4.3.4.3 Permanent deformation at different depths and discussion

The typical permanent deformation development as measured with the MDD equipment at different depths in the HVS test Section 306A4, on the shallow pavement (Road 2212 at Bultfontein) is illustrated in Figure 4.10. The figure indicates that almost the same deformation develops at the top and bottom of the cemented gravel base layer (0 mm and 110 mm) up to approximately one million load repetitions (E80s). This complies almost exactly with the average permanent deformation measured on the surface of the test section (see also previous Figure 4.8 (a)). From one million repetitions onwards, deformation in the base was also recorded and is similar to that of the deep pavement, indicating the crushing failure in the upper section of the base. For the other test sections the permanent deformation results are illustrated in Appendix A, Figures A.7 and A.8. Less crushing was found on HVS Section 307A4, as is indicated in Figure A.7, but compaction of the weaker layer, however, is well defined.

On Section 308A4, permanent deformation behaviour similar to that of Section 306A4 was recorded, but without a well-defined fatigue failure (turning point). This is probably so because tests 307A4 and 308A4 were done with higher wheel loads, ie 70 kN and 100 kN, respectively (40 kN used on Section 306A4). Close inspection of the test results and linear elastic analysis (see Chapter 7), however, indicated that fatigue failure of the cemented gravel base occurred almost immediately after the start of the higher wheel load tests (see Figures A.7 and A.8 in Appendix A).

The preceding results indicate the load-sensitivity in terms of fatigue of the shallower pavement, and also that a 40 kN wheel load is critical in terms of fatigue failure of this pavement. Therefore overloaded vehicles on this road should be avoided.

In Table 4.4, the percentage permanent deformation at various stages of trafficking on the three sections of the shallow pavement is given. The table indicates that up to a million repetitions on the three sections, approximately 34 to 53 percent of the total permanent deformation measured on the surface of the pavement originated from the relatively weak interlayer and the subbase layer (110 mm to 310 mm). The

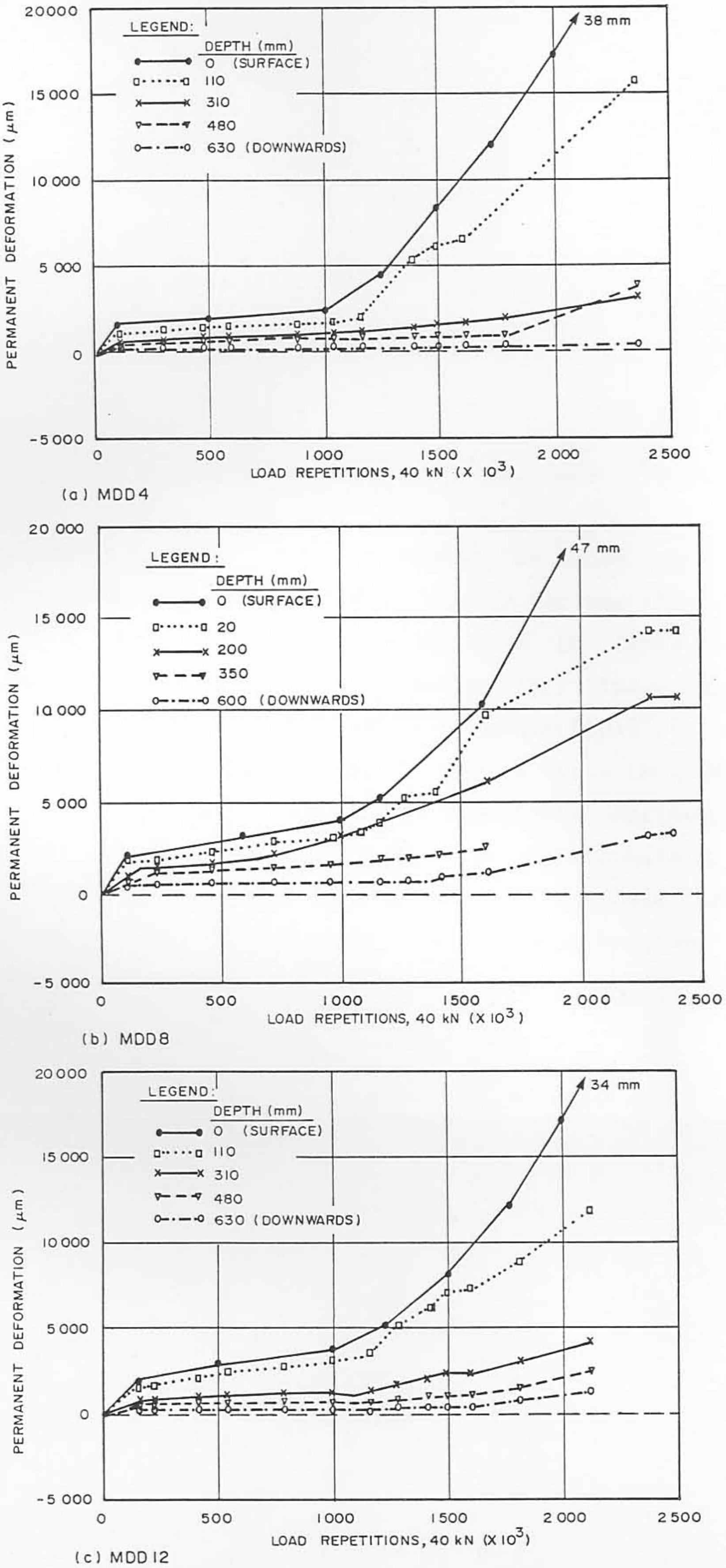


FIGURE 4.10

PERMANENT DEFORMATION AT DIFFERENT DEPTHS AT VARIOUS STAGES OF TRAFFICKING OF A 40 kN DUAL WHEEL LOAD ON HVS TEST SECTION 306A4 (ROAD 2212, BULTFONTEIN) deformation percentage from the base (0 mm to 110 mm) varied between 5 and 35 per cent during this period. At the end of these tests, the percentages were 20 to 36 for the weak interlayer and the subbasse, and 15 to 65 for the base, respectively. This illustrates, in terms of permanent deformation, the initial compaction (densification) in the weak layer, and towards the end of the tests, the subsequent crushing of the base layer.

TABLE 4.4 PERCENTAGE PERMANENT DEFORMATION MEASURED AT THE END OF THE HVS TESTS ON THE VARIOUS TEST SECTIONS ON ROAD 2212 (BULTFONTEIN) (%)

HVS-SECTION	DEPTH (mm)	AT 10^6 REPS.		AT END OF TEST	
		MDD4	MDD12	MDD4	MDD12
306A4	0-110	32	25	58	65
	110-310	34	45	28	24
	310-480	9	10	0	4
	480-630	34	10	8	3
	630- ∞	1	10	6	4
307A4	0-110	35	11	29	15
	110-310	37	49	36	35
	310-480	10	12	15	20
	480-630	15	28	11	21
	630- ∞	3	0	9	9
308A4	0-110	5	17	32	46
	110-310	53	40	32	20
	310-480	13	16	8	10
	480-630	12	13	12	7
	630- ∞	17	14	16	17

4.3.4.4 Rate of permanent deformation, R_L, and relative damage

The different R_L and D_L factors, similar to those calculated earlier for the deep pavement (see Paragraph 4.2.4.4) for the three test sections on Road 2212 (Bultfontein), is summarised in Table 4.5. The table indicates that the rate of deformation (R_L) increases with increased wheel load and higher in situ moisture conditions.

In this case "dry" also refers to the in situ (eqiulibrium) moisture condition of the base, which was laboratory optimum at mod. AASHTO compaction (before stabilisation) plus approximately 2,5 per cent. "Wet" refers to the moisture condition of the base after rain or the introduction of artificial water into the test section, and was optimum (defined as above) plus approximately 3,5 per cent.

