REHABILITATION OF HEAVY DUTY CONCRETE PAVEMENTS WITH HYSON-CELLS OVERLAY

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INTRODUCTION

In container ports pavements are subjected to ultra heavy wheel loads that may greatly exceed those of highway trucks, but often fewer repetitions are applied. These pavements are typically termed heavy duty pavements.

The heavy duty pavement at the Transnet Container holding area at City Deep, Johannesburg had been in service for about 20 years and it showed severe cracking. The pavement was still serviceable and in operation, but rehabilitation or rebuilding had to be done in order to prevent the pavement from becoming unserviceable. . The pavement consisted of a 300mm concrete slab pavement and rebuilding of this pavement was an option, but it involved high expenditure. As the existing concrete pavement had severe block cracking, and in some areas even crocodile cracking, a concrete slab overlay would require a slab of substantial thickness to rehabilitate the pavement.

Concrete-filled geocells has shown substantial promise for new concrete pavements under ultra heavy loading conditions (Visser, 1999) and it was decided to investigate the suitability of these cells as a rehabilitation measure. The geocells, known as Hyson-Cells, offer three-dimensional interlocking cast in-situ blocks. It further offers resistance to slew caused by turning movements of heavy vehicles as well as resistance to the point loads of stacked containers.

Hyson-Cells differs from interlocking pavements in that it is cast in-situ and that interlocking takes place in a three dimensional direction. Models explaining the three dimensional interaction between the blocks are very complex and the structural and functional contribution of such an overlay can best be investigated by experimental techniques.

AIM AND SCOPE OF PAPER

The aim of this paper is present the investigation on the behaviour of concrete filled Hyson-Cells overlay placed on the deteriorated Portland cement concrete container terminal pavement and to evaluate the hypothesis that the overlay will improve the behaviour of the pavement. The secondary objective was to quantify any such improvement in terms of the pavement structural expected life, functional and structural parameters.
The paper presents the field experiment, which had to be conducted to determine the condition of the pavement before and after the construction of Hyson-Cells. After the construction of the overlays, the sections were instrumented with Multi-Depth Deflectometers (MDD) to evaluate the response of the different layers under wheel and container loads. The sections were used for normal

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operations and the wear and crack development were monitored as this defines the future functional performance.

Finally, the output from this experiment gave an indication of the structural strengthening of geocell overlays. In addition the expected future performance of the overlay in terms of expected life, wear and crushing resistance, and distress gave good results.

FIELD EXPERIMENT

Experimental area

An experimental section of 500 m^2 was selected to be representative of fairly severe deterioration at the City Deep container terminal. The area was still under operation and consisted of concrete slabs that roughly measured 5 m in length and 4 m in width. The thickness of the existing concrete slab was 300 mm.

The position of the experimental area was situated in such a way that it could easily be subjected to normal traffic after construction of the overlay. The construction activities did not have a great influence on the normal operations and container storage, since there was enough space to manoeuvre and store containers around the area. The rehabilitation layer thicknesses of 200 mm and 150 mm were contained in the 500 m^2 area. This layout of the two rehabilitation thicknesses was done in order to ensure that both the layer thicknesses were applied on panels with severe cracking (very poor condition) and deterioration, as well as on the less severely deteriorated area (poor condition).

A rail flange was bolted into the existing concrete and acted as an edge restraint. In order to allow heavy vehicle access onto the layer the test area was supplied with a concrete ramp around the perimeter. The ramp proved to be unacceptable for the normal cargo handling vehicle operations. This prevented the inclusion of normal loads onto the area therefore it is uncertain to what extent the pavement was subjected to normal operation after the experiment.

Level survey

In order to be able to evaluate the quality of the constructed overlay, a level survey was executed on the experimental area. It was evident from existing levels that the deterioration did not have an effect on the average gradient of the panels, except in one local area where punch-out of the cracked blocks occurred.

After the construction of the overlay, the area was surveyed once again. In the case of the newly constructed layers, the slopes were mostly maintained in the northerly direction. However, in some areas the slopes opposed the original slopes of the pavement and ponding could be expected.

The new layer did not improve the slopes in the east-west direction. Differences in slope of up to 2% between adjacent panels were found. This was as a result of the small-scale construction and difficulty with quality control on such a small area.

Crack survey

The severe deterioration of the pavement was evident from the amount of cracking shown in Photo 1. A crack survey was executed in order to determine the extent to which the slab had deteriorated. The positions of the cracks were noted in relation to the slab joints.

