ALKALI - AGGREGATE REACTION
1981
ALKALI - AGGREGAATREAKSIE
S252

EVALUATION OF A CONCRETE PAVEMENT AFFECTED BY THE ALKALI-AGGREGATE REACTION USING A HEAVY VEHICLE SIMULATOR

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SYNOPSIS

The entire length (27 km) of the concrete pavement on National Route N2, between Cape Town and Somerset West in the Cape, exhibits cracking caused by an alkali-aggregate reaction. Under traffic these cracks eventually develop until the pavement fails by spalling at the transverse joints. The paper describes an investigation into the load associated deterioration of the pavement using the Heavy Vehicle Simulator. The investigation was designed to study how the pavement breaks down under traffic and to identify the principal mechanisms associated with deterioration in performance.

The study showed that the pavement's residual life is between 0,3 and 1 million equivalent 80 kN axle loads. The pavement will continue to fail under traffic regardless of whether the alkali-aggregate reaction continues unchecked or abates. Overloaded vehicles cause much more rapid failure than legally loaded vehicles and the residual life of the pavement can be extended by adequate enforcement of the legal load limit.

SAMEVATTING

Oor die hele lengte (27 km) van die nasionale pad N2 tussen Kaapstad en Somerset-Wes kom daar krake in die betonplaveisel voor wat deur alkali-aggregaatreaksie veroorsaak word. Druk verkeer laat hierdie krake ontwikkel totdat die plaveisel by die dwarsnate faal en afsplinter. In die referaat word 'n beskrywing gegee van 'n ondersoek wat met behulp van die swaarvoertuignabootser gedoen is na die skade wat deur die aslaste van voertuie aan die plaveisel berokken word. Die ondersoek was daarop gemik om vas te stel hoe die plaveisel onder verkeer verbrokkel en om die belangrikste meganismes uit te wys wat 'n rol in die agteruitgang van die plaveisel speel.

Die navorsing het getoon dat die plaveisel nog tussen 0,3 en 1 miljoen aslaste gelyk aan 80 kN kan dra. Die plaveisel sal steeds onder die verkeer verbrokkel, of die alkali-aggregaatreaksie voortduur of afneem. Oorlaaide voertuie laat die plaveisel veel vinniger verbrokkel as voertuie met wettige aslaste, en die lewe van die plaveisel kan verleng word deur die regulasies ten opsigte van vragperke streng toe te pas.

S252/20

Conference on alkali-aggregate reaction in concrete
Cape Town - South Africa
March 30 - April 3, 1981

Konferensie oor alkali-aggregaatreaksie in beton
Kaapstad - Suid-Afrika
30 Maart - 3 April, 1981

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1. INTRODUCTION

In 1970, approximately 27 kilometres of National Route, N2, between Cape Town and Somerset West were re-aligned and reconstructed as a dual-lane divided freeway incorporating a rigid unreinforced concrete pavement. By 1975, an unusually high incidence of hairline cracking was observed in the pavement. It was established that this was due to an alkali-aggregate reaction[1]. The action of traffic aggravated the cracking so that by 1979 a number of failures at transverse joints were observed. These failures took the form of spalling of the concrete at the joints and required repair by patching. The incidence of failure was relatively small. Approximately 1 per cent of all joints had either failed or were exhibiting signs of incipient failure by late 1979. It was, however, apparent that the pavement might fail progressively under traffic. The National Roads Branch of the Department of Transport and the Cape Provincial Administration jointly requested that the NITRR evaluate the combined effects of the alkali-aggregate reaction and the traffic by means of accelerated trafficking tests on the pavement. These tests made use of a Heavy Vehicle Simulator (HVS)[2,3] drawn from the fleet operated by the NITRR. HVS testing began in February 1980 and continued until November that year.

The objectives of the test programme were :

(a) to determine the rate at which the pavement might deteriorate under traffic and to predict the remaining life of the pavement prior to major rehabilitation being required;

(b) to identify and evaluate the factors controlling the development of traffic-associated distress.

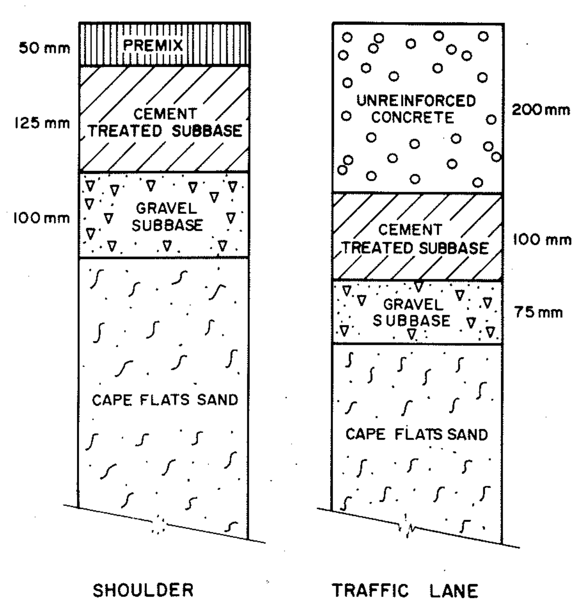

FIGURE 1: Cross-section of the concrete pavement of National Route N2 between Cape Town and Somerset West.

