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Confidential Contract Report CR-2002/81

March 2003

**First Level Analysis Report:  
Comparative Testing of HVS Mk IV+  
and HVS Mk III on Road D2388 near  
Cullinan**

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Comparative Testing of HVS  
Mk IV+ and HVS Mk III on  
Road D2388 near Cullinan**

Version: Final report

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**DOCUMENT RETRIEVAL PAGE****Report No:** CR-2002/81**Title:** First Level Analysis Report: Comparative Testing of HVS Mk IV+ and HVS Mk III on Road D2388 near Cullinan.**Authors:** B S Morton and H L Theyse

<b>Client:</b> Gautrans	<b>Client Report No:</b>	<b>Date:</b> March 2003	<b>Distribution:</b> Restricted
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<b>Project No:</b> TIJ75	<b>OE2:</b> 9431 - Infrastructure Engineering	<b>ISBN:</b>
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**Abstract:**


After many years of owning and operating a Heavy Vehicle Simulator (HVS) Mk III, Gautrans acquired a HVS Mk IV+ in May 2002. In addition to the advanced features that this machine possesses in comparison to its predecessor, the HVS Mk IV+ also has certain operational advantages that will make it more efficient than the Mk III. The HVS Mk IV+ will be utilised in all future Accelerated Pavement Testing (APT) operations undertaken by Gautrans. The differences between the two machines could, however, result in variations in pavement response and test results. Based on this concern and in an effort to ensure uniformity throughout APT with the HVS, a comparative testing project was initiated to compare the effect of the two machines on pavement response.

Differences in the pavement response induced by the HVS Mk III and HVS Mk IV+ may be caused by differences in the trafficking speed of the machines (loading frequency), differences in the total load applied by the machines and differences in the contact stresses applied by different tyre brands and tyre widths used on the two machines. An attempt was made to eliminate the effect of total load by developing total load calibration curves for the two HVSs prior to comparative testing.

The procedure followed during the comparative testing was to identify two test sections for testing. These test sections were subjected to trafficking by each of the HVSs until elastic and plastic response trends could be established for both test sections. The machines were then swapped and trafficking continued until the new elastic and plastic pavement response trends could confidently be compared to the original response trends.

Small but consistent changes in the elastic deflection were observed when the machines were swapped but these changes were too small to influence the interpretation of the elastic response results under normal testing conditions. The changes in the permanent deformation response that were observed when the machines were swapped are of greater concern and could lead to different conclusions regarding the bearing capacity of the test pavement. It is, however, suspected that the observed differences in pavement response could be caused by differences in the applied total load and contact stresses at the operational trafficking speeds of the machines. Further work is recommended to investigate this.

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The views and opinions expressed in this document are those of the authors and do not necessarily represent the views or policy of CSIR Transportek.

## REVIEW STATEMENT

This report has been reviewed internally by CSIR Transportek, and externally by the client, Gautrans.

## GENERIC CONTENTS OF THE FIRST AND SECOND LEVEL HVS ANALYSIS REPORTS

In accordance with the agreement between Gautrans and CSIR Transportek the contents of the first, second and third level analysis reports for HVS testing are defined as follows:

The primary purpose of a first level HVS report is to present a complete and validated set of HVS data without detailed analysis and interpretation of the data. The scope of a first level report is confined to the HVS data and associated test results from a single HVS site. The conclusions of the first level report are therefore site specific with little interpretation and should not be generalised. The primary aim of the second level analysis report is to interpret and explain the observed behaviour contained in the first level report. By combining the results from a number of test sites or combining the HVS and associated test results with data from other case studies on the same material and pavement type, it is possible to determine whether the observed response and behaviour are representative of the response and behaviour of the material and pavement type in general. However, if any pavement behaviour or design models are developed during the second level analysis, their scope is limited to the particular HVS site under investigation. The content of the third level analysis is similar to that of the second level analysis, but the data that were generated from HVS and associated testing on a number of sites are combined to develop general behaviour and design models for the material or pavement type under investigation.

### 1. First Level Report

The final first level report, on the basis of a single HVS test, or of a number of tests combined into a single phase of a larger project, should build on the data from the monthly technical meeting with the purpose of:

- Providing recommendations on the resilient modulus values of the materials in the pavement structure being tested;
- Providing recommendations on the durability of the materials used in the construction of the test section;
- Identifying, if possible, the modes of distress for the particular pavement and materials being tested;
- Identifying, if possible, the most critical mode of distress, which is the mode of failure;
- Quantifying, if possible, the load sensitivity and bearing capacity of the pavement and materials for each mode of distress, preferably with some indication of the variability to be associated with these parameters. The load sensitivity and bearing capacity are only quantified for the load levels at which the tests were done. No general design models

are developed in terms of applied stresses and strains as these form part of the second and third level analyses.

In accordance with the agreement between Gautrans and CSIR Transportek, the contents of the monthly technical presentations should be the same as for the first level HVS report. The monthly technical presentations should, with the additional interpretations of the coordinating committee, form the basis for the first level report. The following guidelines were therefore set for the preparation of the monthly technical presentations:

- Visual condition information
  - At least one composite photograph showing the crack pattern that developed;
  - Any additional visual information of interest from the surface of the test section or from the test pit.
- Surface instrumentation data
  - Average Road Surface Deflectometer (RSD) data, plotted for the duration of the test, with any change in test conditions being indicated on the graph;
  - Average straightedge rut data, plotted for the duration of the test with any change in test conditions being indicated on the graph;
  - Average Profilometer rut, plotted for the duration of the test with any change in test conditions being indicated on the graph;
  - RSD data plotted along the length of the section;
  - Deflection bowl parameters, calculated from the RSD data and plotted along the length of the test section; and
  - Straightedge and Profilometer rut, plotted across the width of the section.
- Depth instrumentation data
  - Elastic depth deflections
    - plotted against the number of load repetitions for the duration of the test with any change in test conditions indicated on the graph;
    - plotted against depth in the pavement structure.
  - Back-calculated resilient modulus values plotted on separate graphs for each of the individual pavement layers for the duration of the test, with any change in test conditions being indicated on the graph.
  - Permanent MDD displacements
    - Plotted against the number of load repetitions for the duration of the test, with any change in test conditions being indicated on the graph;
    - Plotted against depth in the pavement structure, with an indication of the relative contribution of the individual pavement layers to the total permanent deformation.
- Additional material, environmental and operational information
  - Nuclear gauge density and moisture content profiles as per test instrumentation plan;
  - Temperature data as per test instrumentation plan (thermocouples and temperature buttons);
  - Tyre temperature and pressure data;
  - Dynamic Cone Penetrometer (DCP) data for completed DCP tests outside the test section; and
  - Visual, density, moisture content and DCP data for the test section and test pit after completion of an HVS test. This will only be presented at the technical meeting after the completion of a specific HVS test.

Additional work that may be required to address the aims of the first level report may include:

- Regression modelling of the straightedge rut, Profilometer rut and permanent MDD displacement data to quantify the pavement and layer bearing capacities in terms of permanent deformation;
- Bowl parameter analysis in conjunction with back-calculation results to quantify the pavement bearing capacity in terms of effective fatigue, if it is a valid distress mode for the pavement; and
- DCP analysis to classify the pavement and to detect permanent changes in the pavement under repeated loading.

## **2. Second Level Report**

The aims of the second level report are:

- To interpret and explain the response and behaviour contained in the first level report;
- To develop site-specific response and behaviour models for the material or pavement type being investigated, based on the data from one site. These models are calibrated in terms of the stresses and strains imposed on the pavement during HVS testing, whereas the first level report only quantifies the resilient modulus, load sensitivity and bearing capacity for the particular wheel loads at which the HVS tests were done;
- To evaluate the representativeness of the results from the specific site by comparing the HVS and associated test results with similar results from studies done in other locations.

The data from different phases of HVS testing, done at different wheel-loads and moisture conditions on the same site, are combined to achieve the goals of the second level report.

The second level report should attempt to:

- Provide site-specific resilient modulus models for the materials being investigated;
- Provide site-specific pavement response and structural design models (transfer functions) for the modes of distress of the materials being investigated. These models should accommodate the variability of the data that were used to develop the models and should be calibrated for the relevant imposed stress or strain conditions and not only for wheel load;
- Provide guidelines on sound engineering design and construction principles for the materials being investigated; and
- Make conclusions and give guidelines regarding the durability of the materials being investigated.

The second level report should make use of all available data to be able to reach these objectives including:

- The HVS and associated (DCP, nuclear gauge, temperature, etc.) field-test data;
- Standard and advanced laboratory test data associated with the HVS site; and
- Results from other full-scale or laboratory case studies.

## **3. Third Level Report**

The objectives and content of the third level report are the same as those of the second level report but with the aim of developing generalised response and design models. The HVS and associated test data from a number of HVS sites done in different locations and using different materials of the same material type are combined for the third level analysis.

## REFERENCE TO THE HVS DATABASE

The electronic data collected from HVS tests are stored in the HVS database. The contact person for access to the HVS database is:

Name: Mr Colin Fisher  
Contact details: Phone No: (012) 841-3960  
Fax No: (012) 841-2690  
E-mail: Cfisher@CSIR.co.za

The database consists of text files, pavement section details, Multi-Depth Deflectometer (MDD), Permanent Deformation (PD), Road Surface Deflectometer (RSD), Straightedge Rut and Profilometer (PRF) Rut data.

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# 1. INTRODUCTION

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## 1.1. Background to the Project

After many years of owning and operating a Heavy Vehicle Simulator (HVS) Mk III, Gautrans acquired a HVS Mk IV+ in May 2002. In addition to the advanced features that this machine possesses in comparison to its predecessor, the HVS Mk IV+ also has certain operational advantages that will make it more efficient than the Mk III. The HVS Mk IV+ will be utilised in all Accelerated Pavement Testing (APT) operations undertaken by Gautrans in the future. The differences between the two machines could, however, result in variations in pavement response and test results. Based upon this concern and in an effort to ensure uniformity throughout APT with the HVS, a project was initiated to compare the effect of the two machines on pavement response.

An existing HVS test site on Road D2388 near Cullinan was selected for the comparative testing project. Ten experimental sections had previously been tested using the HVS Mk III on the test site. These sections formed part of a project for the assessment of the viability of Labour-Intensive Construction (LIC) of pavement base layers. Construction took place during early 1997, and all ten sections were tested during the period July 1997 to September 1998 (Mancotywa, 2001).

The 100 mm crushed stone base experimental section was selected as the test pavement structure that would be utilised for the comparative testing. This pavement was used as a control section during the investigation of LIC pavements. Initially it was proposed to make use of the 100 mm thick emulsion treated gravel experimental section for the comparative testing. Based on deflection data and visual inspection of the experimental sections, as well as practical considerations with respect to the location of the previous HVS test sections, the decision was taken to make use of the G2 control pavement for the project. Due to the location of the initial ETB test section, the two sections for the comparative testing would have been located at the opposite ends of the ETB test pavement. This would cause major difficulties relating to data collection and supervision of both HVS machines by one HVS operating crew.