Photo 1. Example of cracks on existing container terminal concrete pavement.

The crack survey showed that the extent of cracking varied over the whole experimental section. The cracks were heavily spalled in most cases and can be classified as medium to wide cracks. The TMH9:1992 classifies the cracks on this pavement to a degree rating of 5 (open cracks with significant spalling) and a spacing category of medium to narrow. Medium cracks are assumed to have only partial aggregate interlock whereas wide cracks do not have useful interlock. The cracks had developed to a stage where the pavement can be regarded as a flexible pavement. Relative movement, pumping and stress on the subgrade are expected.

The crack survey after the construction revealed very little evidence of cracking in the Hyson-Cells blocks. Although the geocells results in a product that is artificially jointed, it was important to do an initial crack survey two months after the construction of the layer. This would give an indication of the amount of relative cracking that might take place in time. No evidence of any reflective cracking could be found during this field experiment. More extensive load applications could have resulted in crack deterioration.

A survey on the rehabilitation overlay was also conducted three years after the overlay construction. The degree of cracks according to the TMH 9:1992 is degree 1. These cracks are visible on all the edges of the blocks and some minor spalling was visible.

Dynamic Cone Penetration tests

Use was made of a Dynamic Cone Penetrometer (DCP) as a simple way of determining the characteristics of the underlying layers. Access was obtained to the underlying layers by drilling cores through the existing concrete surface before the construction of the rehabilitation layers. Results of six DCP tests were taken to a depth of 800mm before the construction of the geocell layer. Another two DCP test results were obtained to a depth of about 2m with the installation of the MDD.

Originally the pavement was an unbalanced pavement with the strength concentrated in the top of the pavement structure, the concrete layer. There has been significant deterioration and the strength in the top of the structure has been lost. Therefore the structure, excluding the concrete layer, could be qualified as a well to average and deep to inverted structure (Department of Transport, 1994).

From the DCP curves it was evident that on average the underlying granular material is consistent with a slight increase in stiffness with depth. There are no clear layer interfaces noticeable in the structure except at the contact zone up to 100 mm and 200 mm underneath the concrete layer at only one test hole.

Drilled cores

Cores were drilled from the existing concrete layer to allow for the DCP testing. Further core drilling had to be executed in order to install the MDD's. A secondary purpose of the core drilling was to evaluate the in-situ strength of the existing concrete layer. The drilled concrete cores could not be recovered intact and therefore no strength could be determined by compression testing. The fact that the cores did not stay intact again showed the severity of the concrete layer deterioration.

Overlay construction

The overlay was constructed during April and May 1998, with concrete mixes supplied from two local ready mixed concrete suppliers. The target strength of the mixes was 50 MPa. The average 7 day and 28 day compression strengths of the mixes were 40.7 MPa and 56.7 MPa respectively. Plasticiser admixtures were added on site to ensure a slump of at least 150 mm (Hall and Hall, 1999). The slump of the concrete mix had to be high to give the best workability of the concrete when it was placed. The concrete was then poured and hand worked into place without any vibration.

The area of the poured sections varied in size. Preparation and concrete suppliers mainly controlled the volume of concrete delivered, and thus the area covered. However, the widths were in the region of 3m to allow support for the final finish with a straight edge.

The surface finishes that were used were varied in order to show what different finishes could be delivered. In some areas of the overlay the finish was not acceptable due to fast setting, late delivery of concrete and poor workmanship. The finish was improved by means of a concrete grinding machine. This was done several days after placing the layer and proved to be the more expensive way of correcting the surface finish.

Depth deflection measurement

The pavement was instrumented with Multi-Depth Deflectometers (MDD) to measure the elastic deflection in the pavement layers due to loads. The modules were placed according to the expected pavement layer interfaces deduced from the DCP measurements. The instrumentation was done after construction on the rehabilitated area as well as on the original construction.

Known loads were applied to the surface in order to measure the deflections. Various configurations of loads were applied at various test sequences to these test holes. The type of load configurations used in this experiment were as follows:

- Tractor trailer with a 15ton container (3.6ton, 8ton and 10ton axle loads),
- Reach stacker with 6ton container (40.4ton and 26ton axle loads),
- Reach stacker with 21ton container (61.9ton and 19.5ton axle loads),

- Stacking of 21ton containers, 3 containers high (5.2ton, 10.3ton and 15.5ton per contact respectively).

This data was captured and used in the structural analysis and is discussed below.

Wear and crush resistance

The newly built layers were subjected to normal operational traffic to determine if wear and crushing as well as crack development occurred in order to further evaluate the functional performance. The influence of the point loads of the containers on the overlay was also investigated.