TABLE 1: Properties of the pavement layers

Slab	modulus Poissons ratio cement content density	3,73 MPa 0,16 16,6 % 2162 - 2243 kg/m³
CTB	cement content strength relative compaction	5,6 - 7,9 % 0,6 - 0,7 MPa 102 %
Gravel subbase	relative compaction	98 %
Subgrade	relative compaction	105 %

2. PAVEMENT DETAILS

The pavement comprises a continuous unreinforced concrete slab 7,3 m wide with flexible shoulders surfaced with bituminous premix. The shoulder adjacent to the fast lane is 1,2 m wide while that next to the slow lane is 2,4 m wide. A typical cross-section of the pavement is given in Figure 1 while the properties of the materials in the pavement are given in Table 1. Details of the construction procedures have been given elsewhere[4].

Oberholster et al[5] have reported that, with the Malmesbury shale selected as the aggregate for the concrete used in the road, an alkali-aggregate reaction will take place once the alkali content (Na_2O equivalent) exceeds 2,1 kg/m³ in the concrete. Semmelink[1] states that the cement used in the concrete pavement on National Route, N2, came from a factory which, in 1970, produced cement having an average annual Na_2O equivalent of about 0,85 per cent.

During construction, the design of the concrete mix was modified twice to improve workability and reduce bleeding. Details of the three mixes are given in Table 2, page 2, based on information previously reported[4]. This table shows that the alkali content in the concrete was well in excess of that needed to initiate the alkali-aggregate reaction. Two of the three mixes were studied in the HVS accelerated trafficking tests. These are the mixes designated A and C in Table 2 and include both the high and low cement contents.

3. DEVELOPMENT OF PAVEMENT DISTRESS

Information published by the National Building Research Institute[6] and Semmelink[1] suggests that, once the alkali-aggregate reaction has begun, the deterioration in the concrete occurs most rapidly where it is exposed to cycles of wetting and drying or heating and cooling. These conditions occur in a road pavement. Clear evidence of the alkali-aggregate reaction is found over virtually the entire

TABLE 2 : Details of the concrete mixes used on National Route N2

Mix	A	B	C
OPC (kg/m^3)	354	354	335
Water (kg/m^3)	153	163	145
Sand (kg/m^3)	590	642	639
19 mm stone (kg/m^3)	528	477	502
38 mm stone (kg/m^3)	716	713	728
TOTAL (kg/m^3)	2 341	2 349	2 349
Na_2O equivalent (kg/m^3)	3,0	3,0	2,8

length of the concrete pavement on National Route, N2. Cracks have developed which are concentrated around the edges of the slab and, especially, adjacent to the transverse joints. Measurements made next to the joints have established that the amount of cracking is typically about 5 m in length per square metre of pavement area. The amount of cracking appears to be solely related to the alkali-aggregate reaction because similar intensities were measured on both the trafficked and untrafficked portions of the pavement. Following the system proposed by van der Merwe[7] five stages in crack development can be identified. These can be defined as follows:

Degree of cracking	*Description*
1	Little visible cracking. Alkali-aggregate reaction mainly manifest as faint orange stains on concrete surface.
2	Fine cracks visible. Cracks are darker in colour than surrounding concrete.
3	Obvious cracking especially adjacent to joints. Crack widths range between 1 and 2 mm. No hollow sound when tapped with a hammer.
4	Obvious cracking 1 to 2 mm in width especially within ± 200 mm of joint. Concrete gives hollow sound when tapped with a hammer.
5	Obvious cracking, 2 mm or greater in width. A white powder, comprising finely ground concrete, is observed next to some cracks. Some spalling is evident next to joints. When tapped with a hammer concrete gives a hollow sound.

Inspections of National Route, N2, during 1980 have established that those sections which carry traffic generally exhibit degree 3 cracking although a small incidence of degree 4 and 5 cracking is also evident. On the east-bound carriageway the incidence of degree 4 and 5 cracking appears to be randomly distributed along the length of the road. However, on the west-bound carriageway the incidence of degree 4 and 5 cracking is most pronounced at the western extremity of the road which carries the heaviest traffic. By contrast, a short length of the pavement at the eastern end of the road which has never been opened to traffic is only exhibiting degree 1 and 2 cracking. Thus there is evidence of a synergistic inter-action between traffic and the alkali- aggregate reaction in the development of pavement distress.

4. HEAVY VEHICLE SIMULATOR TESTING

HVS testing commenced in February, 1980. A description of the HVS, its operating characteristics and instrumentation has been given elsewhere[2,3]. For this reason only a summary of those features of testing peculiar to the research conducted on the concrete pavement are given here.

The following variables were selected for study:

(a) The magnitude of the applied wheel load.
(b) The initial degree of cracking.
(c) The effects of the presence or absence of surface water.