On average the rate of deformation, R_L, during the "wet" conditions is approximately 5,5 to 6,5 times higher than during the "dry" conditions on this shallow pavement, and is almost 1,4 times that found for the deep pavement under 40 kN wheel loading (see previous Table 4.2). This indicates a greater load sensitivity in terms of fatigue, of the shallow pavement, compared to that of the deep pavement.

TABLE 4.5 PAVEMENT PARAMETERS OF ROAD 2212 (BULTFONTEIN)

HVS-SECTION	R_L-FACTOR, mm/million reps						D_L *			
	40 kN		70 kN		100 kN		70 kN		100 kN	
	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY	WET
306A4	2,00	13,08	-	-	-	-				
307A4	-	-	5,45	13,57	-	-	2,72	1,03		
308A4	-	-	-	-	8,46				4,23	

* $D_L = (P/40)^r$ (see also Table 4.2)

In Table 4.6 the average relative damage coefficients, r, for this road are summarised.

TABLE 4.6 AVERAGE RELATIVE DAMAGE COEFFICIENT, r * (ROAD 2212)

70 kN		100 kN	
DRY	WET	DRY	WET
1,79	0,05	1,57	-

* See Table 4.3.

The table indicates that r (dry conditions) is almost similar for the 70 kN and the 100 kN, on this road. These values are 16 to 28 per cent higher than those obtained for the deeper pavement (see previous Table 4.3), and indicates a slightly higher load sensitivity of this pavement. Limited deformation results, however, exits for the wet conditions, inhibiting proper calculation of r for the 100 kN test, but indications are that r is very low and indicates damage almost independent of load during wet (excessive porewater pressure) conditions.

It is interesting to note, however, that the relative damage coefficients (r) of Road 2212, are much lower than those obtained from an HVS test on a "very shallow" pavement, ie Road P95/1, near Bronkhorstspruit (Kleyn et al., 1985). On this latter road, which was constructed with a 70 mm lightly-cemented base on an untreated natural gravel subbase, much higher deformation rates and r-coefficients than those found on Road 2212 were obtained.

The corresponding R_L, D_L and r parameters for this pavement (Road P95/1) are summarised in Table 4.7.

TABLE 4.7 PAVEMENT PARAMETERS FOR ROAD P95/1 (BRONKHORSTSPRUIT) (AFTER KLEYN ET AL., 1985)

HVS-WHEEL LOAD	RL- FACTOR (mm/million reps)		D_L - FACTOR		r - coefficient	
(kN)	INITIAL*	FINAL*	INITIAL	FINAL	INITIAL	FINAL
40	13	6	1,0	1,0	-	-
70	82	22	6,3	3,7	3,3	2,3
100	780		32,3		4,5	-

* In Table 4.7, "initial" denotes the condition before fatigue cracking of the cemented gravel base and "final" the state thereafter (equivalent granular state). The initial R_{70} is much higher than R_{40} but decreases markedly in the final state. This is also reflected in the relative damage factor (D_L) as well as the relative damage coefficient, r.

The table indicates that much higher deformation rates (R_L) were obtained for this pavement than for both the two pavements discussed above, indicating that this pavement is much more load sensitive and hence the "weakest" pavement of the three.

4.3.4.5 In situ densities and moisture contents

The in situ nuclear dry densities and oven dry moisture contents on the various test sections after HVS testing were also measured, similar to that of the deep pavement (see Figure 4.6). The results are summarised in Appendix A, Table A.9, and indicate that slight densification was measured in most of the layers within the trafficked areas of the three test sections (positions B and C). For Section 306A4, densification was measured to a depth of approximately 320 mm, and for Sections 307A4 and 308A4, to approximately 450 mm and 600 mm, respectively.

This is in accordance with the permanent deformation results summarised in Table 4.4, which indicates that, at the end of the HVS tests, higher deformations were measured deeper down in the pavement Sections 307A4 and 308A4 than those on Section 306A4, because of the relatively higher HVS test wheel load usedon these sections.

Although crushing failure (similar to that observed on the deep pavement) was noted in the upper section of the cemented gravel base on all the test sections, it was impossible to measure any significant de-densification with the nuclear apparatus, because the crushed layer was not well-defined and relatively thin. The thickness of the crushed layer varied between 10 mm and 30 mm and, in isolated cases, up to 50 mm to 75 mm. The effect of crushing, however, is well illustrated by the permanent deformation results measured on Section 308A4 (see Figure A.8 in Appendix A).

In general, relatively higher final moisture contents were measured in the upper 100 mm of the bases on Sections 306A4 and 308A4, than on Section 307A4, because of the higher rainfall on these sections towards the end of the tests.

The moisture contents measured in the shallow pavement are lower than those found in the deep pavement. These higher moisture contents in the deep pavement are believed to be caused by rain as well as the artificial introduction of water into the deep pavement. Another contributing factor may be the greater extent of the crushing failure in the surfacing and base layer of the deep pavement.

4.4 EXCESSIVELY HIGH SINGLE WHEEL LOAD TESTS

Included in the HVS test programmes on the deep and shallow pavements, excessive high single wheel load tests were planned to verify the failure mechanisms indicated by the relatively lower dual wheel load tests, ie 40 kN, 70 kN and 100 kN.

An aircraft wheel (Boeing 747) at 150 kN with tyre pressure of approximately 960 kPa to 1445 kPa was used for the testing on both the deep and shallow pavements. Two sections (337A4 and 338A4) were tested on the deep pavement (Road 1932 at Rooiwal), and one section (309A4) on Road 2212 at Bultfontein.

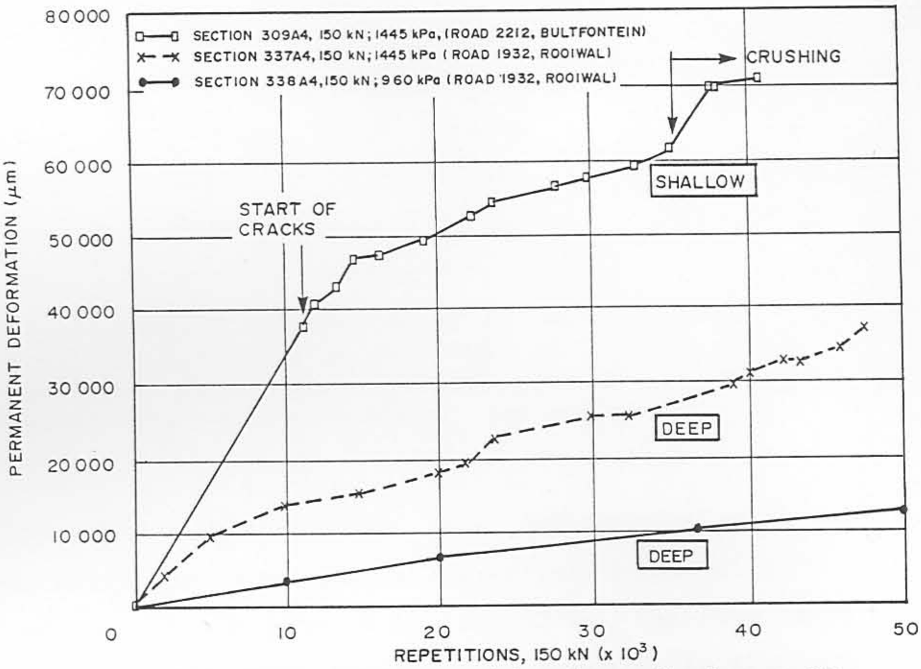
4.4.1 Permanent deformation on the road surface

The average permanent deformation development (rut) at various stages of trafficking on the three sections is illustrated in Figure 4.11 (a), (b) and (c). The figure indicates that relatively higher deformation occurred on the shallow pavement (HVS Section 309A4), compared to that of the deep pavement (HVS Sections 337A4 and 338A4).