Few traffic loads were applied initially on the experimental section due to the difficulties experienced with access to the area. No wear and crushing resistance problems could be identified during those loadings because extended load applications would be needed to make a recommendation.

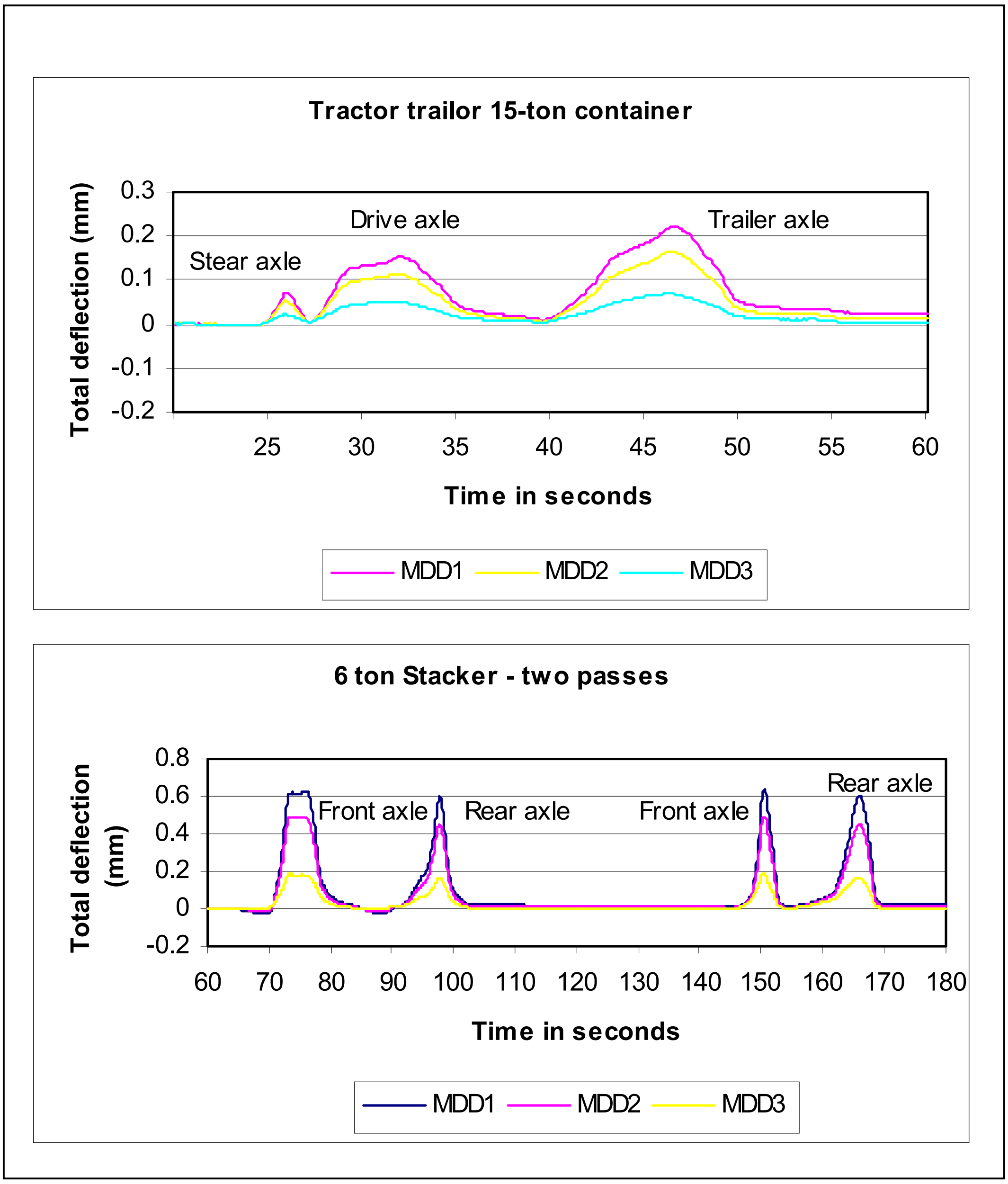

Figure 1: MDD deflection measurement for tractor-trailer with 15-ton container and 6-ton reach stacker [MDD1 at 125 mm, MDD2 at 380 mm, MDD3 at 710 mm depths]

FIELD OBSERVATIONS

Maximum deflection measurement

Figure 1 shows typical transient MDD data sets for the tractor-trailer and 6-ton reach stacker load configuration. Figure 2 shows the maximum deflection measurements obtained from the stacked 21-ton containers.