The objective of the project was to evaluate the effect on pavement performance of a number of variables that differ between the machines. The main variables that could influence the pavement performance results can be summarised as follows:

1. The total load applied by the two HVS machines;
2. The trafficking speed and associated number of repetitions applied per time period;
3. The contact stress magnitude and patterns applied by the trafficking tyres fitted to the two machines.

The project consisted of parallel testing between the HVS Mk IV+ and the HVS Mk III to address the effect of the first two variables listed above. The effect of different contact stresses was not addressed by the current project and a separate proposal will be prepared for such an investigation based on the recommendations from the comparative testing.

The test program consisted of two tasks. The first task was to develop load calibration curves for the two machines that would be used during the HVS testing to ensure uniformity in the total load. The Vehicle Load Monitor (VLM) was used for this calibration. The second task was parallel testing on two test sections (413A4/A5 and 414A5/A4) on the 100 mm G2 crushed stone base experimental section at the Cullinan test site. The calibration curves developed in the first task were utilised to eliminate load as a variable during the parallel testing. The test program consisted of two stages. During the first stage the machines were operated at their normal operating speeds on the two selected test sections. Once a linear response pattern had been established on both sections the machines were swapped on the test sections. Testing was continued at the normal operating speed of each machine, until the linear performance trends had been satisfactory established for the second stage of testing.

All parallel testing was performed in dry conditions, with 471 497 repetitions being applied during the first stage of testing. An additional 228 503 repetitions were applied during the second stage of testing. Based on the calibration curves developed in task 1, HVS Mk IV+ was set at a 66 kN dual wheel load and a tyre pressure of 646 kPa, while HVS Mk III was set at a 62 kN dual wheel load and a tyre pressure of 690 kPa. These setting should, according to the calibration, have resulted in an equally applied load of 60 kN for both machines. The trafficking load and tyre pressure remained constant at these values for each machine, irrespective of the test section under trafficking.

Testing commenced on 11 June 2002 with the HVS Mk III machine, operating at the standard trafficking speed of 5.6 km/h on test section 413A4/A5. The HVS Mk IV+ commenced operation on test section 414A5/A4 on 2 July 2002. Trafficking speed of the HVS Mk IV+ varied between 9 and 10 km/h depending on the productivity of the two machines and to ensure that at the time of swapping the machines, both machines had completed the same number of repetitions. HVS testing was completed on 19 August 2002 by HVS Mk IV+ and on 28 August 2002 by HVS Mk III.

Generally the HVS test section is assigned a specific number indicating which HVS unit was utilised in the testing of the particular section. In such a test program the test section tested using the HVS Mk III the suffix of "A4" would be assigned to the test section number during the first stage of HVS testing. The HVS Mk IV+ test sections would be identified with an "A5" suffix. In this particular project both the HVS Mk III and HVS Mk IV+ machines were used to traffic both the test sections during the comparative testing task, and thus the suffixes have been altered to include the trafficking of both machines as part of the test section notation. The test sections are thus identified as 413A4/A5 and 414A5/A4, respectively. Table 1 contains a summary indicating which HVS machine trafficked each of the test sections during specified time periods in addition to the loading detail and trafficking speed.

HVS Type	Section Number	Trafficking Load	Contact stress	Trafficking speed	Repetitions	Date of Trafficking
Mk III	413A4/A5	62 kN	690 kPa	5.6 km/h	471 497	11/06 - 04/08
	414A5/A4	62 kN	690 kPa	5.6 km/h	228 503	05/08 - 28/08
Mk IV+	414A5/A4	66 kN	646 kPa	9 - 10 km/h	471 497	02/07 - 04/08
	413A4/A5	66 kN	646 kPa	9 - 10 km/h	228 503	05/08 - 19/08

## 1.2. Structure of the Report

This report has the specific objective to compare trends in the behaviour of each of two test sections (413A4/A5 and 414A5/A4) while being subjected to traffic loading by each of the two HVSs in turn. It should be noted that due to the nature of the comparative testing program implemented for this project, the approach to the analysis and interpretation of the data recorded during testing varies from the approach followed for standard HVS tests. The aim of HVS testing is usually to characterise the structural behaviour and performance of the pavement materials and the pavement structure under investigation. The usual approach to the analysis and interpretation of the data would therefore be to enable conclusions to be drawn regarding the behaviour, characteristics and distress of the pavement materials and pavement structure. However, in this report, the focus is on a comparison of the response parameters measured during HVS testing of the two test sections using the HVS Mk III and Mk IV+.

The report presents a comprehensive record of the validated data collected from HVS tests 413A4/A5 and 414A5/A4. Firstly, the general background information is provided. This includes aspects such as:

- The layout, pavement structure and description of the experimental sections;
- Material and construction quality of the test sections;
- Test section location which includes:
  - Elastic surface deflection measurements
  - HVS test positions
- A summary of the instrumentation of the test sections.

The background information is followed by the presentation of the detailed data collected during the HVS tests including:

- Operational data (pavement temperature, tyre temperature and pressure, etc.);
- Moisture content and density data;
- Surface deflection measurements;
- Surface rutting measurements;
- Elastic depth deflection; and
- Permanent deformation measurements.

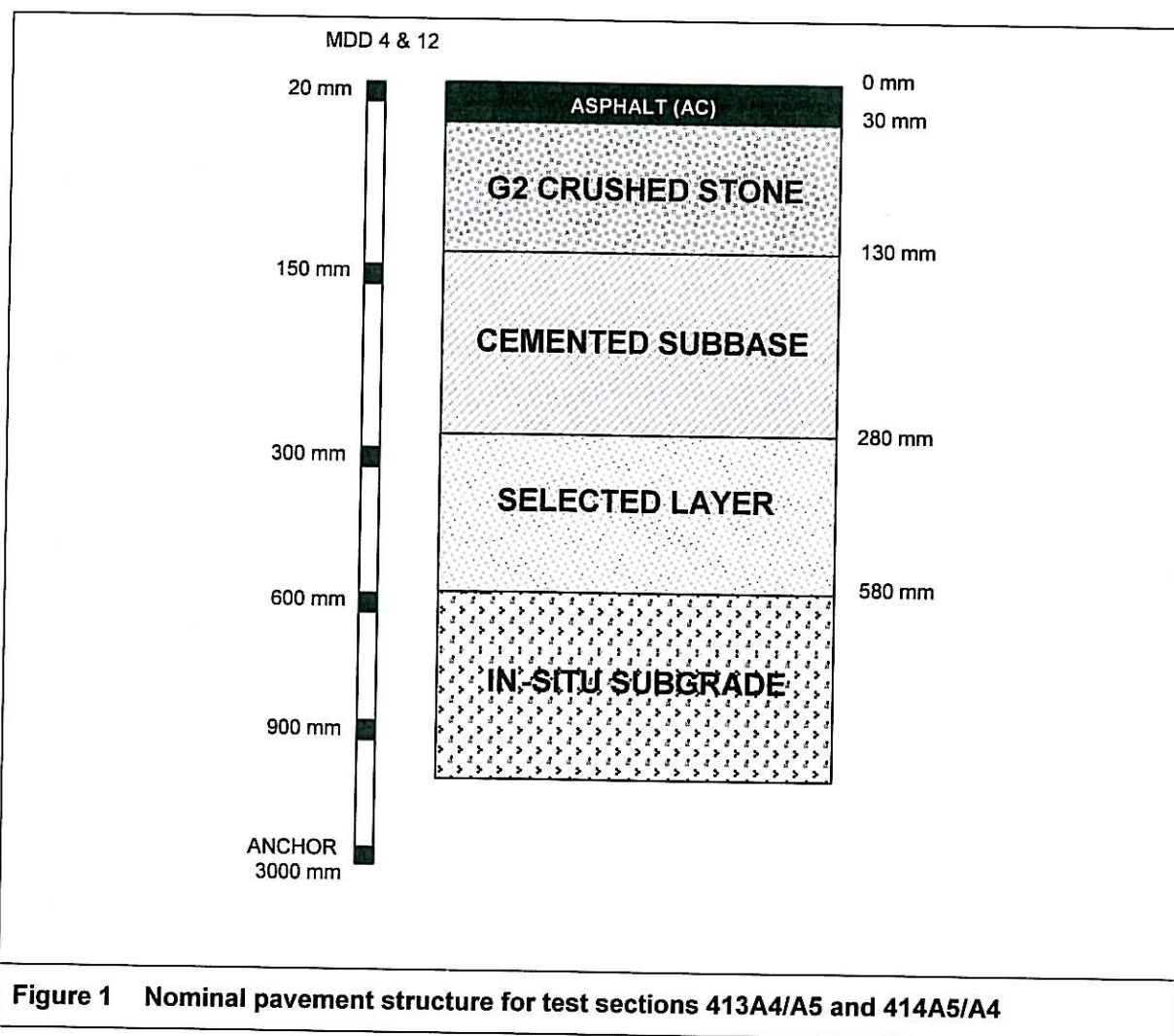
Since the main objective of this project is to compare the pavement response produced by the HVS Mk IV+ and HVS Mk III, interpretation of the results will be limited to the comparison of the performance trends established by the HVS tests. No interpretation of the pavement strength characteristics, the distress mechanisms or the durability of the material will be undertaken in circumstances where they do not have a direct effect on the comparison of the two machines. However, all data recorded during the testing will be

included so as to provide a complete account of the HVS tests and the pavement response, such that these data can be used at a future date if such analysis is deemed pertinent.

## 2. GENERAL ASPECTS AND TEST CONDITIONS

### 2.1. Pavement Structure of the Test Section

The HVS testing was conducted on the previous LIC experimental section constructed near Cullinan on Road D2388. The 100 mm crushed stone control pavement was utilised for the two test sections needed for comparative testing. The test sections were located between chainage positions 2.530 km and 2.625 km. The upper pavement structure consisted of a 30 mm dense graded asphalt wearing course and the 100 mm G2 crushed stone base. The underlying layers consisted of a 150 mm cemented subbase and a sandstone selected layer. Figure 1 illustrates the nominal pavement structure of both the test sections as well as the positioning of the Multi-depth Deflectometer (MDD) modules within the pavement structure. A detailed description of the pavement structure for this experimental section can be found in CR99/011 (Mancotywa, 2001).



## 2.2. Materials of the Test Sections

Due to the nature of the comparative test program, and since the construction materials of the experimental section had previously undergone extensive laboratory testing, no materials testing was conducted during this project. Tables 2 and 3 are extracts from Theyse, 1997 summarising the average material properties over the total length of the crushed stone experimental section. The field compaction is expressed in terms of percentage of the maximum dry density (mDD) from modified AASHTO compaction, except for the crushed stone for which the field compaction is expressed in terms of the Bulk Density (BD).