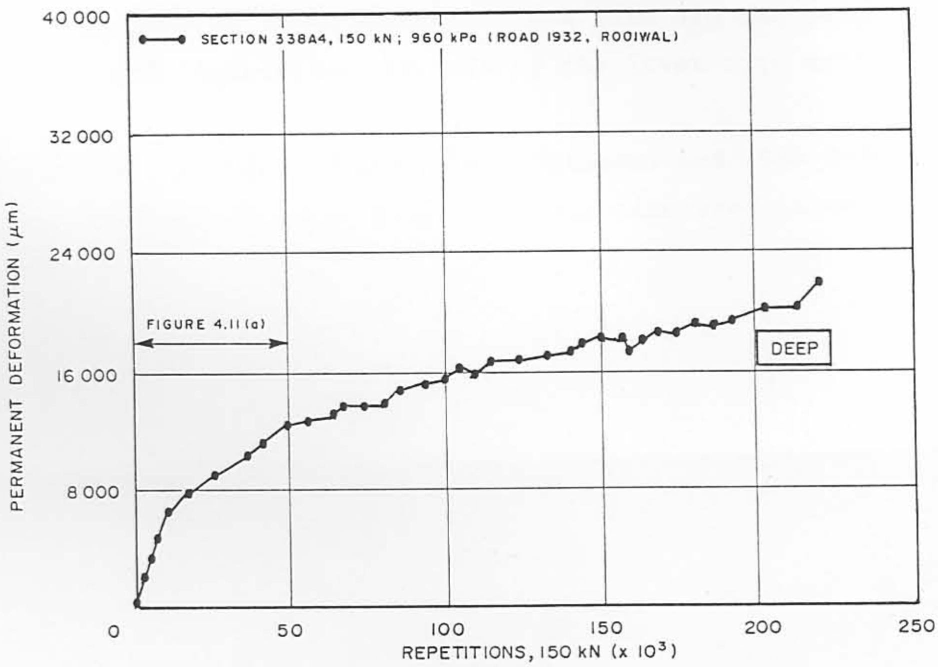
The higher deformation on the shallow pavement was expected, and again demonstrates the load sensitivity of this pavement in terms of fatigue failure of the cemented gravel base layer. The deep pavement is less load sensitive and hence the lower deformation under the same loading and moisture conditions.

It is, however, interesting to note that higher deformation occurred on Section 337A4 of the deep pavement, than on Section 338A4. On the latter section a lower tyre pressure was used, ie 960 kPa, and it is believed that this is mainly responsible for the difference in deformation behaviour on these two tests. In Chapter 5 it is indicated that the rate of crushing (compression failure) in the cemented base and hence the development of permanent deformation, is directly related to the tyre pressure.

Figure 4.11 also indicates that the rate of deformation on all three sections is not constant, but decreases towards the end of the tests.



(a) Comparison of the permanent deformation on the three sections



(b) Section 338A4 (Road 1932, Rooiwal)

FIGURE 4.11

AVERAGE PERMANENT DEFORMATION (RUT) AT VARIOUS STAGES OF TRAFFICKING OF A 150 kN SINGLE WHEEL LOAD ON THREE DIFFERENT SECTIONS

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In the case of the shallow pavement (Section 309A4) this is probably related to the fatigue failure of the base, and subsequent densification of the lower layers, tending to produce a deeper pavement (see Chapter 6).

Excessive cracking of the base was observed at approximately 11 000 repetitions on this section, after which the rate of deformation decreased up to approximately 36 000 repetitions. Hereafter, crushing failure occurred in the base and an increase in the rate of deformation occurred again.

The rates of deformation of the three sections is summarised in Table 4.8.

TABLE 4.8 RATE OF DEFORMATION, R_L^*, OF THE THREE SECTIONS IN mm PER 10^4 REPETITIONS

ROAD	HVS-SECTION	PAVEMENT TYPE	TYRE PRESSURE (kPa)	INITIAL	INTERME-DIATE	FINAL (CRUSHING)
2212	309A4	SHALLOW	1445	33,0	7,5	≈ 33
1932	337A4	DEEP	1445	13,0	5,0	≈ 13
1932	338A4	DEEP	960	4,0	1,3	-

* R_L in this case is measured in mm per ten thousand repetitions, and not million repetitions as indicated in previous Tables 4.2 and 4.8. This is done because of the relatively high deformation rates associated with the single wheel load tests.

The table also indicates that the deformation rates on the deeper pavement decreased from initial relatively high values to intermediate lower values. In the case of Section 337A4, the rate increased towards the end of the test owing to excessive crushing in the upper section of the base. On Section 338A4, however, the rate did not increase during the first 50 000 repetitions, because of the lower tyre pressure.

The effects of crushing (compression failure) and the development of "crushing life" curves from these tests are discussed in more detail in Chapter 5.

4.4.2 Permanent deformation at different depths

In Figure 4.12 (a) and (b), the permanent deformation development at different depths in HVS Section 309A4 is illustrated. The figure indicates the initial fatigue failure of the base, with subsequent compaction in the lower layers, especially the weaker layer and the subbase (depths 110 mm to 310 mm) in the pavement. Towards the end of the test, crushing failure in the base occurred as is indicated by the deformation in the base (depths 0 mm to 110 mm), especially at MDD 10 (see Figure 4.12 (b)).

Figure 4.13 indicates that relatively high deformation occurred in the base from the beginning of the test on HVS Section 337A4, indicating the crushing failure. Relatively low deformations occurred in the lower layers, when compared to those of the shallow pavement (Figure 4.12).

Figure 4.14 illustrates the deformation on Section 338A4, and shows that it is approximately 50 per cent of those measured on Section 337A4 at approximately 50 000 repetitions, and is believed to be directly related to the lower tyre pressure.

Although the variation in strength (bearing capacity) between the two test sections of the deep pavement may have attributed to the difference in deformation development, the effect of crushing in the cemented gravel base was well demonstrated by these tests. So too is the marked difference in failure mechanisms between the deep and shallow pavements.

In Figure 4.15, the various stages in the failure of the shallow pavement is illustrated. The figure indicates that the failure mechanism consists of various stages, starting with fatigue failure of the cementitious gravel bases, followed by "punch in" into the relative soft underlying subbase layer, crushing and then complete fracturing.

