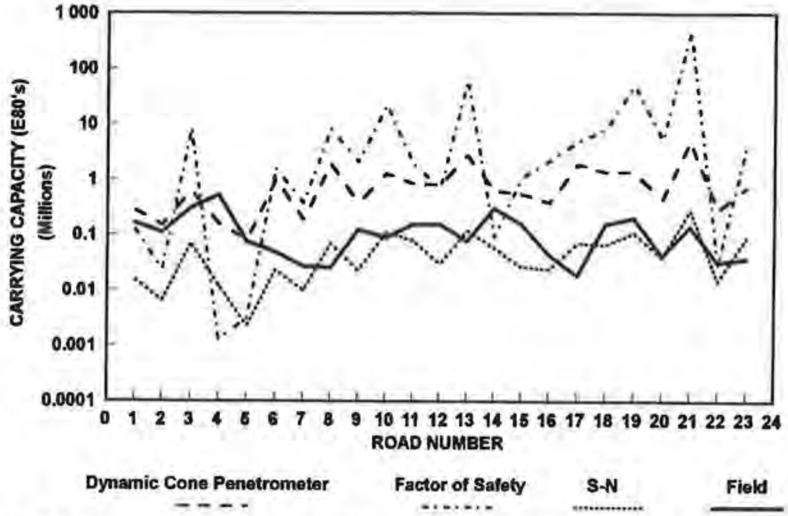

FIGURE 4 Comparison between carrying capacities of pavement structures determined from field measurements and with various design methods.

method (5) for wet material. The material properties used in the calculations are given in Table 4.

The pavements are assumed to be supported by in situ material with a CBR of at least 3 (G10). Layers shown in the catalog with lower strength than the in situ subgrade may be omitted if there is adequate strength for the total pavement depth.

The materials in the catalog are classified by their soaked bearing strength in terms of CBR. However, the proposed pavement structures relate to performance at field moisture content. This is the same approach used in the TRH 4 (*1*) catalog. When existing roads are upgraded, the pavement materials of the existing road must be classified in terms of the soaked CBR to relate to the catalog. Procedures to accomplish this with the DCP and other test methods have been documented (*21*).

Comparison With Other Catalogs

The TRH 4 (*1*) design catalog was used as the basis for comparison. The structures proposed in the TRH 4 cat-

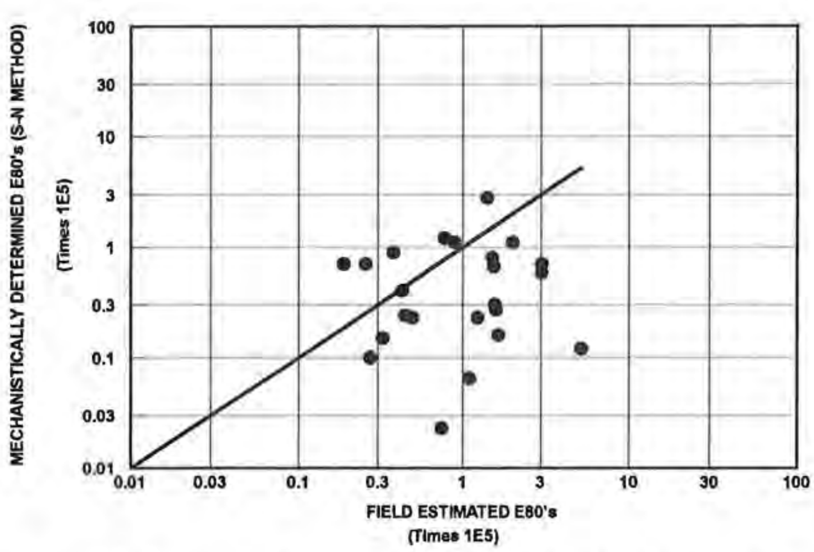

FIGURE 5 Comparison between field-estimated and mechanistically calculated carrying capacities of various low-volume roads.