Figure 2 shows the typical maximum deflection measured with depth at the MDD nodes. From these results it was evident that the greatest contributing factors to high deflections are the reach stackers and point loads of the containers. The tractor-trailer combination gives deflections that compares well with typical normal heavy traffic on public roads.

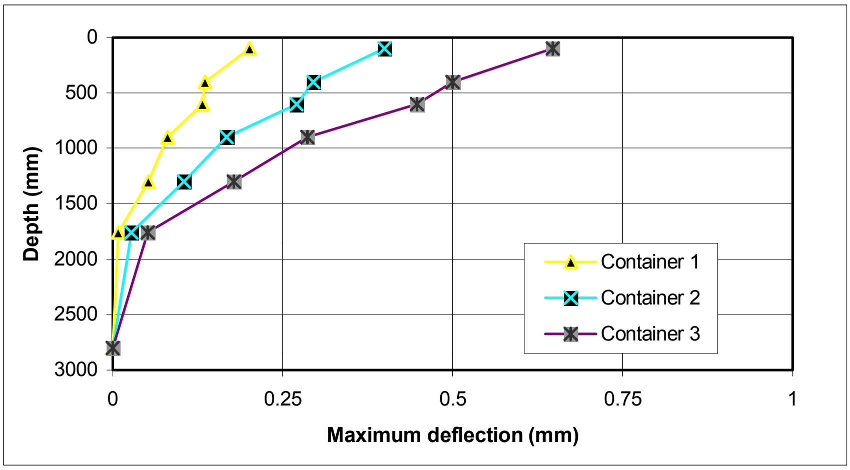

Figure 2: Maximum deflection under stacked containers of the 200 mm concrete filled Hyson-Cells overlay.

Observations and remarks with regards to these figures are as follows:

- It was assumed that the MDD anchor gives zero deflection, and maximum deflection occurs at the surface.
- The deflections show a peak as the vehicle wheel passes over the hole. This peak is the maximum deflection.
- The difference in deflection for different axle loads is visible.
- With the approach of the wheel a slight upward movement is noticeable before the load takes effect and positive deflection occurs. This occurs mainly at the shallow MDD's.
- Deflections almost return to zero after each load, which is an indication of elastic (recoverable) response of the soil. However, some plastic strain is visible when the last axle has passed.
- Except for tractor trailer the MDD depth deflection curves show high reduction in deflection with depth.
- The containers show remarkable deflection change when stacked on each other.
- The variation in deflection measurements between poor pavement condition compared with the very poor condition are evident.

DEFLECTION ANALYSIS

The maximum deflections were measured at depth on a typical 1.5 m pavement structure. The deflections under the stacked containers were used to compare the improvements of the rehabilitation as presented in Table 1.

Table 1. Comparison of improvement between the two overlay thicknesses

	Percentage reduction in deflection under three stacked containers	
Depth	**200 mm over very poor pavement**	**150 mm over very poor pavement**
150	41%	9%
450	35%	9%
750	37%	17%
1050	31%	12%
1350	8%	None
	Percentage improvement under two stacked containers for deflections	
Depth	**200 mm over very poor pavement**	**150 mm over very poor pavement**
150	60%	13%
450	53%	10%
750	54%	15%
1050	52%	9%
1350	35%	None

From the comparison listed in Table 1 it is clear that the 200 mm overlay contributed significantly to reduce the deflections in the underlying layers. Although the three containers are giving extreme high point loads, the 150mm overlaid pavement still gives good load spreading, which is particularly important for the deteriorated stabilised subbase layers.

Back calculation analysis

The depth-deflection data of the various holes were used to back calculate the stiffness of the various layers at each hole. ELSYM5 was used in the back calculation. The specific loads and their wheel configurations as they were applied on the various holes, are summarised as the input data in Table 2.

For each load application an initial estimated stiffness, i.e. the seed modulus, was used for each layer and the deflection calculated at the depth of the installed MDD's. These deflections, as a result of the estimated stiffness, were compared with the measured deflections and the stiffness was adjusted to find deflections that agreed with the measured deflections. The deflection at the anchor depth of the MDD's were assumed to be zero. In all the test holes except one, the calculated deflection agreed within 1 per cent of the measured values.