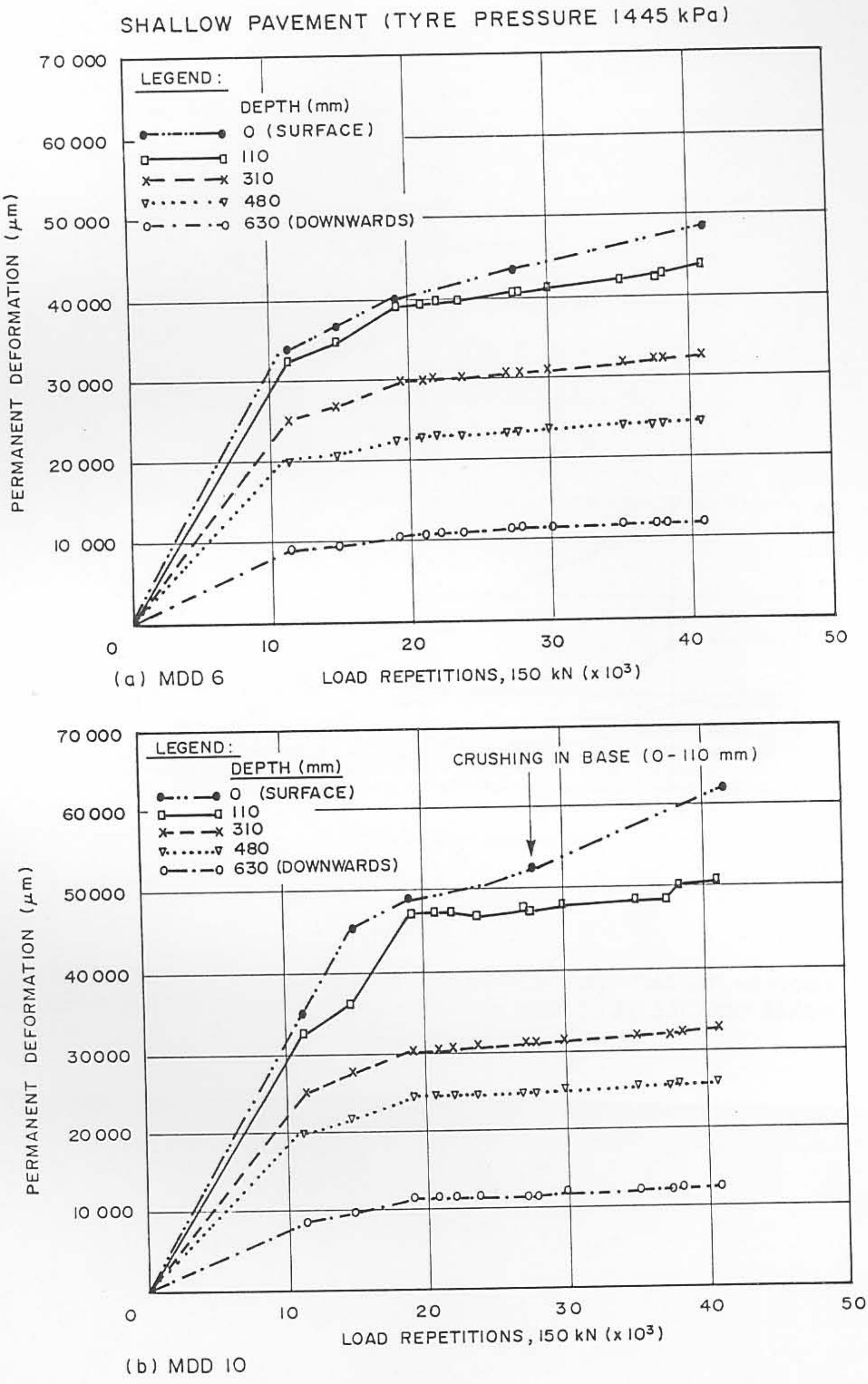


FIGURE 4.12

PERMANENT DEFORMATION AT DIFFERENT DEPTHS AT VARIOUS STAGES OF TRAFFICKING OF A 150 kN SINGLE WHEEL LOAD ON HVS TEST SECTION 309A4 (ROAD 2212 (BULTFONTEIN)

DEEP PAVEMENT (TYRE PRESSURE 1445 kPa)

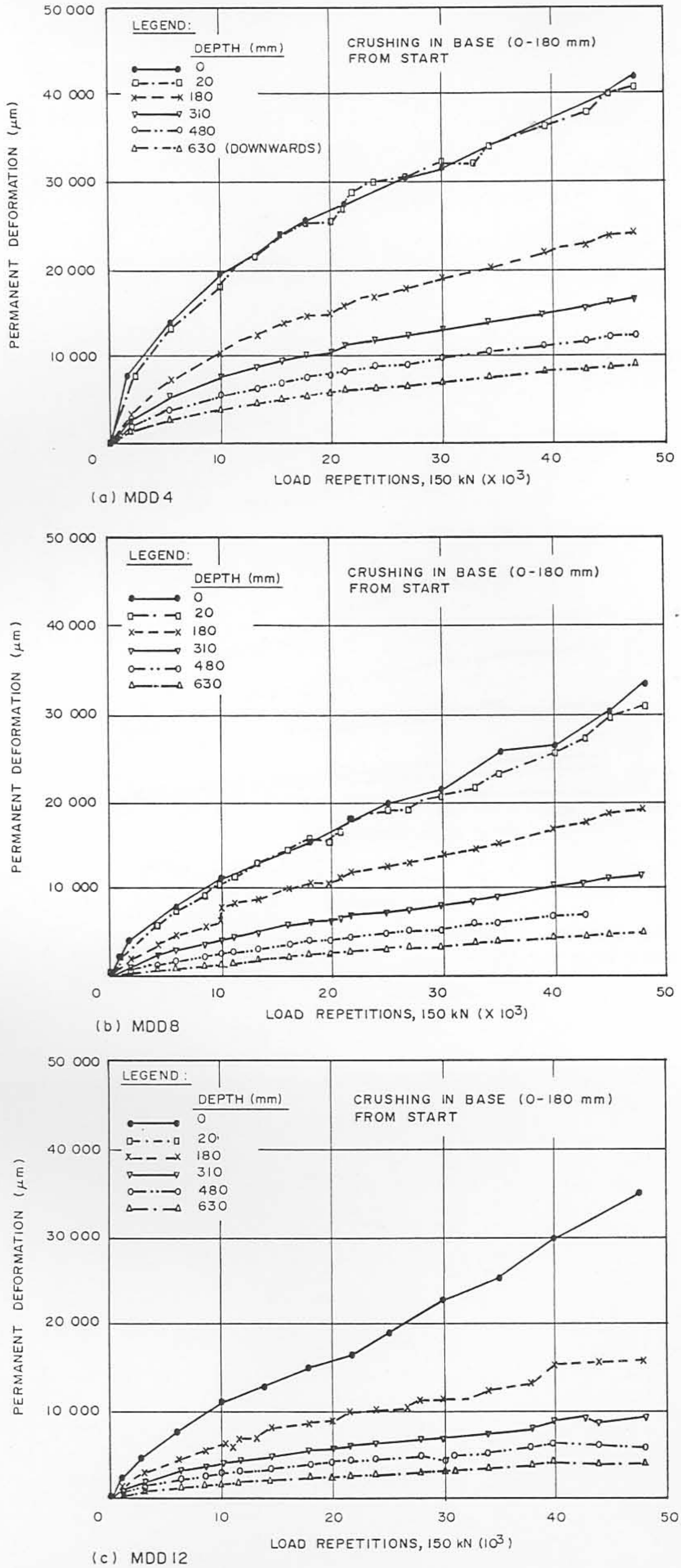
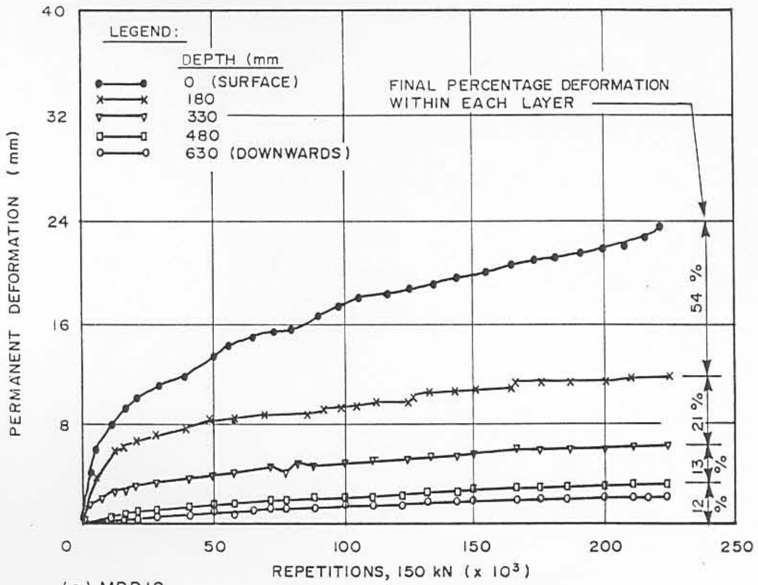