TABLE 3 Proposed Design Catalog for Low-Volume Roads with Granular Bases and Subbases Compiled with *S-N* Design Method

TRAFFIC CLASS	TRAFFIC (80's)	PAVEMENT STRUCTURES		
		MODERATE TO DRY REGIONS	WET REGIONS	LOW MAINTENANCE
E0-1	< 5 000	# 150 G6* 150 G8 150 G9 G10**	150 G5 150 G7 150 G9 G10	25 A+ 150 G6 G10
E0-2	5 000 - 30 000	150 G5 150 G7 150 G9 G10	150 G4 150 G6 150 G8 G10	25 A 150 G6 150 G7 G10
E0-3	30 000 - 100 000	150 G4 150 G6 150 G8 G10	150 G4 150 G5 150 G6 150 G7 G10	25 A 150 G5 150 G9 G10
E0-4	100 000 - 200 000	150 G4 150 G5 150 G8 G10	150 G3 150 G6 150 G9 G10	25 A 150 G4 150 G9 G10
E1-1	200 000 - 400 000	150 G4 150 G5 150 G7 150 G9 G10	150 G3 150 G6 150 G8 G10	25 A 150 G4 150 G8 G10
E1-2	400 000 - 800 000	125 G2 150 G6 150 G9 G10	125 G2 150 G5 150 G9 G10	25 A 150 G4 150 G5 150 G8 G10

\# *Double surface treatments assumed on all pavement structures unless otherwise indicated.*

* *Notation - 150 mm layer of G6 quality material.*

** ***Pavement assumed to be supported by in-situ material having a CBR of not less than 3 (G10) and semi-infinite depth. Layers shown in the catalogue with lower strength than the in-situ subgrade may therefore be omitted provided that adequate strength exists for the total pavement depth.***

\+ *25 mm asphalt.*

alog for design traffic volumes of 2×10^5 and 8×10^5 E80s in a moderate to dry region were compared with structures from TPA catalogs (E. G. Kleyn, unpublished data) and Road Note 31 (*3*).

Comparisons between design catalogs are not always straightforward. Traffic classes and material classification frequently do not correspond; interpolation and approximation are required. The comparison described in this paper is no exception. The TPA and Road Note 31 material specifications had to be approximated to TRH 14 standards. The traffic classes do not correspond directly either. However, an effort was made to include most of the relevant data to give a sense of how the different catalogs compare.

The comparison is shown in Table 5. Comparison of pavement structures for design traffic volumes of 200,000 to 300,000 E80s indicates that the 100-mm G4 material proposed as base by the TRH 4 catalog may not be adequate. The TPA and Road Note 31 designs require approximately the same quality and thickness base and subbase material as the *S-N* method. However, for the same performance, the *S-N* method requires fewer selected layers and the use of lower-quality material than the other catalogs do.

Comparing pavement structures proposed by the catalogs for design traffic volumes of 800,000 to 1 million E80s indicates that the 100-mm G4 material proposed as base by the TRH 4 catalog may not be adequate.

TABLE 4 Material Properties Used for Calculations with MICHPAVE in Mechanistic Analysis of Granular Pavement Structure Proposed for Design Catalog (in Imperial units)

MATE-RIAL TYPE	K_0*	K_1** (psi)@	K_2#	POISSON RATIO	COHE-SION (psi)	ϕ+ (degrees)	DENSITY (pcf) (kg/m^3)
G2	0,80	17 994	0,35	0,20	0	45	140 2242
G4	0,75	2717	0,44	0,25	0	45	135 2162
G5	0,70	9611	0,22	0,33	0	43	130 2082
G6	0,60	6848	0,36	0,35	0	40	130 2082
MATE-RIAL TYPE	**K_0**	**MODULUS OF ELASTICITY (psi)**		**POISSON RATIO**			**DENSITY (pcf) (kg/m^3)**
		DRY	**WET**				
G7	0,50	34 783	17 391	0,35	-	-	110 1762
G8	0,50	26 087	13 043	0,35	-	-	110 1762
G9	0,50	20 290	10 145	0,35	-	-	110 1762
G10	0,50	13 043	6 522	0,35	-	-	110 1762

* *Earth pressure coefficient used in MICHPAVE.*

** *Value of K_1 in the equation $M_r = K_1\,\Theta^{K2}$ used in MICHPAVE to describe the non-linearity of granular materials.*

@ *Program written for imperial units (1 psi = 6,9 kPa).*

\# *Value of K_2 in the equation $M_r = K_1\,\Theta^{K2}$ used in MICHPAVE to describe the non-linearity of granular materials.*

\+ *Angle of internal friction from the Mohr-Coulomb failure theory.*

The base layer required by the TPA and Road Note 31 designs is thicker but of a slightly poorer quality material than that of the *S-N* method design. The TPA and *S-N* method designs require similar subbase layers, which are of a poorer-quality material than the subbase layers required by the TRH 4 and Road Note 31 designs. The subbase required by the Road Note 31 design is also thicker than the subbases required by the other catalogs. For the same performance, the *S-N* method requires fewer selected layers constructed of a lower-quality material than the other catalogs.