After the stiffnesses were determined, the bulk stress for each of the loads was determined in the middle of the layer. With depth the layer thickness increased significantly and the total stress may vary significantly within a specific layers. In order to determine whether the modulus of elasticity is stress dependent a plot was made with the resilient modulus (M_r) and total bulk stress (θ). A typical example of this relationship at Hole 2 is shown in Figure 3. With the stiffness stress relation plots, the stress dependency of each layer was investigated.

Poor correlation factors were found for the stress dependency, which suggested that there was no stress dependency of the underlying layers. The M_r for this pavement therefore was assumed to be constant for all load conditions and design M_r values were calculated as the average for each layer.

Table 2 Summary of loads and load configuration applied on the pavement

	Comment	Axle load (ton)	Wheels per axle	Load per wheel (kN)	Wheel spacing (mm)	Tyre press (MPa)	Contact Radius (mm)	MDD position to wheels/contact
Tractor Trailer	Front Axle	3.6	2	17.66	NA	0.7	NA	Under
	Drive Axle	8	4	19.62	350	0.7	NA	Between
	Trailing Axle	10	4	24.53	350	0.7	NA	Between
Reach Stacker (6ton container)	Front Axle	40.39	4	99.1	770	0.9	NA	Between
	Rear Axle	26	2	127.6	NA	0.9	NA	Under
Reach Stacker (21ton 2container)	Front Axle	61.87	4	151.7	770	0.9	NA	Between
	Rear Axle	19.54	2	95.8	NA	0.9	NA	Under
First container	Contact point	21	NA	NA	NA	NA	52.5	Under
Second container	Contact point	42	NA	NA	NA	NA	52.5	Under
Third container	Contact point	63	NA	NA	NA	NA	52.5	Under

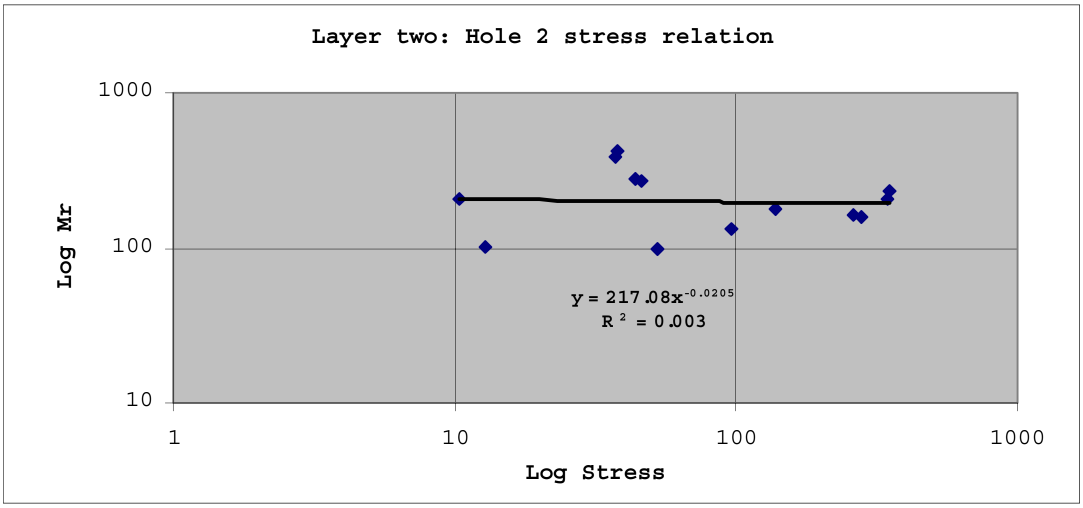

Figure 3: Hole 2:Log M_r and Log Stress relation for layer two (granular).

DETERMINING REHABILITATION PAVEMENT LIFE

In order to determine the estimated design M_r values, 1.5 m deep pavements were used as shown in Figure 4.

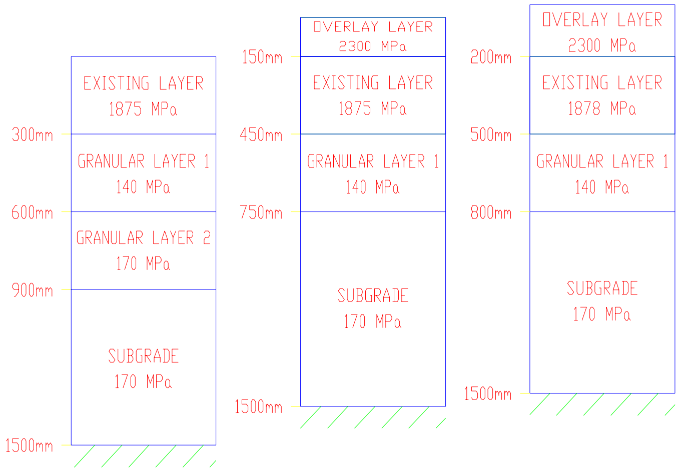

Figure 4. Standard pavement layout with design M_r values.