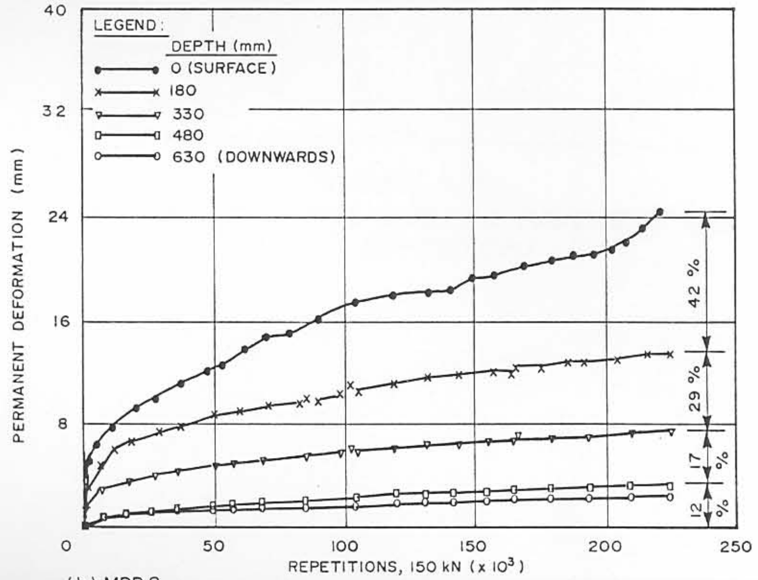
FIGURE 4.13

PERMANENT DEFORMATION AT DIFFERENT DEPTHS AT VARIOUS STAGES OF A 150 kN SINGLE WHEEL LOAD ON HVS TEST SECTION 337A4 (ROAD 1932, ROOIWAL)

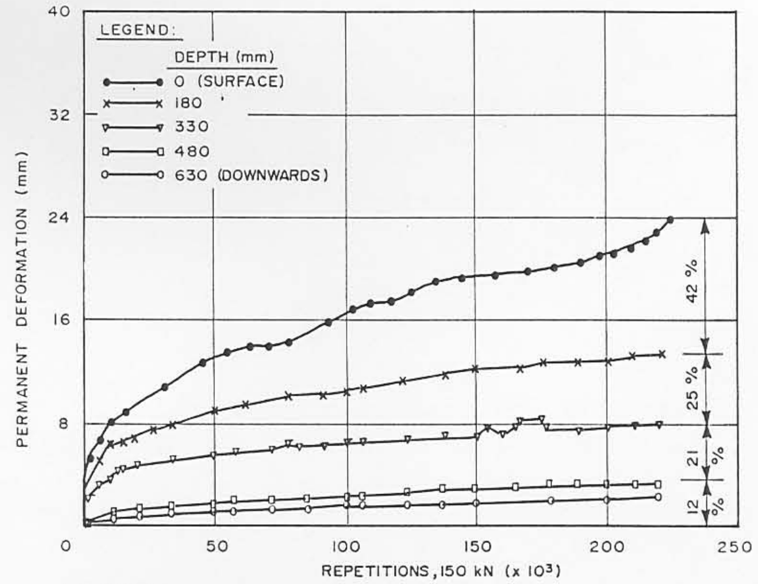
DEEP PAVEMENT (TYRE PRESSURE 960 kPa)



(a) MDD12



(b) MDD 8



(c) MDD 12

FIGURE 4.14

PERMANENT DEFORMATION AT DIFFERENT DEPTHS AT VARIOUS STAGES OF TRAFFICKING ON HVS TEST SECTION 338A4 (ROAD 1932, ROOIWAL)

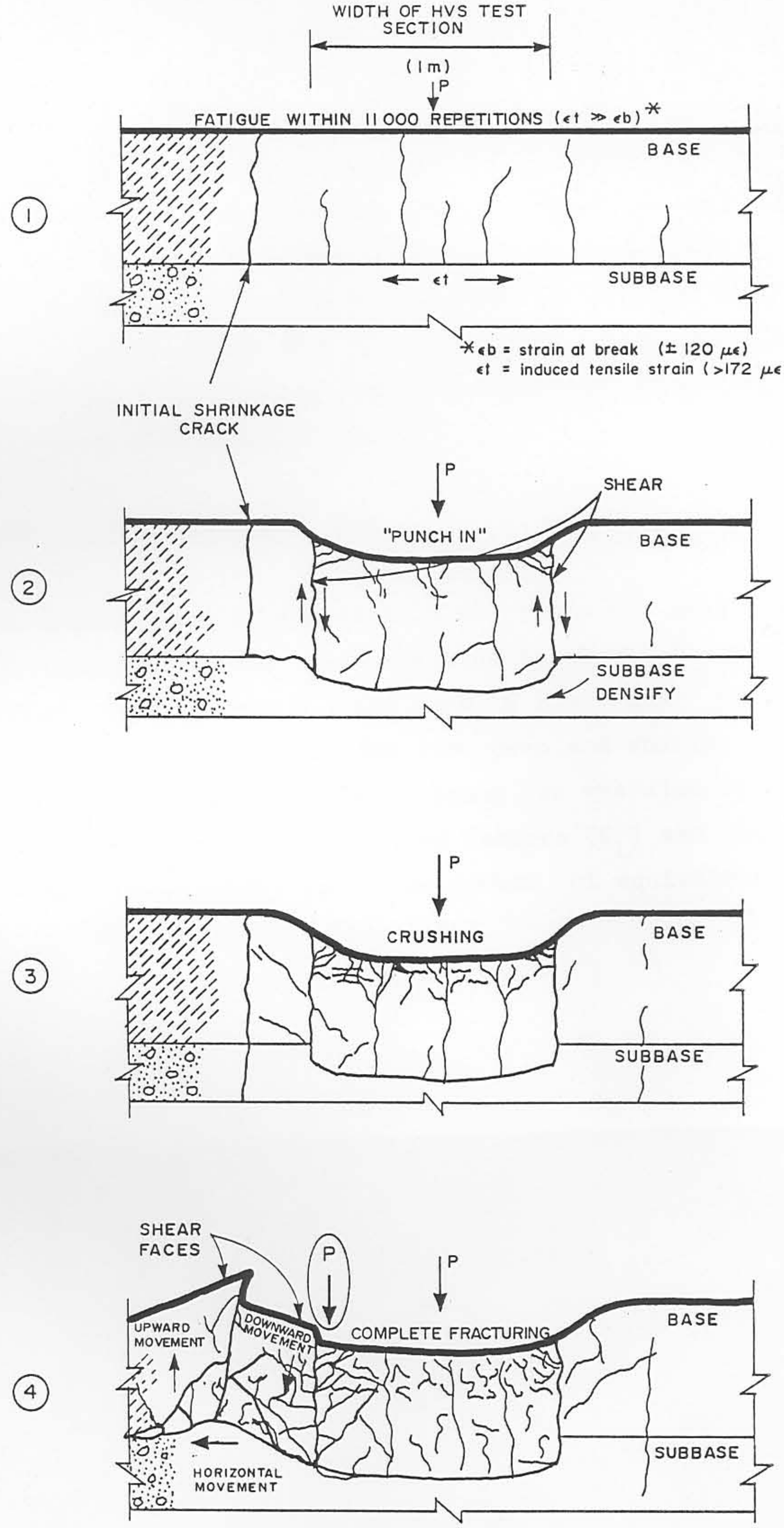


FIGURE 4.15

STAGES OF FAILURE IN THE SHALLOW PAVEMENT 2212, SECTION 309A4 (BULTFONTEIN)

For the deep pavement the stages of failure consist only of the last two phases depicted in Figure 4.15, viz crushing and complete fracturing, without excessive deformation and densification in the lower layers.