Material	Layer thickness (mm)	Laboratory density and OMC		Field density, compaction and moisture content		
		mDD/BD (kg/m <sup>3</sup> )	OMC (%)	Dry density (kg/m <sup>3</sup> )	Compaction (%)	MC (%)
Crushed Stone	100	2188 (mDD) 2565 (BD)	7.5	2157	98.5 <sup>1</sup> 84.1 <sup>2</sup>	3.6
Sandstone conglomerate (selected layers and subbase)	300	2155	7.1	2150	99.8 <sup>1</sup>	5

<sup>1</sup> percent of mDD

<sup>2</sup> percent of BD

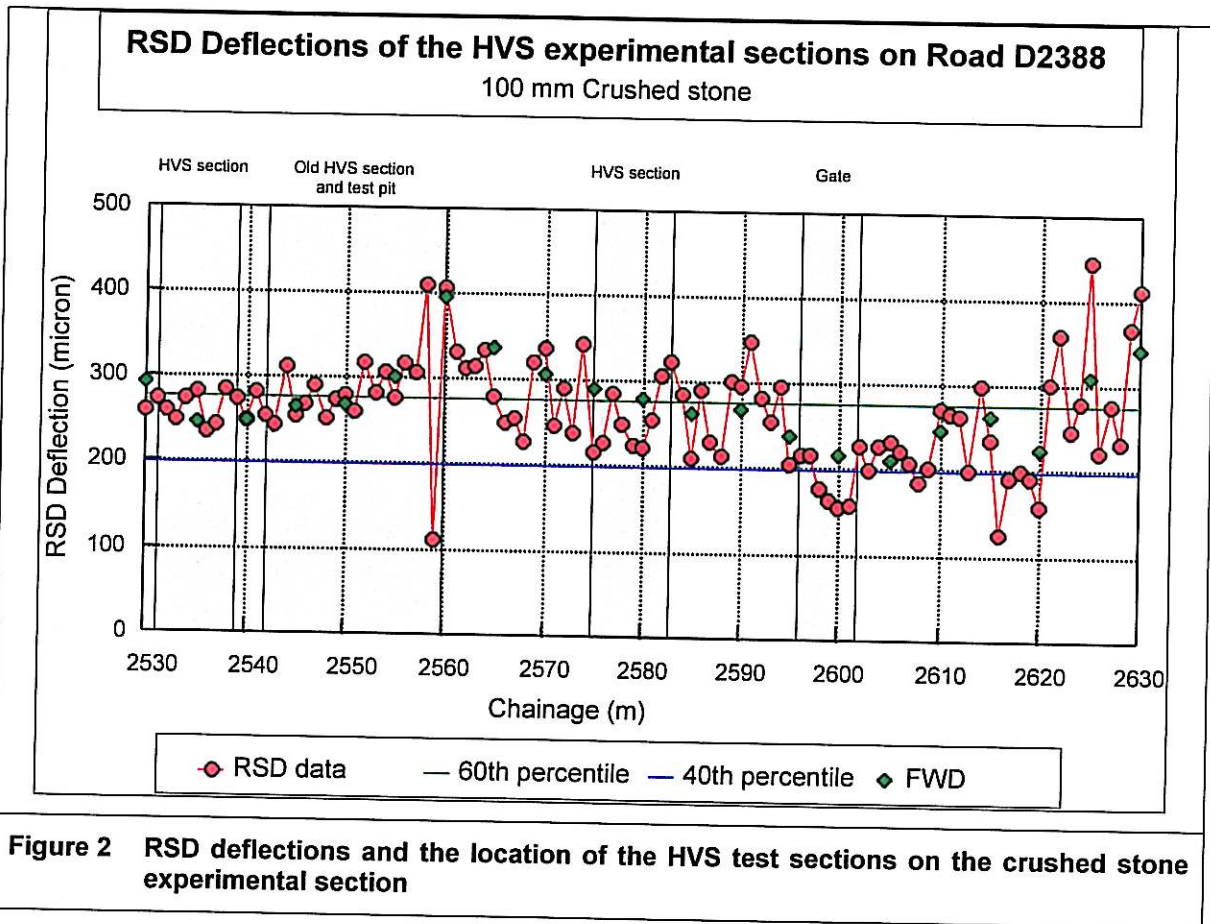
	Laboratory compaction (%)	CBR (%)	UCS (kPa)
Crushed Stone	98	111%	-
Cement-treated sandstone conglomerate subbase	97	-	1940 kPa
Sandstone conglomerate selected layers (km 2,43 to 2,76)	98	79%	-

It is evident from Tables 2 and 3 that the selected and subbase layers were all compacted to densities in excess of the design specification for these layers. The crushed stone base layer, which was intended to be a G1 layer, did not satisfy the density requirement for a G1 (86 % of AD) or a G2 (100 to 102 % mod AASHTO maximum dry density) and is classified as a G3 base layer based on the data in Table 2. This classification is revised in the next section of this report based on the density data collected at the two test sections during HVS testing.

## 2.3. Test Section Selection

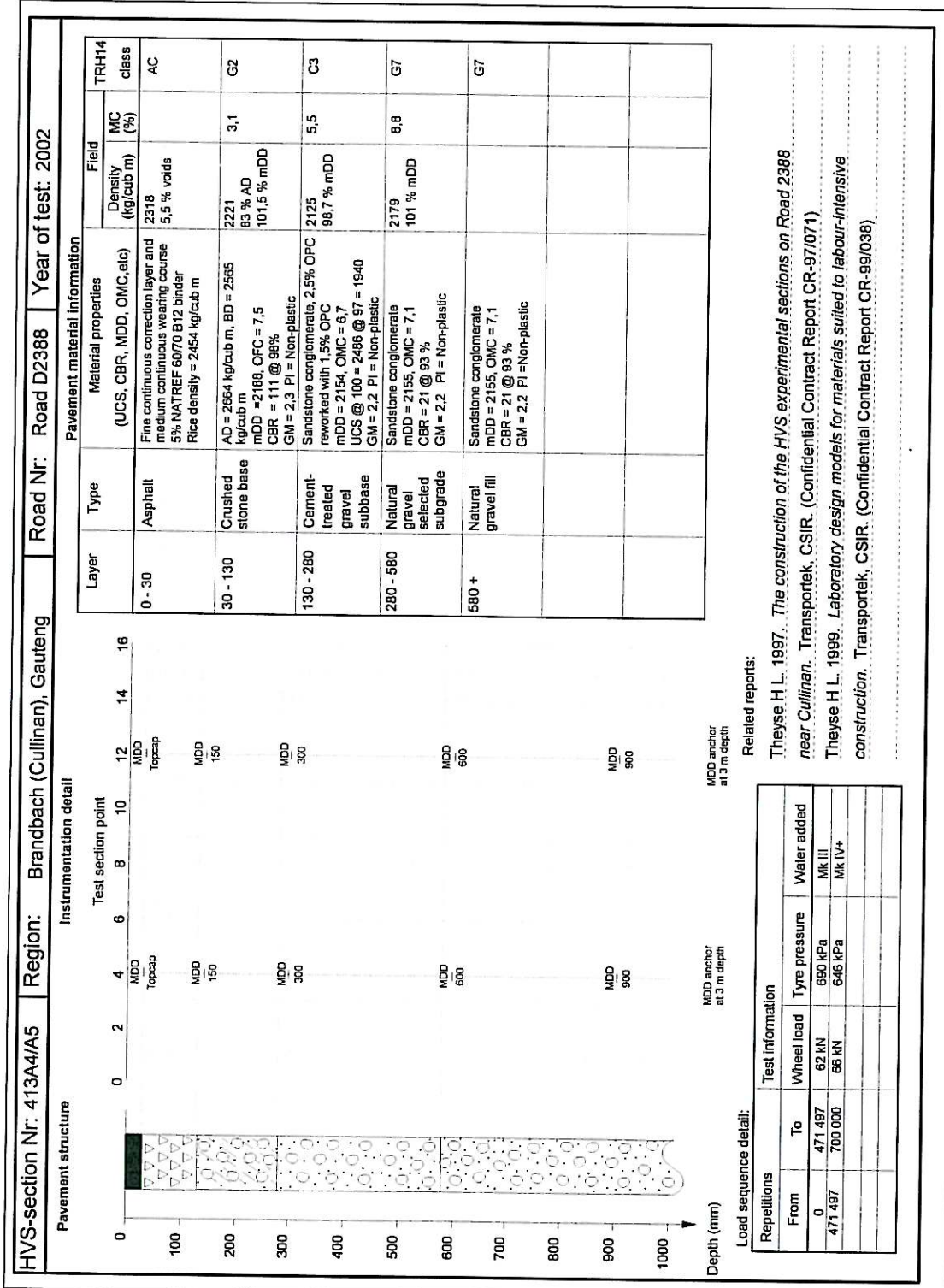
Initially the 100 mm ETB test pavement was selected for testing, but was discarded due to logistical problems of locating two HVS machines on two uniform test sections within the experimental ETB pavement section. The alternative test sections on the 100 mm crushed stone base pavement were thus used for the comparative testing. Figure 2 shows the road surface deflection from RSD testing in 1997 and the location of the HVS test sections. The initial HVS test section 398A4, tested during the LIC project, was located between 2548 and 2556 m. HVS test section 413A4/A5 was located between 2531 and 2539 m, while test section 414A5/A4 was located between 2575 and 2583 m.





#### 2.4. Summary of the Pavement and Instrumentation Detail of the Test Sections

The summary sheets presented in Figures 3 and 4 show the Multi-Depth Deflectometer (MDD) instrumentation detail and the material properties for test sections 413A4/A5 and 414A5/A4. The material properties are based on the results obtained from extracts of Theyse, 1997 but the dry density and moisture content results were calculated from the strata gauge readings taken during HVS testing. These density results indicate a higher density for the base layer of the two HVS test sections than the average reported for the full length of the crushed stone experimental section (Table 2). The crushed stone base layer of the HVS test sections is therefore classified as a G2 material based on the strata gauge readings as apposed to the G3 classification based on the results from Table 2. The MMD module levels were chosen so as to approximately coincide with the pavement layer interfaces. The physical size of the MDD modules limited the minimum distance between modules to 130 mm. Thermocouples were installed in test sections 413A4/A5 and 414A5/A4 at depths of 0 and 25 mm, on both the traffic and caravan sides, at points 4 and 12 (See Figure 5). The loading sequence, which consists of the load repetitions at which test conditions were changed, is also shown in Figures 3 and 4.