Each of these variables is now considered in more detail.

a) Selection of the wheel loads

Traffic Axle Weight Classifier (TAWC) measurements were taken in 1978 and further observations were done in 1980. On the most heavily trafficked portion of the west-bound carriage approximately 500 E80s/lane/day were measured reducing to 100 E80s/lane/day near Somerset West. From an analysis of the data between 15 and 36 per cent of all rear axles of vehicles using the road exceed the legal limit of 8,2 tonnes. Moreover, between 2 and 10 per cent of all rear axles were loaded to 12 tonnes or more.

Accordingly, in the HVS investigation, it was decided to employ wheel loads of 40 and 60 kN (equivalent to axle load of 8,2 and 12,3 tonnes) because this would cover the range of the majority of overloads applied to the pavement. In addition, in order to accelerate the rate of HVS testing, a third load level of 95 kN (axle load of 19,5 tonnes) was also used.

b) Initial degree of cracking

Both the trafficked and untrafficked portions of the pavement were tested to establish a relationship between the number of HVS wheel load repetitions and the number of axle loads by actual traffic needed to cause failure in the pavement. The rate of accumulation of distress under

HVS trafficking could be compared for pavements with different initial loading histories. Any differences in response could then be attributed to the effects of the actual traffic carried by the pavement.

The trafficked portion of the road generally exhibited cracking of degree 3 or greater whilst the un-trafficked pavement exhibited degree 1 or 2 cracking. Sections exhibiting degree 3 cracking were selected for testing on the trafficked pavement while, in the untrafficked length, sites having degree 2 cracking were selected.

c) Surface water

There was strong evidence that free (surface) water plays a role in the rate of development of cracking caused by the alkali-aggregate reaction. It was decided, therefore, to duplicate the tests conducted at the two highest wheel loads both with and without surface water being applied for the duration of HVS testing.

d) Testing procedures

Two sites were selected for study. The first of these was located on the east-bound carriageway approximately 9 km east of the D F Malan interchange. The second site was chosen to be on the west-bound carriageway of the untrafficked spur of the pavement at the eastern extremity of the concrete road. At the first site, mix A in Table 2 was used during construction whilst at the second site, mix C was used. Details of the accelerated trafficking tests that were carried out at these two sites are summarised in Table 3.

e) Research measurements and instrumentation

The research measurements fell into two categories. These are :

(i) Measurements designed to record and quantify the development of surface cracking under accelerated trafficking.

(ii) Measurements designed to determine the structural behaviour of the pavement during the progress of each HVS test.

Each of these categories is now considered.

i) *Crack measurement.* A full-scale replica of the pavement surface was traced on mylar sheeting for each test. This replica provided a permanent record of crack development. Mylar sheeting was chosen because of its strength and high dimensional stability.

ii) *Measurements of structural behaviour.* Two categories of instrumentation were used to monitor the structural response of the pavement to HVS trafficking. These were :

(a) Sub-surface instrumentation installed within the pavement subgrade, and
(b) instruments mounted on the road surface.

In a rigid pavement the principal indicators of behaviour are the vertical deflection and deformation resulting from any given history of loading. These deflections and deformations were measured using multidepth deflectometers (MDDs)[8] installed at various depths within the pavement.

Semmelink[1] had shown that one consequence of the alkali-aggregate reaction in the concrete pavement was the production of predominantly horizontal cracking in the slabs. This was supported by information published by the NBRI[6]. For this reason the MDD modules were installed at the top and bottom of the slab. MDD modules were also installed at the bottom of the cement-treated subbase and in the subgrade. The depths at which the modules were anchored, measured from the surface, were 50, 180 and 300 mm.

The behaviour of the various test sections was routinely monitored using data from the MDDs. However, from time

TABLE 3 : Summary of HVS tests

Site	Test No	Dates	Dual Wheel load kN	Surface condition	Initital degree of cracking	Total load repetitions
1	83A2	Feb 1980	95	Wet	3	108 000
	84A2	Feb/April 1980	60	Wet	3	834 000
	82A2	April/May 1980	60	Dry	3	837 000
	85A2	May/Aug 1980	40	Wet	3	1 354 000
	97A2	Aug/Sept 1980	95	Dry	3	245 000
2	109A2	Sept 1980	95	Wet	2	85 000
	110A2	Sept/Oct 1980	60	Wet	2	199 000
	112A2	Oct/Nov 1980	40	Wet	2	324 000
	129A2	Nov 1980	50	Wet	2	83 000

capabilities of the joints. In a few tests the transient faulting movements across selected joints were monitored as a means of observing changes in load transfer.

ii) *Spalling at the transverse joints.* The appearance of the pavement after failure is illustrated schematically in Figure 2 and photographically in Figure 3. The spalled areas extended along both sides of the joints (the numbers marked on the areas indicate the order in which they broke from the parent slabs). In general, the spalled concrete was restricted to a zone not more than ± 250 mm on either side of each joint. As trafficking proceeded, corner and longitudinal cracks sometimes developed in the pavement (cracks 5 and 6 in Figure 2).

This type of behaviour was found to be typical of all of those HVS tests which led to pavement failure. It was encouraging to note that this sort of behaviour was similar to that found under normal traffic. Comparison of the crack replicas of the pavement after traffic-induced failures with those drawn before HVS testing established that the boundaries of the concrete spalls almost invariably ran along pre-existing cracks. This showed that the effects of trafficking were not to cause the initiation of fresh cracks in the concrete but were rather to widen and develop cracks already generated by the alkali-aggregate reaction.