4.4.3 In situ densities and moisture contents

In situ nuclear dry density (Appendix A, Table A.9) and oven dry moisture contents on the previous discussed sections (309A4 and 337A4), indicate that the density in the upper 100 mm of the cemented gravel base of the shallow Section 309A4 at measuring point 4 (MP 4), is relatively low, especially at position C when compared to that at a depth of 200 mm to 300 mm. This is a reflection of the excessive crushing of the base that occurred during HVS testing on this section. At position D, excessive fracturing of the base layer outside the test section inhibited accurate measurement of density.

Marked densification, however, occurred from a depth of 200 mm to approximately 875 mm on this section. This was also indicated by the permanent deformation measurements illustrated in Figure 4.12.

De-densification (crushing) was measured in the upper 100 mm, in the base of Section 337A4 (at positions A and B). Crushing and fracturing occurred well outside the test area (position A) as was also found on Section 309A4. This was largely due to the excessively high single wheel loading, which approached a point load situation on these sections, resulting in these excessive failures, both inside and outside the trafficked area (See Figure 4.15).

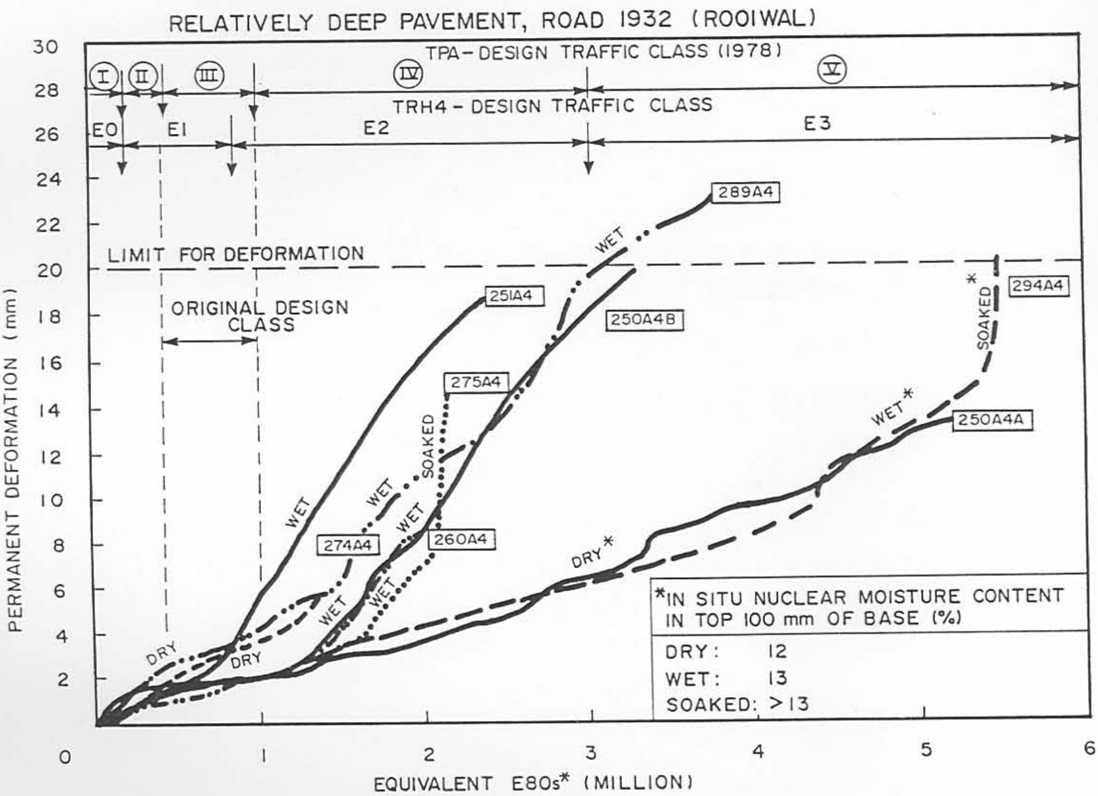
4.5 PERMANENT DEFORMATION VERSUS E80s

The permanent deformations of the various HVS tests can only be compared if the actual load repetitions are normalised in terms of equivalent 80 kN axles (E80s). Paragraphs 4.2.4.4 and 4.3.4.4 give the relative damage factors and r-coefficients for the deep and shallow pavements. These parameters do not appear to be constant, as was also indicated by Maree (1982). By applying the calculated factors (D_L) and coefficients (r) to the actual load repetitions, the number of equivalent E80s for each loading other than 40 kN is calculated.

Figure 4.16 illustrates the permanent deformation of the deep pavement, at different stages of equivalent E80s, and is a summary of the previous results similar to Figure 4.2. The figure indicates that the rate of deformation is largely influenced by the moisture content of the base. Similar rates of deformation were obtained on the different sections under the same moisture conditions. The figure also indicates that the time of increase in the moisture content is of critical importance to the **effective structural capacity** of the pavement. Taking a failure criterion of 20 mm rut (limit for deformation), relatively early wetting of the base may result in an effective structural capacity of approximately 1 to 2 million E80s, while the capacity during relatively dry conditions is in excess of 4 to 5 million E80s for this pavement.

Although there is a large difference in capacity mainly related to the moisture conditions in the base of this pavement, a capacity of **more than twice** the original capacity for which this pavement was designed, was measured. It appears that this type of design may be used for higher traffic classes than currently used by the TPA (TPA, 1978). According to the TPA-classification of pavements, this pavement was originally designed as a TPA-Class III pavement (0,4 to 1 million E80s) and according to the results above, this pavement design may easily be used for a **Class IV or even Class V category**, under relatively dry conditions. On this type of pavement, however, the **tyre pressure** should be strictly controlled in order to further extend the life of these pavements by avoiding premature crushing failure of the base.

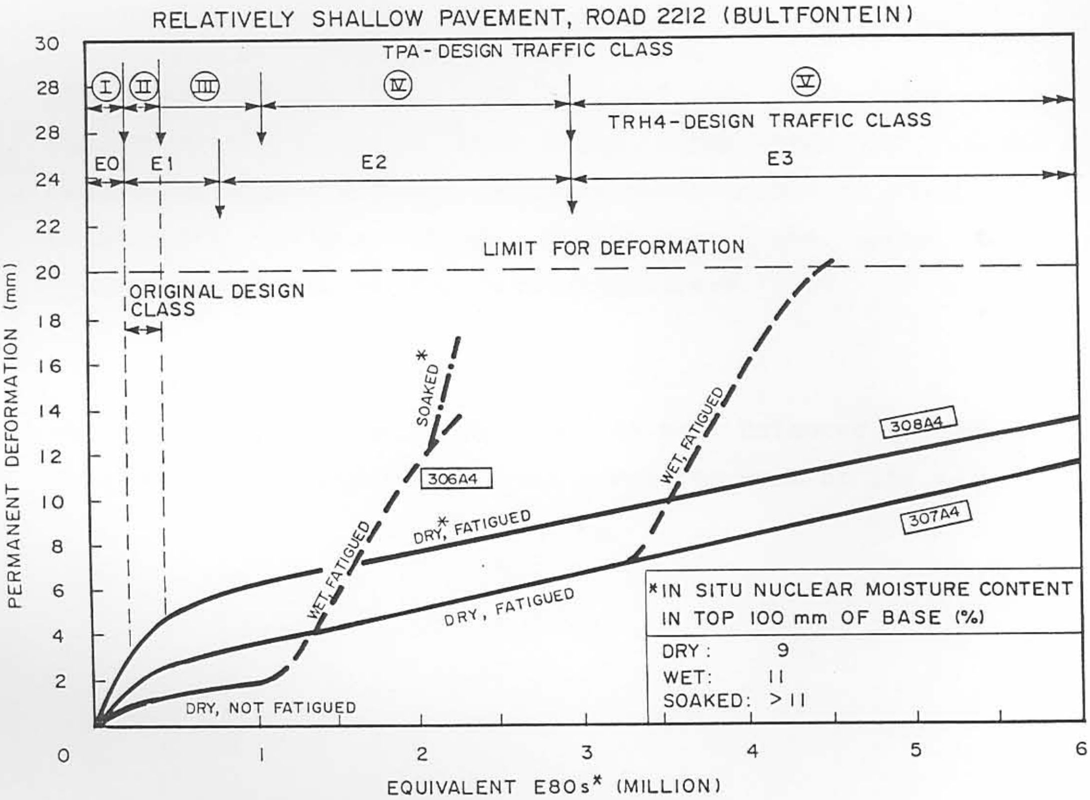
Figure 4.17 illustrates the permanent deformation of the different HVS test sections on the shallow pavement at various stages of equivalent traffic (E80s). Although this type of pavement is load sensitive in terms of fatigue, the rate of deformation is also largely influenced by the moisture content and the state of the base and subbase layers. This pavement was designed as a relatively shallow pavement to carry 0,2 to 0,4 million E80s, ie TPA-Class II. HVS results show that the effective structural capacity of this pavement appears also to be much higher than originally anticipated. This pavement can also be used for **Class IV**, and even **Class V**, under relatively dry conditions.