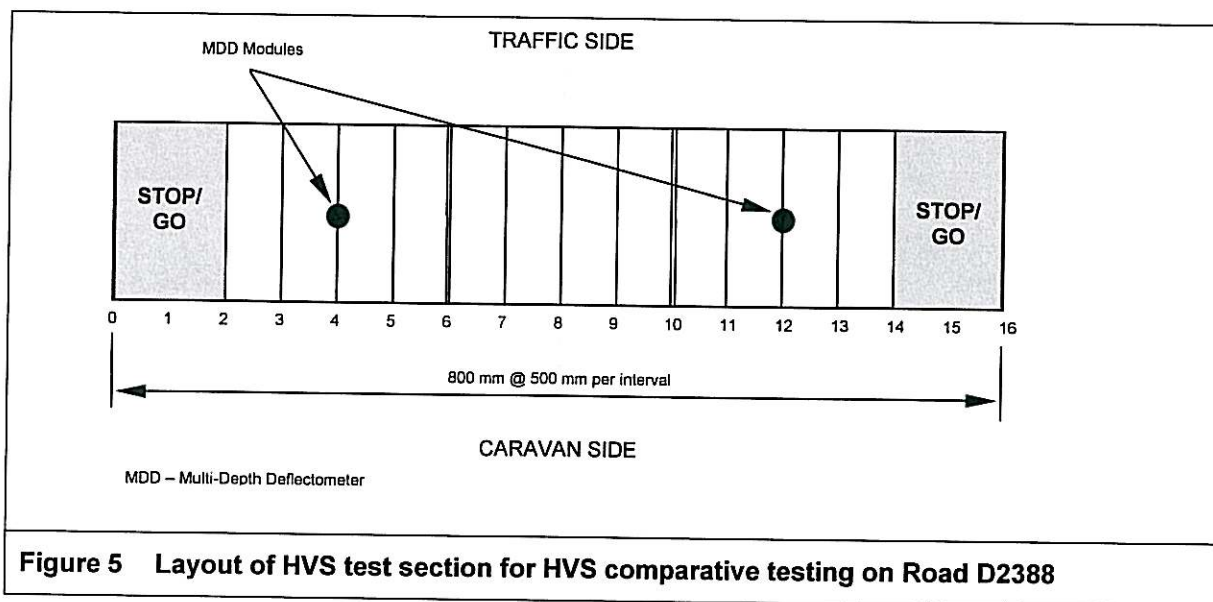


**Figure 3** Details of the structural, instrumentation and load sequence information for HVS test 413A4/A5



## 2.5. Typical Layout of a Test Section

The general instrumentation layout for an HVS test section consists of three MDD stacks, positioned at points 4, 8 and 12 along the centreline of the 1 m wide test section (See Figure 5). In test sections 413A4/A5 and 414A5/A4 only two MDD stacks were installed in each section at points 4 and 12 respectively.



**Figure 5** Layout of HVS test section for HVS comparative testing on Road D2388

### 3. HVS TESTS RESULTS

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This chapter presents the validated and processed data from HVS tests 413A4/A5 and 414A5/A4. Firstly general information that is not specific to either test section is presented. Included in this discussion is an explanation of how MMD depth deflection data are analysed. These explanations are included since such analyses of depth deflection data are not standard pavement engineering procedures. Thereafter the validated data for each of the test sections is presented. Comparisons, made between the results of the validated data, are made in Chapter 4 of this document. A deviation from the standard 1<sup>st</sup> level analysis method is the inclusion of a comparison of the performance of the HVS Mk IV+ and HVS Mk III, in terms of production performance and pavement response performance. This comparison is included in Chapter 5.

The data from each of the HVS test sections are presented according to the following outline:

- Operational and environmental data
  - Tyre Data;
  - Rainfall and temperature data, and
  - Density and moisture content data.
- Surface response parameters
  - Visual distress;
  - Surface deflection data from the Road Surface Deflectometer (RSD), and
  - Rut data from straight edge and Laser Profilometer measurements.
- Depth response parameters
  - Depth deflection data from the MDD, and
  - MDD permanent displacement;

As mentioned previously, the main objective of the test program was to compare the variation in pavement response under HVS Mk IV+ and HVS Mk III loading. As a result, limited amounts of data were collected in terms of tyre pressure and temperature; rainfall and ambient and ambient temperature data. Since the test sections were located less than 50 meters apart, temperature data was collected on the HVS MK IV+ only.

Each machine operated using the tyres prescribed for the machine. The HVS Mk IV+ operated on 12R22.5 Goodyear tyres while the HVS Mk III operated on 11R22.5 Continental tyres. The variation in tyre size and specifications necessitated a variation in tyre pressure during testing to conform to the recommendations of the tyre supplier. The HVS Mk III is not equipped with tyre temperature and pressure transducers and thus tyre pressure and temperature data was collected only for the HVS Mk IV+. It should be noted that although the tyre type and pressure differed between HVS Mk III and HVS Mk IV+, the project was not planned in such a way as to enable the effect of these variables to be isolated from the results. The pavement performance results should therefore be viewed with this variation in mind. The differences in tyre contact pressures between the HVS Mk III and HVS Mk IV+ and the effect of this difference on pavement response and behaviour will be investigated in a separate project in future.

### **3.1. General Overview**

#### **3.1.1 Condition of the asphalt wearing course prior to HVS testing**

The asphalt wearing course had been constructed 5 years prior to the comparative HVS testing. There were very fine map cracks on the asphalt surfacing of the test sections. These fine cracks were probably the result of ageing of the binder. The lack of other forms of surface distress can be attributed to the location of the test sections on the extended shoulder of the existing road and thus the sections have received very little, if any, traffic since their construction in 1997. Repetitive loading on the section caused these fine cracks to close-up during the HVS testing.

#### **3.1.2 Example of the analysis of the Elastic MDD Depth Deflection Data**

Figure 6 shows an example of a printout that is generated by an Excel spreadsheet utilised for the 1<sup>st</sup> level processing of the depth deflection data from the MDD system. The printout in Figure 6 is only an example from a current HVS test, showing the layout of the spreadsheet and does not contain any data relating to the test sections discussed in this document. The individual graphs for the HVS tests on the two G2 base layer sections will be discussed and shown in detail in subsequent sections of this document. The trafficking load for the example that is shown, increased from 40kN to 80kN after 958 715 repetitions. Deflections were therefore measured at 40 kN up to 958 715 load repetitions after which 40 and 80 kN deflections were measured.

Starting from the top left-hand corner the first graph shows the 40 kN deflections plotted against the installation depths of the MDD modules for the duration of the test (both 40 and 80 kN trafficking loads). The top right-hand graph shows the 40 kN depth deflection plotted against the number of load repetitions. The two graphs immediately below the top row show the same type of deflection data, but for the 80 kN deflection load only (from 958 715 repetitions onwards).

It is possible to calculate the average vertical strain for each of the instrumented pavement layers from the deflection measured at two successive MDD modules and the initial distance between the modules. The average vertical elastic strain therefore represents the slope of the deflection profiles plotted in the two left-hand graphs of the 1<sup>st</sup> and 2<sup>nd</sup> row of Figure 6. The left-hand graph in the 3<sup>rd</sup> row of Figure 6 therefore shows the average vertical elastic strain plotted against load repetitions for the individual pavement layer under a 40 kN deflection load. The left-hand graph in the bottom row of Figure 6 shows similar data but for the 80 kN deflection load.

By extrapolating the slope of the deflection profiles (shown in the left-hand graphs of the 1<sup>st</sup> and 2<sup>nd</sup> row in Figure 6) downwards to a point where the vertical (depth) axis is intersected, it is possible to obtain an estimate of the depth at which the deflection becomes zero. This depth is referred to as the Depth of Zero Deflection (DZD). The DZD data are shown plotted against the load repetitions in the right-hand graphs in the 3<sup>rd</sup> and bottom rows of Figure 6.