Excavation of the pavement at failed transverse joints established that there was a continuous network of both horizontal cracks and of cracks extending vertically throughout the entire thickness of the slab. This is illustrated in Figure 4. The effects of HVS trafficking were to develop these cracks in the vicinity of the transverse joints so that the slab tended to disintegrate into a number of separate blocks each roughly 15 to 200 mm square and about 60 to 100 mm thick. Inspection of these blocks showed clear evidence of the alkali-aggregate reaction

FIGURE 4: Evidence of vertical and horizontal cracking at a transverse joint.

along the fracture planes. In this respect it was observed that the concrete normally developed cracks and failure planes through the aggregate rather than through the cement matrix of the concrete. The disintegration of a slab adjacent to a transverse joint into discontinuous blocks was manifest initially by the pavement yielding an increasingly hollow sound when tapped with a hammer. As HVS trafficking progressed individual blocks began to break loose from their neighbours and to move visibly under each passage of the HVS test wheels. Eventually such blocks could be rocked from side to side by gentle hand pressure alone. Once the blocks had broken loose from the parent slab they began to develop faulting or stepping movements of up to about 5 mm relative to their neighbours. This was accompanied by the appearance of a powdery material at the surface which was believed to be finely ground concrete produced by the individual blocks grinding against one another. The removal of this finely ground concrete was facilitated by the presence of surface water. This led to the development of permanent vertical deformations in the concrete slabs adjacent to the transverse joints.

The general appearance of a transverse joint which had failed by accelerated trafficking was similar to those failures which were found to have occurred in service under actual traffic. However, it was observed that, although the slabs failed structurally during the various HVS tests, they did not attain the final stage of failure reached under real traffic, which involved the complete dislodgement of one or more blocks from next to the joint. This is of some importance because it is only at this stage that maintenance measures become imperative to ensure safe traffic operation.

iii) *Deterioration of the cement-treated subbase.* During a number of exploratory borings made at selected joints along the road, evidence has been found of disintegration in the cement-treated subbase to the extent that it has proved impossible to recover intact cores. The deformation and deflection of the cement-treated subbase beneath the concrete slab increased during the HVS tests. Thus there was evidence of deterioration in the subbase caused by accelerated trafficking.

b) The effects of wheel load on structural performance

It was determined that, as shown in Figures 5 and 6, page 6, both the deflection and deformation of the pavement increased during the HVS tests with an increase in either the number of load repetitions or the magnitude of the wheel load. This type of behaviour was observed at both the top and bottom of the slab and at the bottom of the subbase. The effects of HVS accelerated trafficking were to produce rapid increases in pavement deflection until, near the onset of spalling, values of deflection of 0,3 mm or more were observed. In general, however, it was determined that spalling did not begin until the pavement deflections were greater than about 0,2 mm, ie approximately twice as large as the values ruling at the start of the HVS tests.

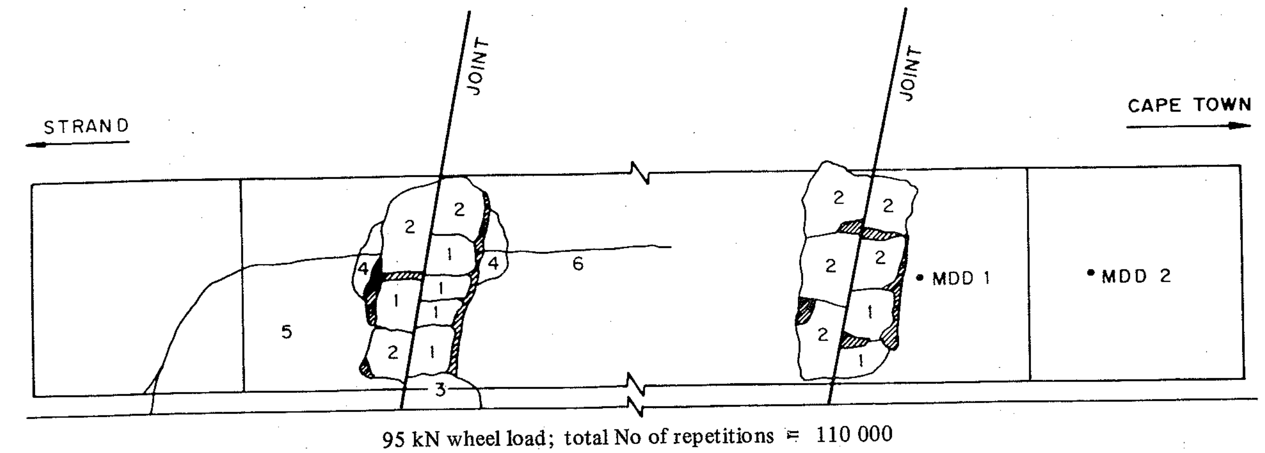

FIGURE 2 : Diagrammatic appearance of the surface of the pavement showing order of spalling of the concrete slabs

to time, these data were supplemented by observations of the surface behaviour of the pavement. Surface instrumentation was installed to measure surface strains and the vertical movements across opposite sides of the transverse joints. Surface strains were monitored by means of foil strain gauges cemented to the road surface whilst faulting movements across the joints were measured by displacement transducers (LVDTs).