The catalog compares well with most current design catalogs, except for the TRH 4 catalog designs, which may be inadequate in the E0 and E1 design traffic classes.

Conclusions and Recommendations

The development of a design catalog for low-volume roads using granular materials and bituminous surfacings is described. The materials used in the catalog are described in the standard TRH 14 (2) material specification that is widely used in South Africa. *S-N* design method used for the development of the catalog is briefly discussed. Important aspects concerning the design method include the following:

- The method was developed with data accumulated from HVS testing of in situ pavements incorporating granular layers.
- The method is based on elastoplastic material behavior, which implies nonlinearity and the accumulation of plastic strain with each load cycle.
- A function that accurately fits permanent deformation compared with load repetition data for tests with a large number of load repetitions [$y = (mx + a)(1 - e^{-bx})$] was used in the development of the model.

The design method was verified by comparing the expected life of 23 low-volume road pavement structures

TABLE 5 Comparison Between *S-N* Method and TRH 4, TPA, and Road Note 31 Catalogs

CATALOGUE	DESIGN TRAFFIC (E80's)	STRUCTURE
TRH 4 (CSRA, 1985a)	200 000	100 G4* 125 G5 150 G7 150 G9 #
	800 000	100 G4 150 G5 150 G7 150 G9
TPA (Kleyn, unpublished data)	300 000	150 G3/G4 150 G6 150 G8 150 G9
	1 000 000	150 G3 150 G6 150 G7 150 G8
ROAD NOTE 31** (TRL, 1992)	330 000	150 G3/G4 150 G5/G6 200 G7
	769 000	150 G3/G4 200 G5/G6 200 G7
S-N METHOD (Wolff, 1992)	200 000	150 G4 150 G5 150 G8
	800 000	125 G2 150 G6 150 G9

* *Notation - 100 mm layer of G4 quality material.*

\# *Subgrade CBR of more than 3 assumed.*

** *Catalogue actually specifies GB1 to GB3 as base material. GB3 was selected as base material.*

Note. Material codes approximated to TRH 14 standards.

as determined from field measurements with the expected life of the same pavement structures as determined mechanistically with the *S-N* design method. The pavement lives calculated were found to compare relatively well.

The catalog was compiled on the following basis:

- The designs are based on the standard 80-kN axle load;
- A 20-mm rut was used as failure criterion;
- Layer thickness of 150 mm were generally used, unless the cost of the layer was significant;
- The pavements are supported on a subgrade with a CBR in excess of 3; and
- The pavement structures relate to performance at field moisture content.

Comparison with other low-volume road catalogs indicated that for the same performance, the *S-N* method designs require construction of fewer selected layers and lower-quality material than designs proposed by the other catalogs. Allowance was made for differences in material specification and loading equivalency in the comparison of the different catalogs.

The use of the catalog is recommended in the design and upgrading of roads in the South African environment.

ACKNOWLEDGMENTS

This paper is based on research done by the Division of Roads and Transport Technology (DRTT) of the CSIR for the Department of Transport. The Director General of the Department of Transport and the Director of DRTT are thanked for their permission to publish this paper.

REFERENCES

1. *Structural Design of Interurban and Rural Road Pavements.* TRH 4. Technical Recommendations for High-

ways, Committee of State Road Authorities, Pretoria, South Africa, 1985.