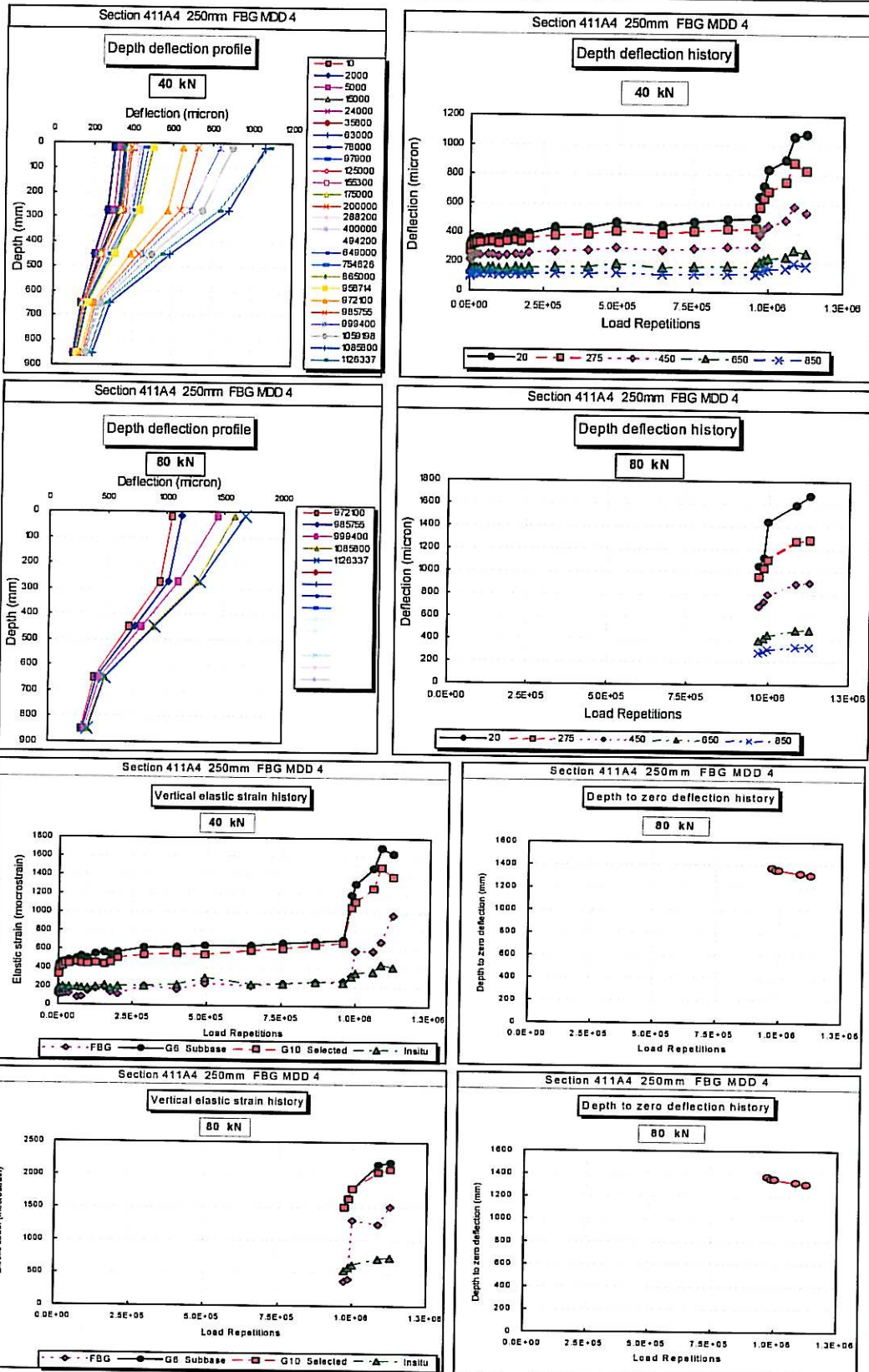


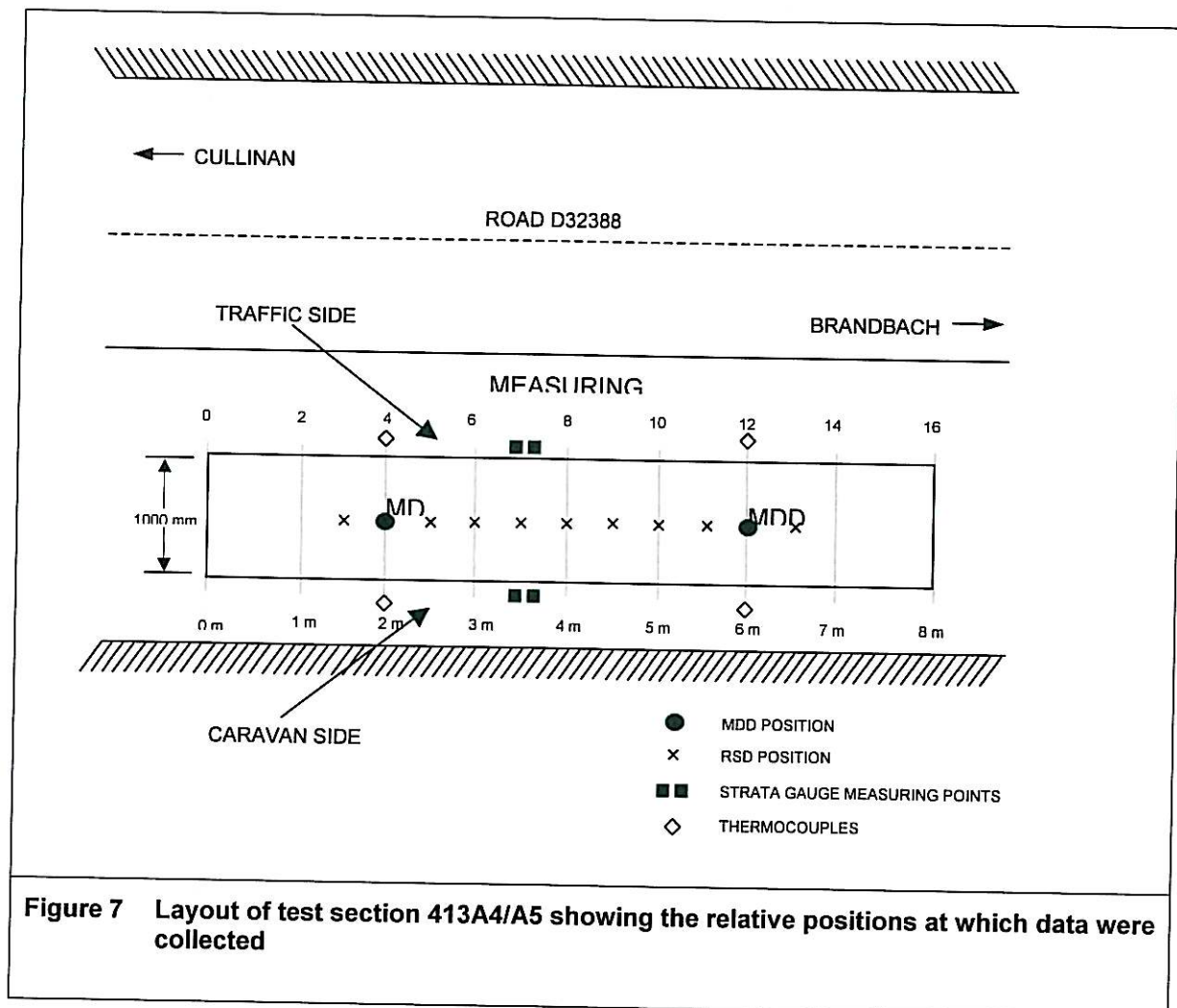
Figure 6 Example of the MDD depth deflection 1<sup>st</sup> level data processing done on the Excel spreadsheet

### 3.2. Section 413A4/A5

The data presented in this section are grouped according to the following structure:

- Operational and environmental data;
  - HVS tyre pressure data;
  - Pavement temperature data;
- Surface response data;
  - Visual distress;
  - Road Surface Deflectometer (RSD) data;
  - Manual and Laser Profilometer rut;
- Depth response data;
  - Depth deflection data (MDD deflections);
  - MDD Permanent Displacement (PD) data.

Figure 7 shows HVS test section 413A4/A5 and the relative positions at which data were collected.



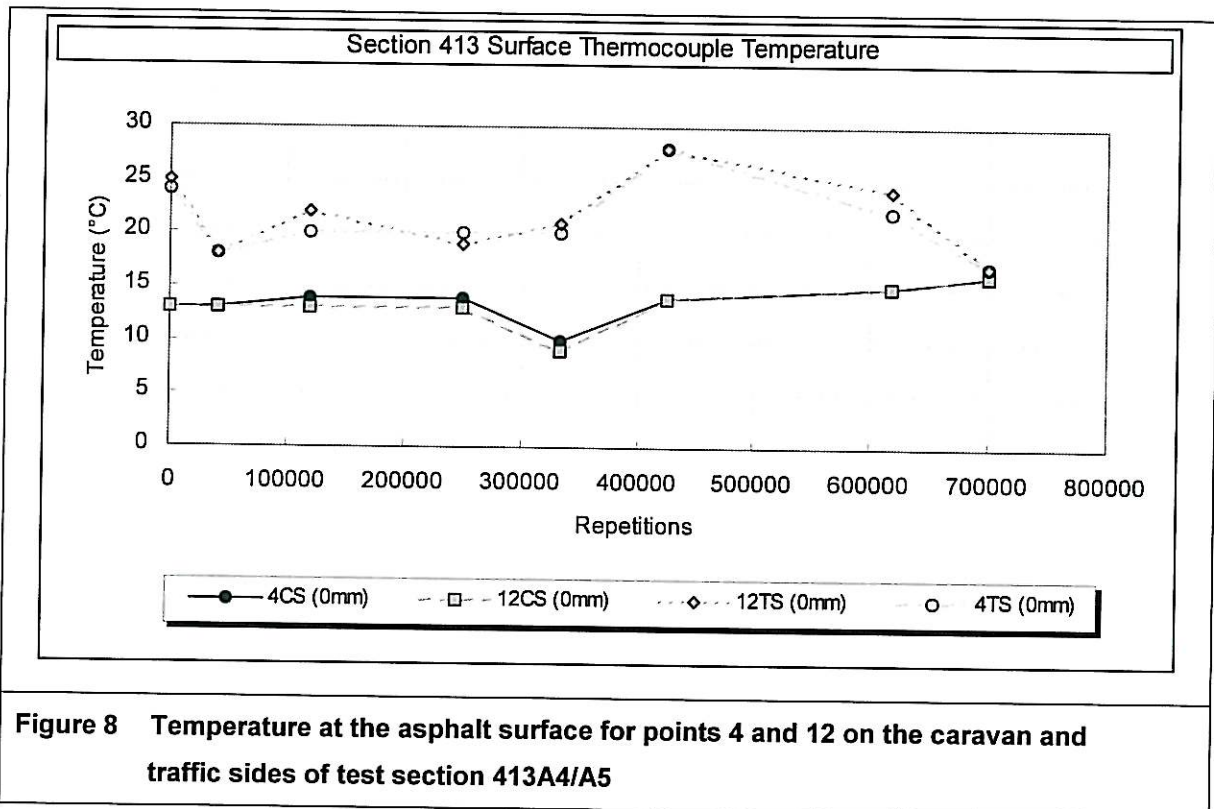


### 3.2.1 Operational and environmental data

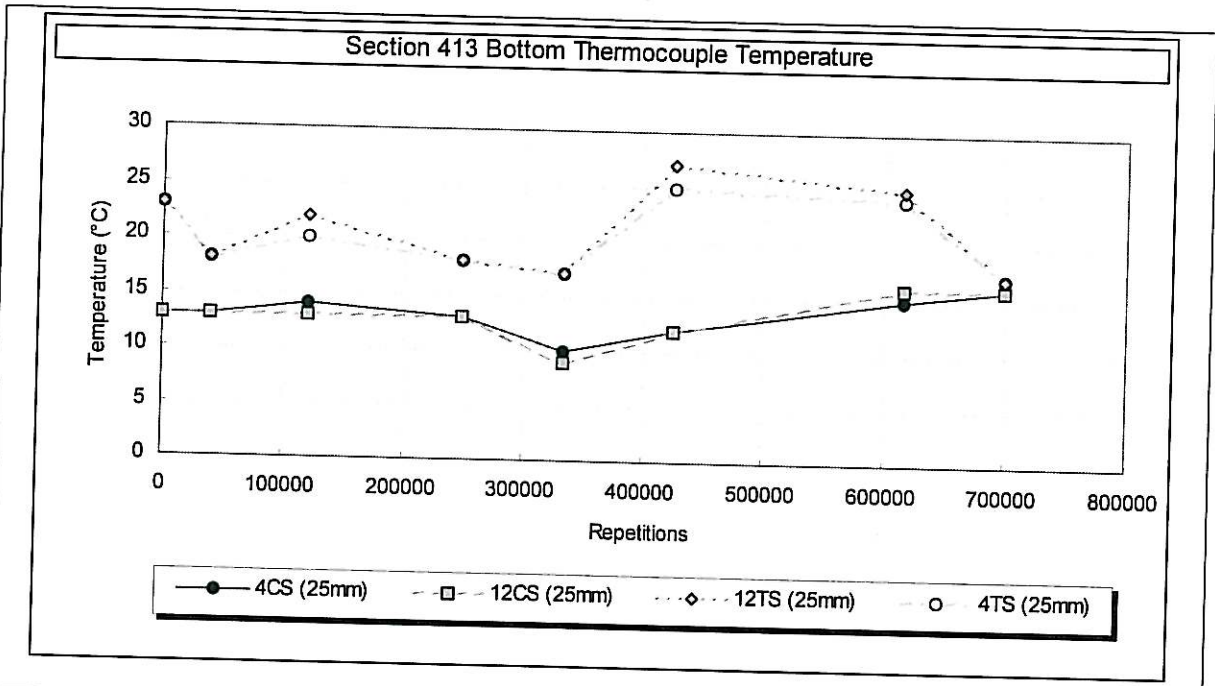
No rainfall data and limited temperature data was collected during the testing of HVS section 413A4/A5.