$^{*}\ D_L = \left(P_L/40\right)^r$ = VARIABLE, AS INDICATED IN TABLE 4.3

FIGURE 4.16

THE PERMANENT DEFORMATION OF THE DIFFERENT HVS TEST SECTIONS ON THE RELATIVELY DEEP PAVEMENT (ROAD 1932), AT DIFFERENT STAGES OF EQUIVALENT (E80s) TRAFFIC



$* \; D_L = \left({}^{P_L}/_{40} \right)^r$ = VARIABLE, AS INDICATED IN TABLE 4.6

FIGURE 4.17

THE PERMANENT DEFORMATION OF THE DIFFERENT HVS TEST SECTIONS ON THE RELATIVELY SHALLOW PAVEMENT (ROAD 2212), AT DIFFERENT STAGES OF EQUIVALENT (E80s) TRAFFIC

Overloading of this type of pavement however must be avoided in order to extent the life of the base further without **premature fatigue failure.**

The above are some of the most important findings from these HVS tests and also indicate large potential savings for the TPA, and the costs of pavements in general (Without the savings calculated during this current study, estimations by the TPA are that the HVS-program in Transvaal is currently saving approximately R13 million per year, directly as a result of HVS and HVS-related research in that Province, Kleyn, 1989).

4.6 SUMMARY OF THE PERMANENT DEFORMATION BEHAVIOUR OF PAVEMENTS WITH CEMENTITIOUS BASE LAYERS

The permanent deformation behaviour of pavements where cemented bases and subbases are the main controlling layers, is illustrated in Figures 4.18 and 4.19. Figure 4.18 indicates that the strength - balance of these pavement largely controls the rate of deformation. This rate, which is a prime indicator of the behaviour of the pavement, is basically linear for shallow pavements, but may increase markedly at a point of fatigue of the base layer, which is primarily controlled by the trafficking wheel load and to a lesser extend by the in situ moisture content of the lower layers. If the wheel load is higher than the critical load for fatigue of the base, fatigue failure occurs almost immediately, after which the rate may decreases owing to better balance of the pavement system (compaction of lower layers, etc).

Conversely, if the wheel load is lower than the critical load, fatigue failure occurs at a much later stage, after which the rate may increase because of higher moisture contents which result in lower load transfer between the fatigue cracks in the base, and lower shear strength (bearing capacity) of the supporting layers.

If the pavement (deep or shallow) is well balanced and maintained, the rate should approximate a linear curve for most of its life.