5. RESULTS

a) General behaviour of the pavements under HVS traffic

All of the test pavements shared certain common response attributes in that they all deteriorated under accelerated trafficking, irrespective of the test conditions. This behaviour is in marked contrast to earlier HVS studies of rigid pavements[9]. These established that, for a sound pavement designed in accordance with Draft TRH4[10], prolonged trafficking with wheel loads up to 100 kN had little effect on the behaviour of the pavement.

For the concrete pavement on National Route, N2, the deterioration caused by HVS trafficking was manifest in three ways. These were :

(i) a progressive loss of stiffness in the pavement,
(ii) the development of spalling at the transverse joints, and
(iii) deterioration in the cement-treated subbase.

Each of these aspects of response is now considered.

i) *Loss of stiffness caused by HVS trafficking.* Irrespective of the magnitude of the applied wheel load, all of the test pavements exhibited a progressive decrease in stiffness during the progress of each HVS test. In general, this was evident as a progressive increase in the deflection of the pavements as indicated by the multi-depth deflectometers (MDDs).

Evidence of decreases in slab stiffness caused by trafficking were provided by observations of slab curvature and by measurements of surface strain on the top of the concrete slab. The experimental evidence indicated a progressive loss in slab stiffness due to the development or propagation of cracks.

The most serious cracking occurred adjacent to the transverse joints. This led to a change in the load transfer

FIGURE 3: Typical appearance of a transverse joint after HVS testing.

c) The effects of wheel load on spalling

The deterioration in structural performance caused by accelerated trafficking described above was eventually accompanied by disintegration of the slabs adjacent to the transverse joints. The rapidity and extent of breakdown was found to depend on the initial degree of cracking, the state of the subbase, the wheel load and the number of wheel passes.

The data in Figures 7 and 8 establish that, in respect to the development of spalling and disintegration adjacent to the transverse joints, the concrete road is particularly sensitive to any overloading especially within the range 40 to 60 kN. Here, the initial degree of cracking or the previous history of normal traffic loads does not appear to be of much significance. This is in contrast to the structural behaviour of the road where overloads above 60 kN appear to have the most detrimental effect.

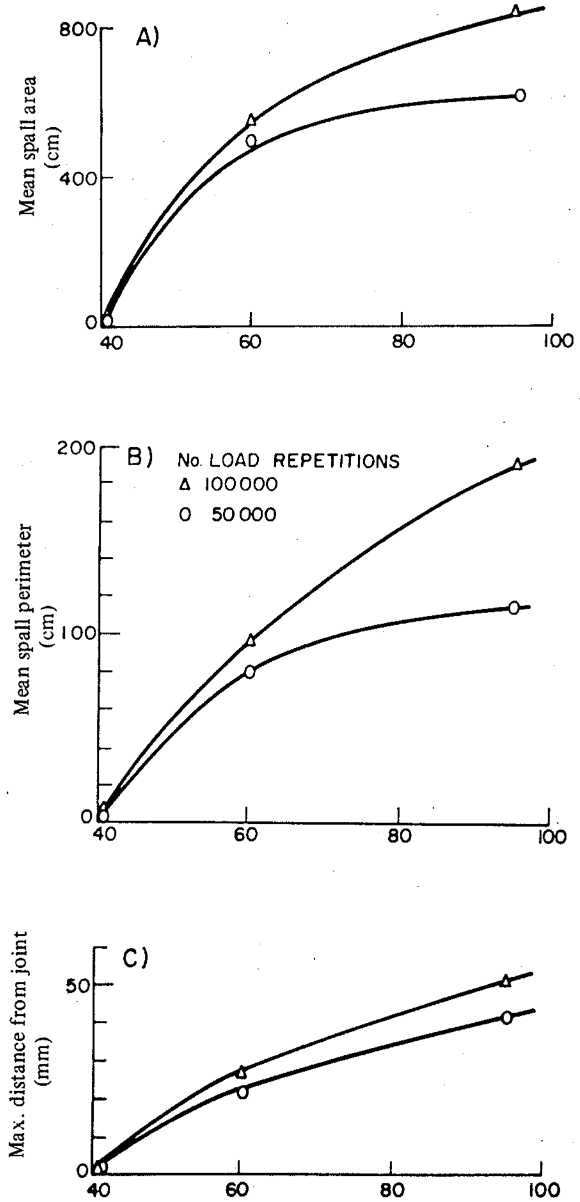

FIGURE 7: Rate of development of spalling at transverse joints.

6. SUMMARY OF THE EXPERIMENTAL FINDINGS

The principal findings of the experimental work were as follows :

(a) Under accelerated HVS trafficking the concrete road showed distress at all the wheel loads studied within the range 40 to 95 kN.

(b) The visible signs of distress caused by HVS loading were similar to those caused in service by real traffic.