#### *Pavement temperature data*

Pavement temperature data was collected from the thermocouples installed in test section 413A4/A5. Temperature buttons were not installed on the test sections for the comparative tests. Data collection was undertaken at the time of deflection and rut measurements, which is normally done between 8H00 and 12H00. Figure 8 shows the thermocouple surface temperature data of test section 413A4/A5, while Figure 9 shows the temperature at a depth of 25 mm in the asphalt concrete surfacing of this test section.



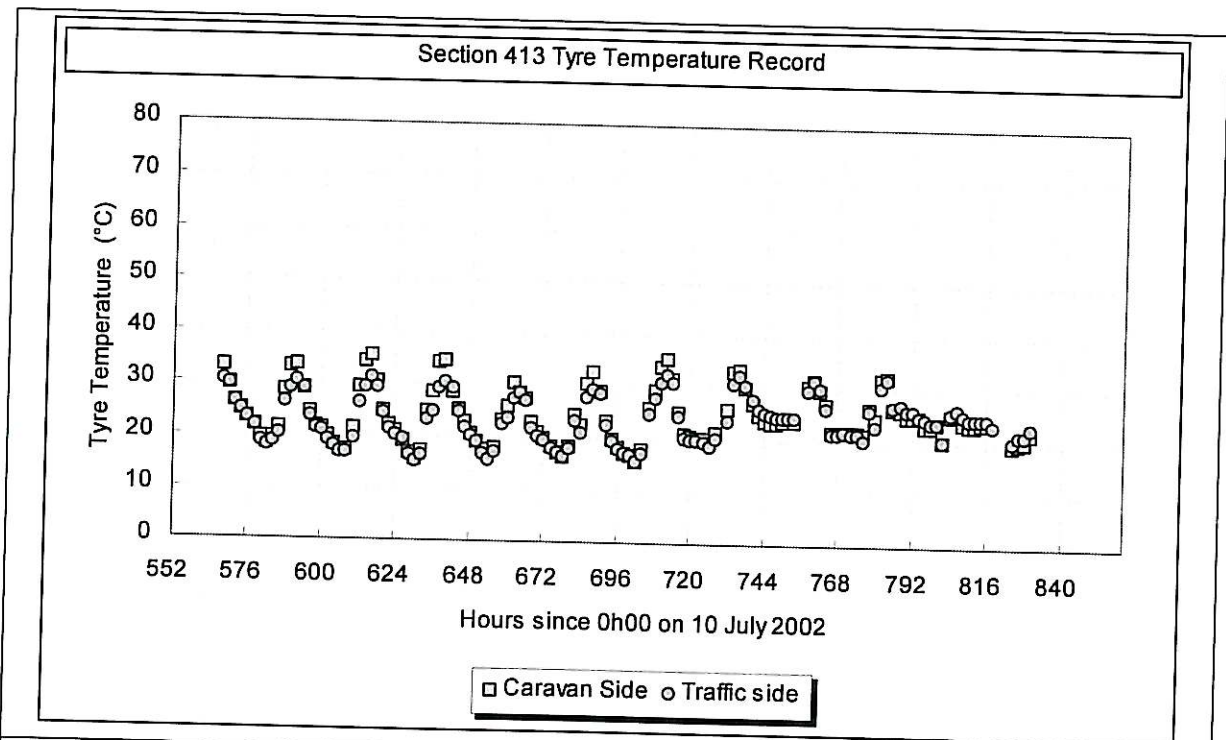
**Figure 8** Temperature at the asphalt surface for points 4 and 12 on the caravan and traffic sides of test section 413A4/A5



**Figure 9** Temperature at 25 mm depth in asphalt for points 4 and 12 on the caravan and traffic sides of test section 413A4/A5

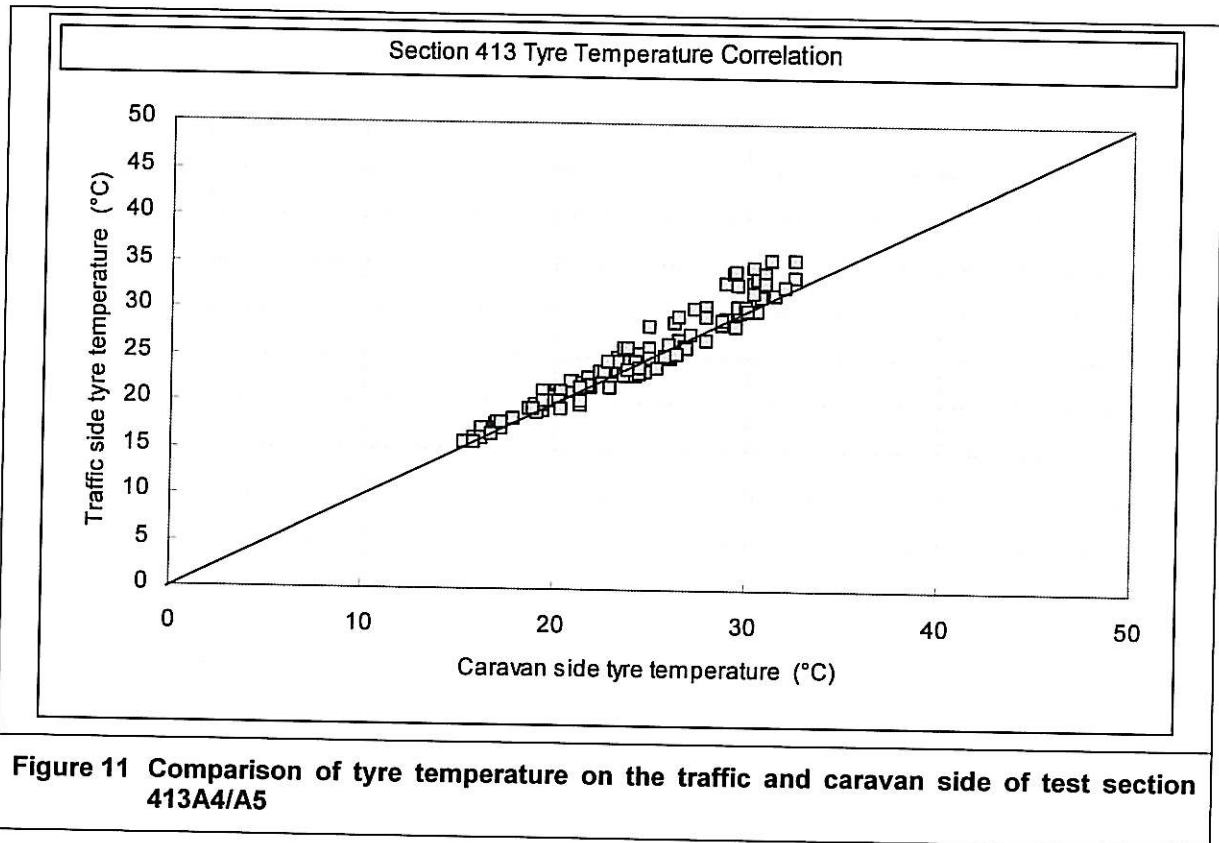
**HVS tyre temperature and pressure data**

Figure 10 shows the tyre temperature record for the trafficking completed by the HVS Mk IV+ on test section 413A4/A5. Figure 11 compares the tyre temperature on the traffic and caravan side tyres.



**Figure 10** Tyre temperature data for HVS Mk IV+ on section 413A4/A5

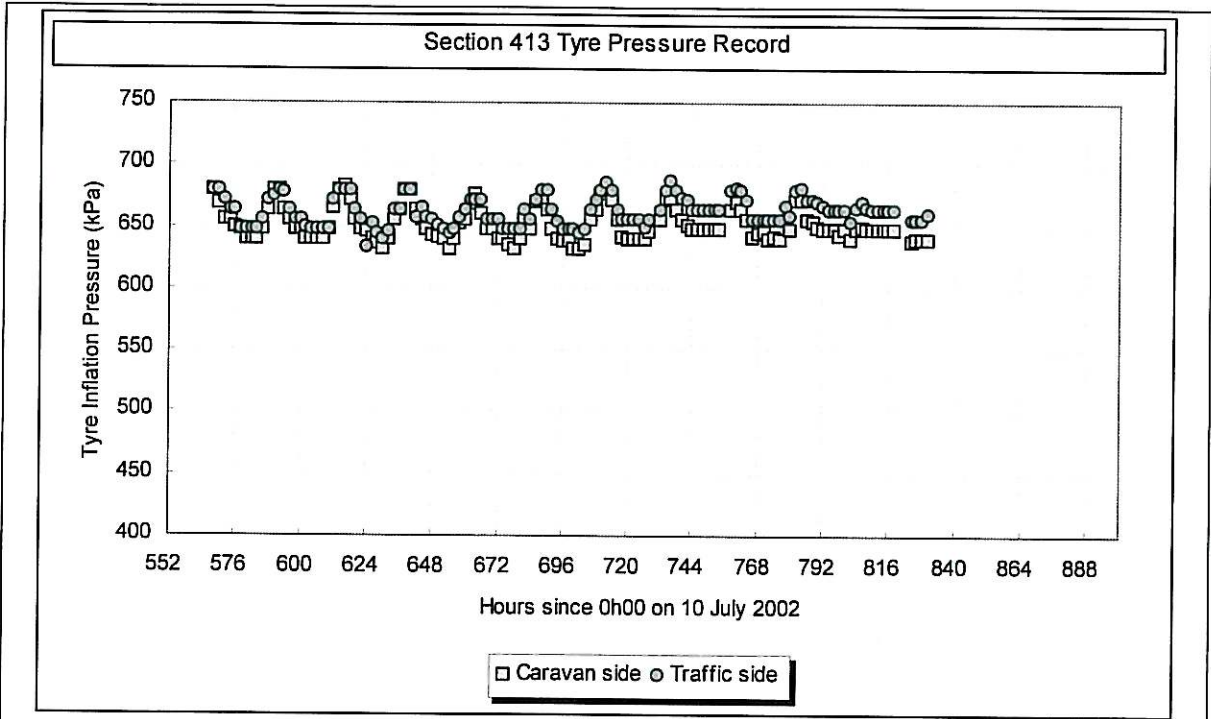
Figure 11 plots slightly above the line of equality caused by the traffic side being exposed to solar radiation. The correlation between traffic and caravan side tyre temperature is close, with variations becoming more evident at tyre temperatures above 25°C.