The design M_r values were obtained by averaging the back calculated effective mudulus values for each layer at the applicable holes. These values are shown in Table 3. The final design M_r values were obtained by averaging the averaged layer modulus values for all test holes. As shown the coefficient of variance is high. This is most probably due to material variability. From previous research an effective M_r of 2300 MPa was found as the modulus of concrete filled Hyson-Cells (Visser, 1999).

Table 3: Averaged M_r values

M_r (Mpa)	Hole 1 Original	Hole 2 Original	Hole 4	Hole 4a	Hole 6a	Average	Std. Deviation	Coeff. of variation
200mm overlay	NA	NA	NA	NA	2300	2300		
150mm overlay	NA	NA	7247	4948	NA	6098	1626	27
300mm existing concrete	3373	1258	633	374	3733	1874	1571	84
300mm granular layer 1	50	202	149	190	97	138	64	46
Granular layer 2	142	131	243	203	102	164	57	35
Granular layer 3	221	119	243	203	102	178	63	36

For each of the design pavements in Figure 4 the expected repetitions to 20 mm rutting were determined by using the South African Mechanistic Design Method (Maree and Freeme, 1981). This was done by using the design M_r values in ELSYM5 for each pavement. A vertical compressive strain was calculated at the various depths in the pavement and expected repetitions were obtained for before rehabilitation as well as for the different overlays. The axle load used for the calculation was that of the reach stacker front axle with a 21ton container. Thus the expected equivalent axle repetitions for the various levels are summarised in Table 4.

Table 4 Rehabilitation expected repetitions.

	NO REHABILITATION		150 mm OVERLAY		200 mm OVERLAY	
Depth below original pavement mm	**Vertical strain ($\mu\varepsilon$)**	**Expected repetitions**	**Vertical strain ($\mu\varepsilon$)**	**Expected repetitions**	**Vertical strain ($\mu\varepsilon$)**	**Expected repetitions**
300	1322.0	1.81*E05	773.6	3.84*E07	671.7	1.58*E08
600	708.8	9.22*E07	488.5	3.81*E09	441.1	1.06*E10
900	549.5	1.17*E09	386.1	4.01*E10	349.2	1.09*E11

Studying Table 4 the following is noted:

- In all three cases the critical layer is the layer directly under the original concrete layer. This layer was originally stabilised but had broken down and is in an equivalent granular state.
- If the "do nothing" option is chosen the pavement may provide another 181 000 repetitions of the reach stacker to a rut depth of 20mm. This failure criterion had already been reached and forms the reason for this research.
- The 150mm overlay offers another expected 38 million repetitions to a rut depth of 20 mm.
- The 200mm overlay offers another expected 158 million repetitions to a rut depth of 20 mm.

CONCLUSIONS

The hypothesis that a concrete filled Hyson-Cells overlay leads to improved behaviour of the pavement is accepted. It was clearly demonstrated that both thicknesses of Hyson-Cells layers resulted in lower deflections and strains in the pavement compared with similar load conditions without the overlay.

The level of improvement may be quantified. It was shown that the 150mm Hyson-Cells overlay resulted in a slight reduction in deflection. In contrast the 200mm overlay resulted in a significant reduction in deflection on the same pavement.

A back analysis was conducted using the measured data and the ELSYM5 elastic layer programme to determine the in-situ stiffness values. Low correlation coefficients were obtained for stiffness plotted against stress level. This suggested that the materials in the pavement were not stress dependent, and the same design stiffness values could be used for all loads.

By using the stiffness values, the remaining life of the deteriorated pavement was compared with the rehabilitated pavements. A significant improvement of pavement life to 38 and 158 million reach stacker repetitions was found for the 150 and 200 mm overlay thicknesses respectively.

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Background: Bennie Du Plessis

Bennie graduated at the University of Pretoria in 1995 after which he gained experience in the road construction in the Free State Provincial Government. He briefly spent time in the consulting industry before enrolling for his Masters degree in civil engineering at the University of Pretoria, directing his attention towards pavements. During his full time studies he was also involved in geotechnical laboratory test work and did some part time lecturing at the University. After being in the academic environment for three years he re-entered the consulting industry joined Stewart Scott in 2001.