(c) Pavement distress was manifested either by decreases in stiffness (observed as increases in pavement and layer deflections) or by the development of spalling leading eventually to the disintegration of the slab adjacent to the transverse joints.

(d) Both pavement deformations and deflections increased non-linearly with increasing wheel load.

(e) There is evidence that overloading above 60 kN is detrimental to pavement behaviour.

(f) The cement-treated subbase deteriorated under traffic.

(g) There was substantial experimental evidence of the existence of both horizontal and vertical cracks in the slab.

(h) Spalling developed along pre-existing cracks caused by the alkali-aggregate reaction. In general

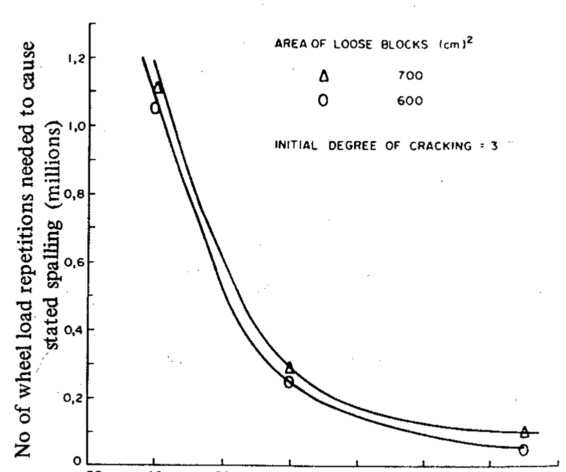

FIGURE 8: Effect of wheel load and number of repetitions on the spalling of the concrete.

For a designated number of wheel load repetitions it was determined that the relationships between pavement deflection and wheel load were distinctly non-linear. The degree of non-linearity was more pronounced for the concrete slab than for the cement-treated subbase.

In addition to studying the deflection and deformation of the pavement as a whole, the movement within the slab and subbase layers was also investigated. It was found that these layer deformations and deflections also increased, in a non-linear fashion, with increase in the wheel load.

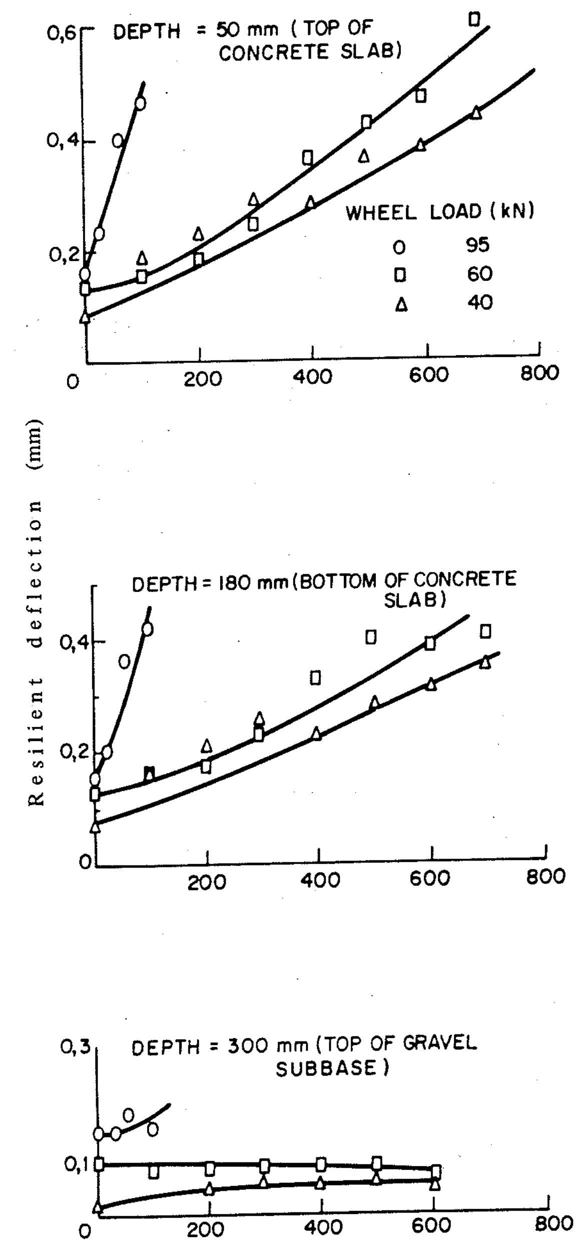

FIGURE 5: Deflection of the pavement at different wheel loads and depths.

The contribution of the subbase to the structural capacity of the pavement and its susceptibility to damage increased as the wheel loads applied to the pavement increased between 60 and 95 kN. In other words, overloading the pavement beyond 60 kN had a greater effect on the cement-treated base than on the concrete slab.