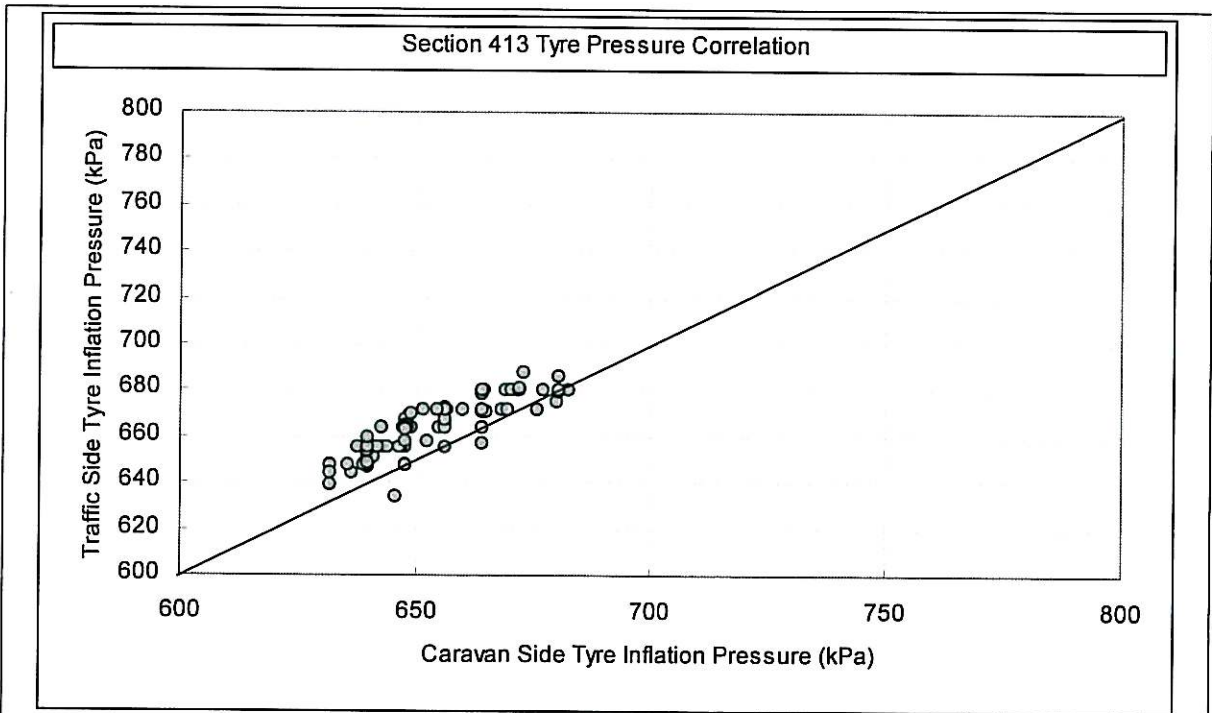
**Figure 11 Comparison of tyre temperature on the traffic and caravan side of test section 413A4/A5**

Figure 12 shows the tyre pressure data collected for the period during which the HVS Mk IV+ trafficked test section 413A4/A5. (No tyre pressure and temperature data was collected for HVS Mk III as this HVS is not equipped with the necessary sensors). Figure 13 shows the relationship between the traffic and caravan side tyre inflation pressure data.

The tyre inflation pressure remained relatively constant for test section 413A4/A5 while being tested with the HVS Mk IV+. The tyre pressure correlation between the traffic and caravan sides shows that traffic side tyre pressure was higher than the caravan side tyre pressure. Since tyre pressure is directly related to tyre temperature it is believed that the higher tyre pressure are also the result of increased exposure to solar radiation experienced by the traffic side tyre.



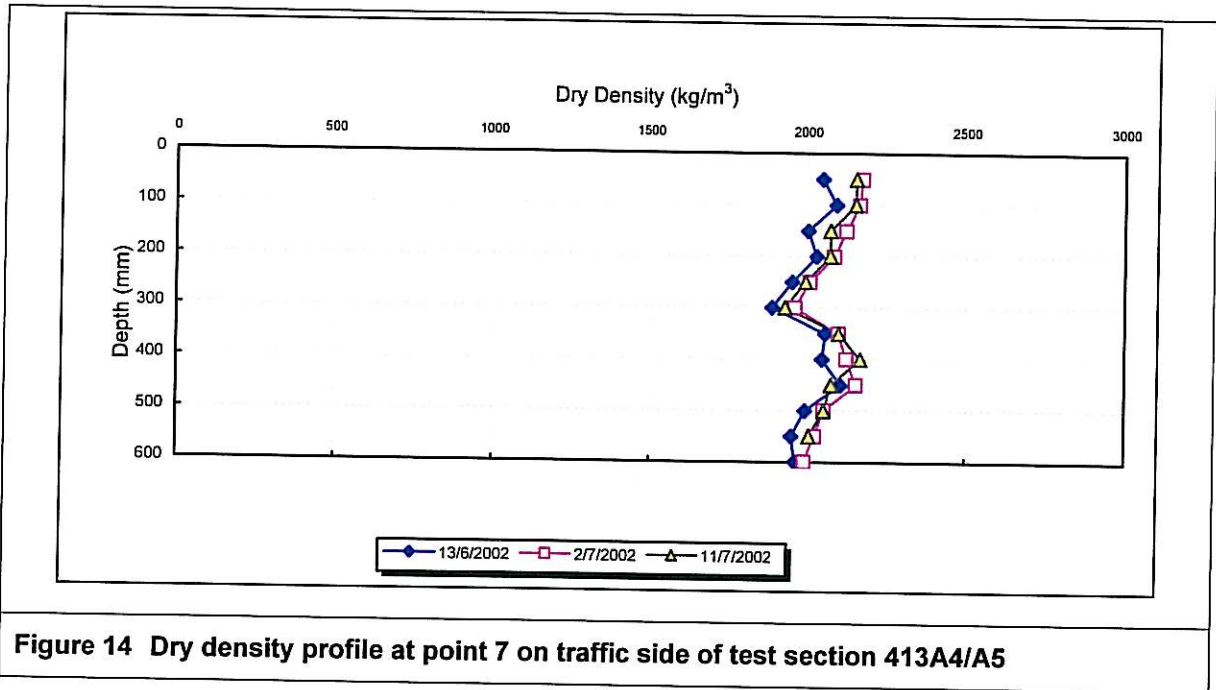
**Figure 12 Tyre inflation pressure data for test Section 413A4/A5**



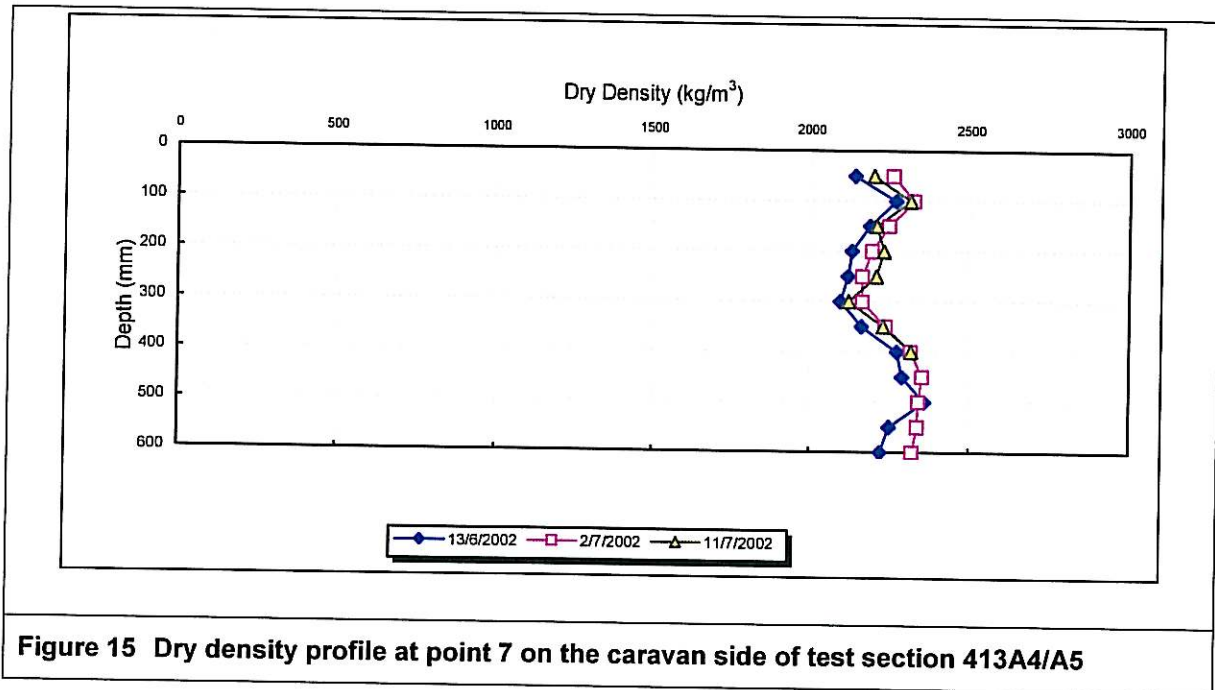
**Figure 13 Comparison of tyre inflation pressure between the traffic and caravan sides on Section 413A4/A5**

**Strata gauge density and moisture content data**

Figures 14 and 15 show the dry density on the traffic and caravan side, respectively, for test section 413A4/A5 at point 7. The data was measured using a Campbell strata density gauge.



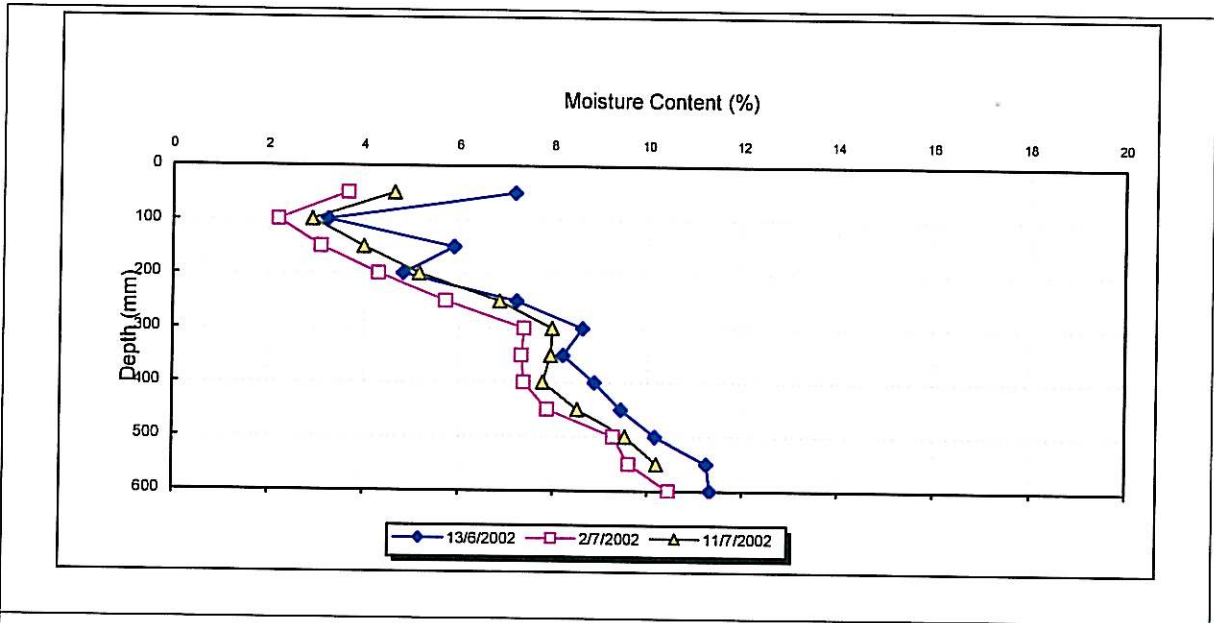
**Figure 14 Dry density profile at point 7 on traffic side of test section 413A4/A5**