2. *Guidelines for Road Construction Materials.* TRH 14. Technical Recommendations for Highways, Committee of State Road Authorities, Pretoria, South Africa, 1985.
3. *A guide to the Structural Design of Bitumen-Surfaced Roads in Tropical and Sub-Tropical Countries.* Road Note 31 (Draft 4th Edition). Transport Research Laboratory, Department of Transport, London, United Kingdom, 1992.
4. Wolff, H. *The Elasto-Plastic Behaviour of Granular Pavement Layers in South Africa.* Ph.D. dissertation. Department of Civil Engineering, University of Pretoria, Pretoria, South Africa, 1992.
5. *The Mechanistic Design Method Used to Evaluate the Pavement Structures in the Catalogue of the Draft TRH 4 1980.* Technical Report RP/2/81. National Institute for Transport and Road Research, CSIR, Pretoria, South Africa, 1981.
6. De Beer, M., E. Horak, and A. T. Visser. The Multi-Depth Deflectometer (MDD) System for Determining the Effective Elastic Moduli of Pavement Layers. In *First International Symposium on Non-Destructive Testing of Pavements and Back Calculation of Moduli,* ASTM STP 1026, ASTM, Philadelphia, Pa., 1988.
7. Wolff, H., A. T. Visser, E. G. Kleyn, and M. De Beer. The Elasto-Plastic Behaviour of Crushed Stone Bases in Flexible Pavement Structures. In *Proc., Seventh International Conference on Asphalt Pavements, Nottingham, United Kingdom,* 1992.
8. Paige-Green, P. *The Use of Marginal Base Course Materials in Some Low Volume Roads in the Orange Free State.* Interim Report IR 88/033/1. South African Roads Board, Research and Development Advisory Committee, Pretoria, South Africa, 1991.
9. Paige-Green, P. *The Use of Marginal Base Course Materials in Three Low Volume Roads in the Transvaal.* Interim Report IR 88/033/2. South African Roads Board, Research and Development Advisory Committee, Pretoria, South Africa, 1991.
10. Paige-Green, P. *The Use of Marginal Base Course Materials in Three Low Volume Roads in the Western Transvaal.* Interim Report IR 88/033/3. South African Roads Board, Research and Development Advisory Committee, Pretoria, South Africa, 1991.
11. Paige-Green, P. *The Use of Marginal Base Course Materials in Some Low Volume Roads in the Transvaal.* Interim Report IR 88/033/4. South African Roads Board, Research and Development Advisory Committee, Pretoria, South Africa, 1991.
12. Paige-Green, P. *Interim Recommendations on the Use of Marginal Base Course Materials in Low Volume Roads.* Interim Report IR 88/033/5. South African Roads Board, Research and Development Advisory Committee, Pretoria, South Africa, 1991.
13. Paige-Green, P. *The Use of Marginal Base Course Materials in Three Low Volume Roads in the Eastern Transvaal.* Interim Report IR 91/201/1. South African Roads Board, Research and Development Advisory Committee, Pretoria, South Africa, 1991.
14. Paige-Green, P. *The Use of Marginal Base Course Materials in Three Sections of Low Volume Roads in the Eastern and Western Transvaal.* Interim Report IR 91/201/2. South African Roads Board, Research and Development Advisory Committee, Pretoria, South Africa, 1991.
15. Paige-Green, P. *The Use of Marginal Base Course Materials in Three Sections of Low Volume Roads in the Western Transvaal.* Interim Report IR 91/201/3. South African Roads Board, Research and Development Advisory Committee, Pretoria, South Africa, 1992.
16. Paige-Green, P. *Interim Recommendations on the Use of Marginal Base Course Materials in Low Volume Roads in the Transvaal.* Interim Report IR 91/201/4. South African Roads Board, Research and Development Advisory Committee, Pretoria, South Africa, 1992.
17. Kleyn, E. G. *Aspects of Pavement Evaluation and Design as Determined with the Dynamic Cone Penetrometer (DCP)* (in Afrikaans). M.Sc. thesis. Department of Civil Engineering, University of Pretoria, South Africa, 1984.
18. Maree, J. H. *Design Parameters for Crushed Stone in Pavements* (in Afrikaans). M.Sc. thesis. Department of Civil Engineering, University of Pretoria, Pretoria, South Africa, 1978.
19. Maree, J. H. *Aspects of the Design and Behaviour of Road Pavements with Granular Bases* (in Afrikaans). Ph.D. dissertation. Department of Civil Engineering, University of Pretoria, Pretoria, South Africa, 1982.
20. *Appropriate Standards for Bituminous Surfacings for Low Volume Roads.* Manual 10. Southern African Bitumen and Tar Association, Roggebaai, South Africa, 1992.
21. *Towards Appropriate Standards for Rural Roads: Discussion Document.* Department of Transport, Pretoria, South Africa, 1992.