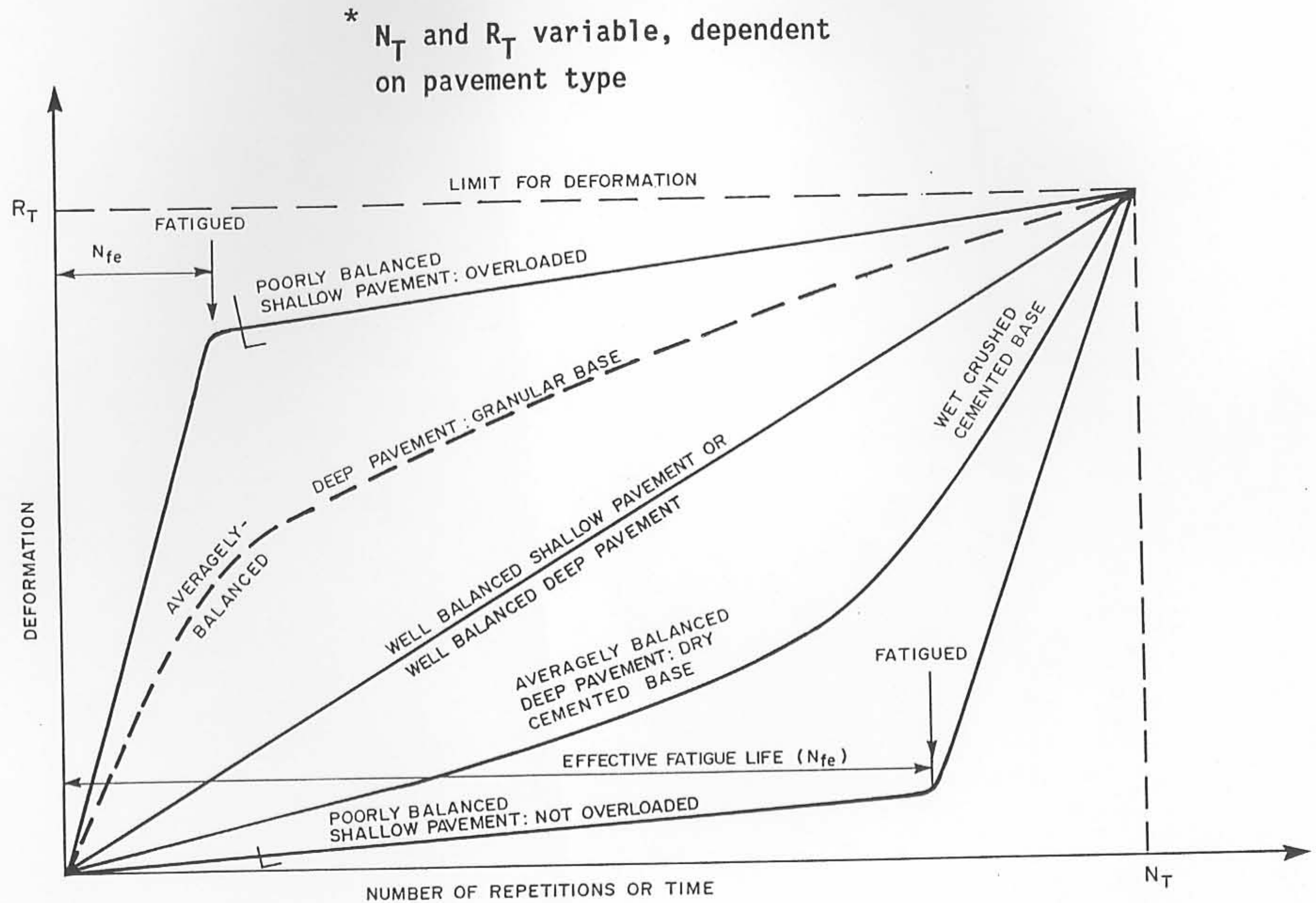


FIGURE 4.18

GRAPHICAL REPRESENTATION OF THE PERMANENT DEFORMATION OF LIGHTLY CEMENTED GRAVEL BASE AND GRANULAR BASE PAVEMENTS

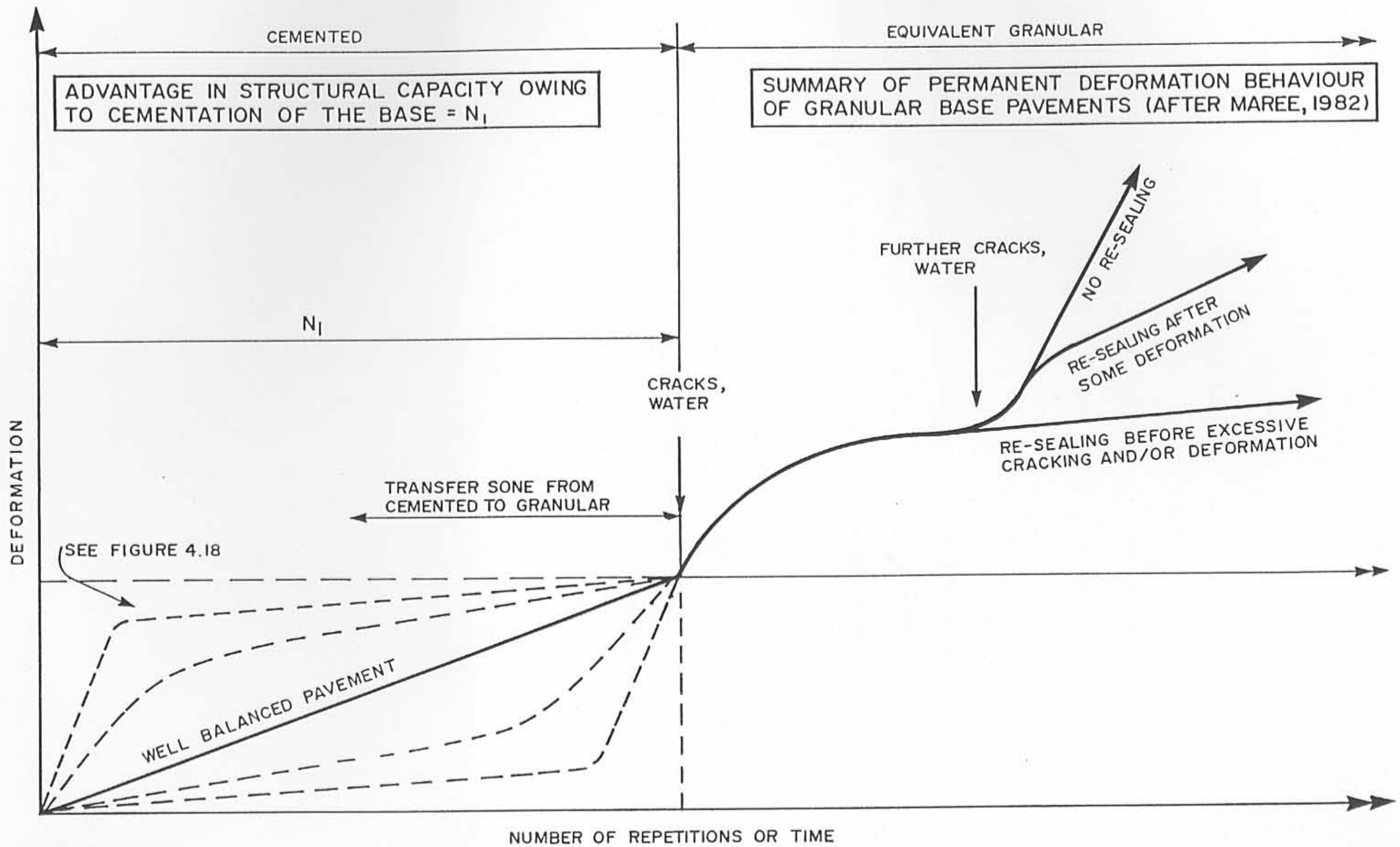


FIGURE 4.19

GRAPHICAL SUMMARY OF THE PERMANENT DEFORMATION OF LIGHTLY CEMENTED GRAVEL BASE PAVEMENTS, IN BOTH THE CEMENTED AND EQUIVALENT GRANULAR STATES

For relatively deep cemented base pavements, the rate appears to be non - linear, owing to crushing failure, which reverts the cemented base to an equivalent granular base. If the moisture content of the crushed material increases, the rate of deformation also increases.

For deep granular base pavements, the rate is also non - linear, mainly owing to slight densification of the granular material (if material is of good quality). During densification the rate decreases, but may increase owing to an increase in moisture content of the base.

In Figure 4.19 a summary of the behaviour of pavements with initial cemented base and subbase layers is given. The figure indicates that the behaviour of a cemented pavement may change to that of a granular pavement (see Maree, 1982). Changes in the rate of deformation, however, are strictly a function of the pavement balance, the moisture contents of the various pavement layers, quality of materials, maintenance, etc.

The potential advantage in structural capacity, owing to the initial cementation (or cohesion) of the base, is well illustrated in the figure.

4.7 CONCLUSIONS

(a) Extensive HVS testing on two basic type of pavements with lightly cemented layers indicated that these pavements can carry more than double the design traffic than was originally anticipated. The effective structural capacity of these pavements may be in excess of 5 million E80s if tyre pressure and overloading is controlled.

(b) The moisture content of the base layer is of critical importance, and is one of the major parameters influencing the rate of deformation in both shallow and deep pavements.

(c) The basic failure mechanism of relatively deep pavements with lightly cemented base layers is crushing (compression) failure in the upper portion (0 mm to 75 mm) of the base layer, changing the pavement from a deep to an inverted pavement.

This may be termed a "shallow" failure owing to the relatively good support from the lower layers and subsequent deformation from the top of the base layer.

(e) The basic failure mechanism of relatively shallow pavements with cemented bases, is a quite sudden fatigue failure of the base layer ("sudden death"). This failure may be termed a "deep" failure, owing to the initial lack of support and subsequent deformation in the lower layers.

(f) The rate of deformation of pavements with lightly cementitious layers is approximately linear but may change as a result of fatigue failure of the base and increase in moisture content of the lower layers.

(g) The relative damage coefficient based on the rate of deformation of pavements with cemented layers is relatively low, and varies between 1,2 to 1,5 for deep, and between 1,6 and 1,8 for relatively shallow, and up to 4,5 for very shallow pavements in the relatively dry conditions. For relatively deep granular materials a value of 3,0 is recommended (Maree, 1982).

(h) Surface deflection is not a good indicator of the effective rate of deformation on these pavements. The combination, however, of several DCP parameters viz DN, DNR, DSN, for the upper layers as well as surface deflection may provide a better prediction of behaviour (See Appendix A for discussion on this aspect).

(i) The current DCP model for structural capacity, based on the DSN_{800} only (Kleyn, 1984) totally overestimates the effective structural capacity of these pavements. The model should be improved to compensate for the important effect of strength - balance of pavements also (See also Chapter 6).

(k) In the deep pavements tested, more than 67 per cent of the permanent deformation during the relatively dry state, and 75 per cent during the relatively wet state, originates from the base layer owing to crushing and subsequent deformation in the upper section of the layer.

(l) Relatively low deformations (5 to 35 per cent) resulted initially from the base of the shallower pavements tested. Owing to fatigue failure and subsequent crushing, this percentage increased to a final range of 15 to 65 per cent.

(m) The permanent deformation measured on the surface of the pavement is an accumulation of the deformation at different depths in the pavement and may not correctly explain the complete failure mechanism.

(n) Permanent deformation at different depths in the pavement (measured with the MDD) appears to be very useful in assisting with the description of the failure mechanism associated with the pavements tested.

(o) In situ nuclear dry density and moisture content measurements in and outside the test area assisted in explaining the failure mechanisms of the pavements.

(p) As was found for granular base pavements, the state of the surfacing can have a major influence on the behaviour of the pavement, because the surfacing controls the penetration of water into the cemented gravel base and large pothloles may develop in the deeper pavements especially, due to the crushed state in the top of the base.

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