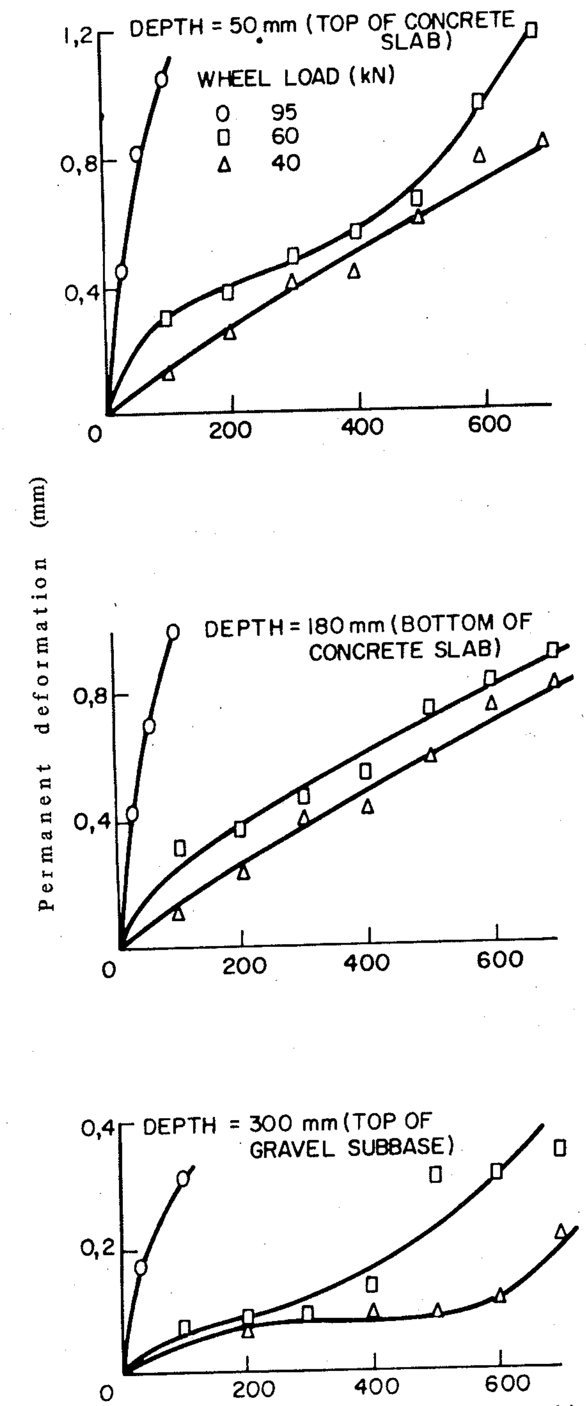

FIGURE 6: Deformation of the pavement at different wheel loads and depth.

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TABLE 4 : Estimated remaining life

Traffic E80s/lane/day	Estimated remaining life before rehabilitation required (YRI) (1980)	Location
500	2 to 6	Occurs on the westbound carriageway near Cape Town
300	4 to 10	Occurs on the eastbound carriageway near Cape Town
200	5 to 12	Occurs on the Somerset West end of the N2
100	7 to 14	

there was no evidence of the HVS generating new cracks in the slab.

(i) The ultimate effects of HVS trafficking were to cause a breakdown of the concrete slab adjacent to the transverse joints into a number of individual blocks. These blocks, however, tended to remain locked into the pavement. However, under actual traffic rocking and faulting occurred.

(j) Increase in the wheel load increased the rapidity of disintegration of the slabs and also tended to increase the area of distress.

(k) The pavement was shown to be highly sensitive to overloads in the development of spalling. However, neither the initial degree of cracking nor the amount of preloading by normal traffic appeared to influence spalling significantly for the particular HVS sites studied.

(l) The effect of water is to increase the rate at which individual pieces of concrete are dislodged and to wash out the fines produced under the abrasive action of traffic.

(m) Water did not significantly affect the rate at which individual blocks broke loose (as illustrated in Figure 2).

7. CONCLUSIONS

The main objective of the experimental work was to estimate the potential life of the concrete road before major maintenance is needed. As a result of the alkali-aggregate reaction virtually the entire length of the road already exhibits degrees of cracking which equal or exceed those evaluated in the study described here. The HVS tests showed that spalling can be induced by either normal axle loads, or, at a much faster rate, by overloaded axle loads irrespective of the initial degree of cracking. Accordingly it is to be expected that all of the pavement is potentially liable to fail under traffic regardless of whether the alkali-aggregate reaction continues unchecked or abates. In this respect, it is important to note that the reaction has already caused sufficient damage to the entire pavement to facilitate failure by spalling if the traffic conditions in terms of either the overall intensity or the number of overloads are sufficiently unfavourable.

It has been determined that accelerated trafficking invariably leads to a loss in the structural capacity of the concrete slab, eg as expressed by the stiffness of the pavement. This occurs irrespective of whether the pavement is induced to spall or not. Here much of the traffic load is carried by the cement-treated subbase.

It has been shown that this subbase deteriorates under traffic especially where overloads above 60kN must be carried by the pavement.

Using the extent of spalling and basecourse deformation as equivalency criteria it was determined[11] that the exponent, n, in the AASHTO equation was 3,5 for the pavement of the concrete road. Applying this value to the data from those HVS tests in which failure occurred showed that the residual life of the pavement was between about 0,3 and 1,0 million equivalent 80 kN axle loads (E80). The estimated remaining life is given in Table 4. This suggests that the expected life of the pavement is between approximately two and five years for the most heavily trafficked sections. For the lightly trafficked areas, carrying only about 100 to 200 E80s/lane/day, the anticipated life of the pavement is between five and fourteen years.

ACKNOWLEDGEMENT

The authors wish to thank the Director of the National Institute for Transport and Road Research for permission to publish this paper.

DISCUSSION

Mr G H van Alphen (Hawkins, Hawkins and Osborne, Roggebaai, South Africa - Resident Engineer during construction of the N2 concrete pavement) commented that the 'as built' records did not agree with the figures which had been given in Table 1. The cement content of the cement treated base (CTB) was specified at 2,5 per cent and the average unconsolidated compressive strength at completion was 5,6 MPa ± 1,43 MPa. Deterioration of the CTB due to alkali-aggregate reaction was doubtful because, taking an alkali content of the cement of 0,85 per cent Na_2O equivalent the cement content of the CTB would have given too low an alkali content per m^3 to result in alkali-aggregate reaction. In Table 1 the concrete modulus of the slab was given as 3,73 MPa. He further asked what modulus had been used (referred to). The modulus of rupture during construction measured on 100 mm x 100 mm beams was in excess of 5 MPa.

Dr Freeme agreed that one of the difficulties in investigating these roads (which were about 10 years old) was to obtain comprehensive information about the original construction, especially if one had not been present at the time. His information had come from a report by Pienaar which was referenced in the paper. The cement content and strength of the CTB given by Mr van Alphen were probably more correct. He was aware of the cement content in the CTB but did not know whether there was in fact any alkali-aggregate reaction therein. Structural support from that pavement had deteriorated fairly markedly, and was not as strong as it had been originally. When the pavement was opened, the CTB was found to be fairly loose and friable; so that although he had not personally identified the alkali-aggregate reaction it could have existed in the CTB. Referring to the third question, he replied that it had been the modulus of rupture. This was again work which had been reported by Mr Pienaar. Members of Dr Freeme's Institute had not personally made any measurements and he understood it to have been the beam bending test. He could only assume that Mr Pienaar had taken these measurements himself and that they might have differed from some of the as-built records in this particular case.

Mr P A Myburgh (CPA, Department of Roads, Cape Town) noted that the thickness of the cement treated base on the shoulder had been reported as 125 mm while it was in fact 150 mm. He felt that the term 'life of pavement' was not correctly used and suggested that the end of this 'life' should be defined as when the road surface had, due to some distress mechanism, degenerated to a state where the safe passage of vehicles was no longer possible. He agreed that distress due to HVS testing closely resembled that due to actual traffic, but stressed that this occurred only in a narrowly confined zone. This type of distress posed only a minor maintenance problem, i.e. the removal of spalled material and patching, which was relatively inexpensive. At this stage he believed that for some time to come it would be possible to maintain this road at a high level of service at minimum cost, and, therefore, did not share the author's pessimism relating to the residual life of the pavement.

Dr Freeme replied that the thickness of the subbase at the shoulder of the pavement was reportedly different from the sections that were actually opened up and measured, i.e. 125 mm, and it would have been preferable to note the average thickness of the total pavement. The life of the pavement that had been used was defined as up to the level where blocks broke loose in the pavement and pieces of concrete started to pop out of the structure, and it was clear that by means of some simple rehabilitation, as had been shown in a few of the pictures, one could extend the overall life of the pavement far beyond that.

Dr P A Loudon (Van Niekerk, Kleyn and Edwards, Cape Town) asked what was the significance of the fact that cracks began at the joints and whether reinforcing would have reduced this occurrence.

Dr Freeme replied that the state of cracking in the pavement was sufficient for it to deteriorate however badly cracked it was at present. Reinforcing (as used in bridges) might have helped, but if water had been able to penetrate and corrosion had begun it would have been of little use. It may have extended the life by about 2 years, but would not have solved the long term problem. Structurally speaking, he was certain that as soon as the cracks had occurred and were sufficiently large to allow quite a large amount of water to get into the pavement, the steel would have started deteriorating at a fairly rapid rate. Thus using low alkali cement, not structural reinforcing, was clearly the answer.

Dr D E Davis (Portland Cement Institute, Halfway House) asked Dr Freeme to comment on whether the two directional effect of the heavy vehicle simulator would give unrealistic results in terms of actual single-direction traffic.

Dr Freeme said it was clear that the heavy vehicle simulator did accelerate the rate of deterioration of the pavement and thus there was not an exact equivalency between the HVS wheel loads and actual traffic. It was also clear from the traffic records that the concrete pavement itself was failing in exactly the same way as it failed under the HVS test, except at the very end where the blocks were being pulled out of the pavement. The heavy vehicle simulator could not simulate that action. In the sections that were tested afterwards which were opened up to traffic, those blocks were actually again pulled out by real traffic. The figures that were studied appeared to be fairly realistic in terms of the way the life of the pavement had been defined. The section from Cape Town to the Strand, for example, a year ago had not contained a section in which these little pieces of concrete had started to break loose. Currently almost every kilometre contained loose pieces of concrete, so it was clearly deteriorating at a similar rate to that obtained from heavy vehicle simulator tests.