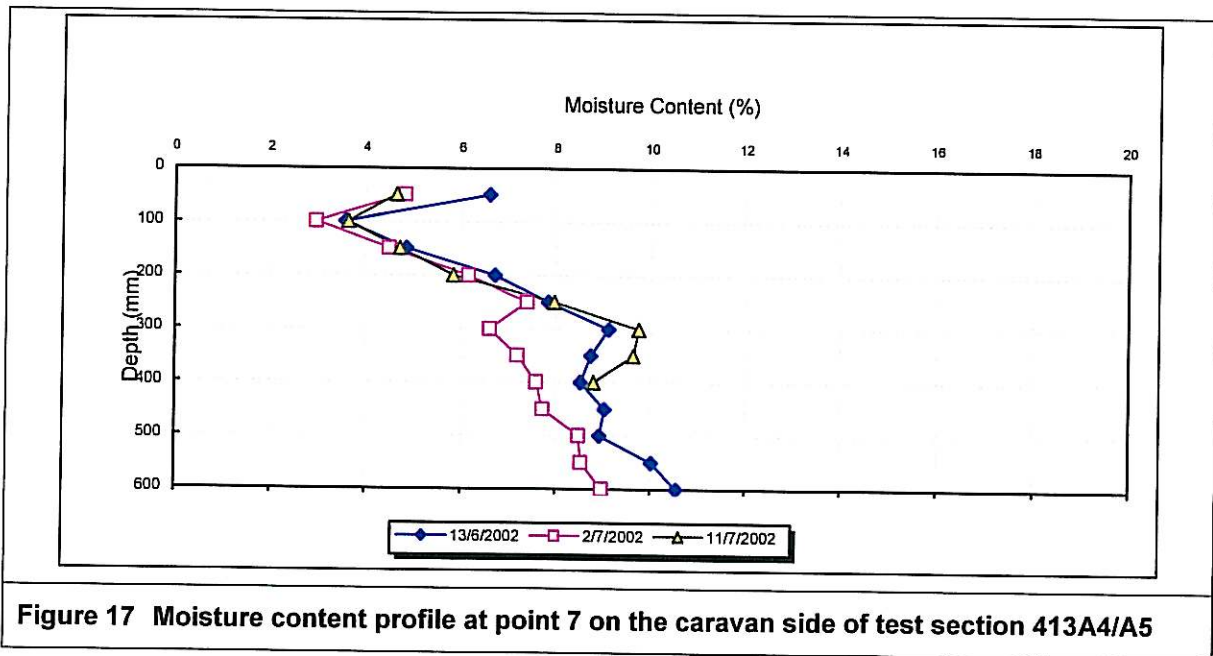
**Figure 15 Dry density profile at point 7 on the caravan side of test section 413A4/A5**

Figures 14 and 15 show that the dry density decreases with depth through the constructed pavement layers down to a depth of approximately 350 mm, which is the interface between the subbase with the selected layers. Generally, dry densities on the caravan side were higher than those measured on the traffic side at point 7 but no explanation can be given for this difference without further investigation.

Figures 16 and 17 show the moisture content profiles for the traffic and caravan sides at point 7 on test section 413A4/A5, as measured by the Campbell strata density gauge. The moisture content is generally high throughout the profiles, with good correlation between the traffic side and the caravan side moisture contents, and limited variation between the moisture content in the pavement throughout the test program.



**Figure 16** Moisture content profile at point 7 on the traffic side of test section 413A4/A5



**Figure 17** Moisture content profile at point 7 on the caravan side of test section 413A4/A5

### 3.2.2 Surface response data

#### Visual distress

Limited visual distress monitoring was performed on test section 413A4/A5. A hydraulic oil spill on the test section on 9 July (324 666 repetitions), resulting from a ruptured hydraulic pipe on the HVS test carriage, caused significant softening of the binder. Subsequently, the visual distress monitored after the spill was not representative of the pavement performance under HVS trafficking due to the softening of the asphalt layer. Prior to the spill very little visual distress was evident on the test section and the fine map cracking present prior to trafficking had disappeared.

At the completion of testing, small areas at the extremity of the test section showed localised rutting. The localised ruts occurred at the positions at which the test carriage changed direction and were evident on the outer edges of the 1 m test strip. The primary cause of this rutting is unknown, but it is believed to be the combined effects of the turnaround position, the hydraulic oil leak and the possible ingress of water (used to wash the section after the oil spill) through the damaged asphalt surface.

#### Road Surface Deflectometer (RSD) data

Figure 18 shows the average centre line surface deflection for test section 413A4/A5. Test load and tyre pressure were set at the trafficking conditions as given in Table 1. Apart from the initial "bedding-in" phase, the period directly following the hydraulic oil leak and the swapping of the machines (471 497 repetitions), the surface deflection trend is relatively linear and the rate of increase in deflection is low.

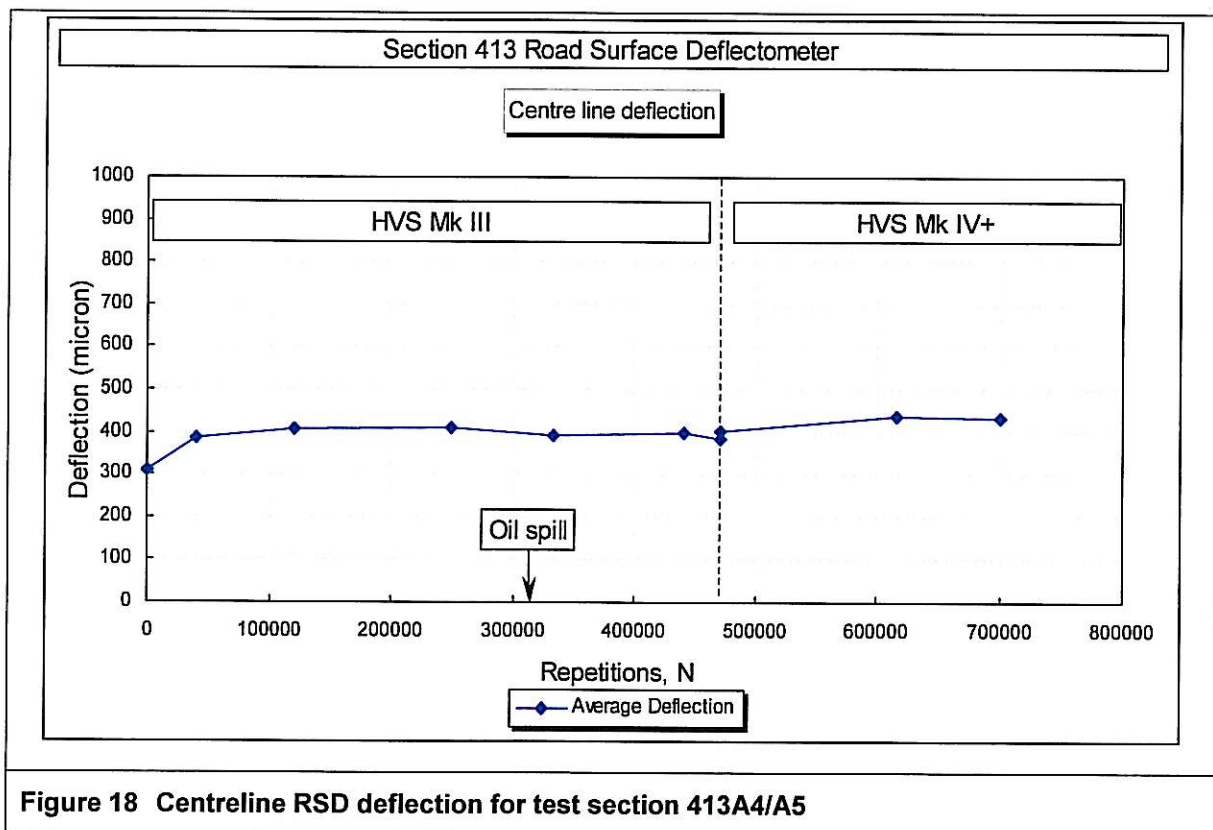
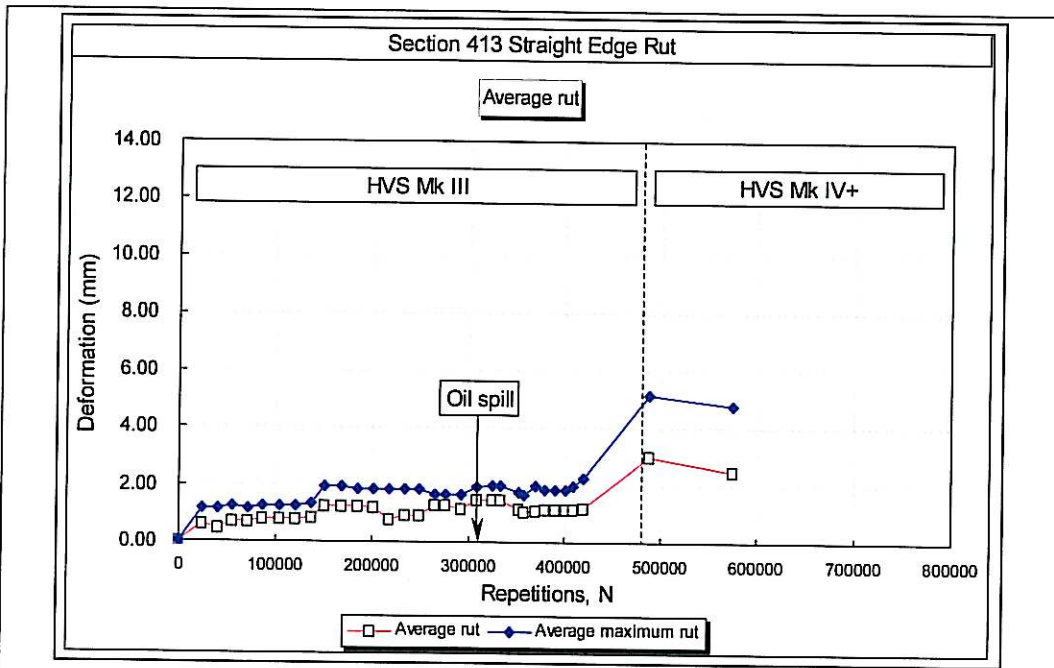


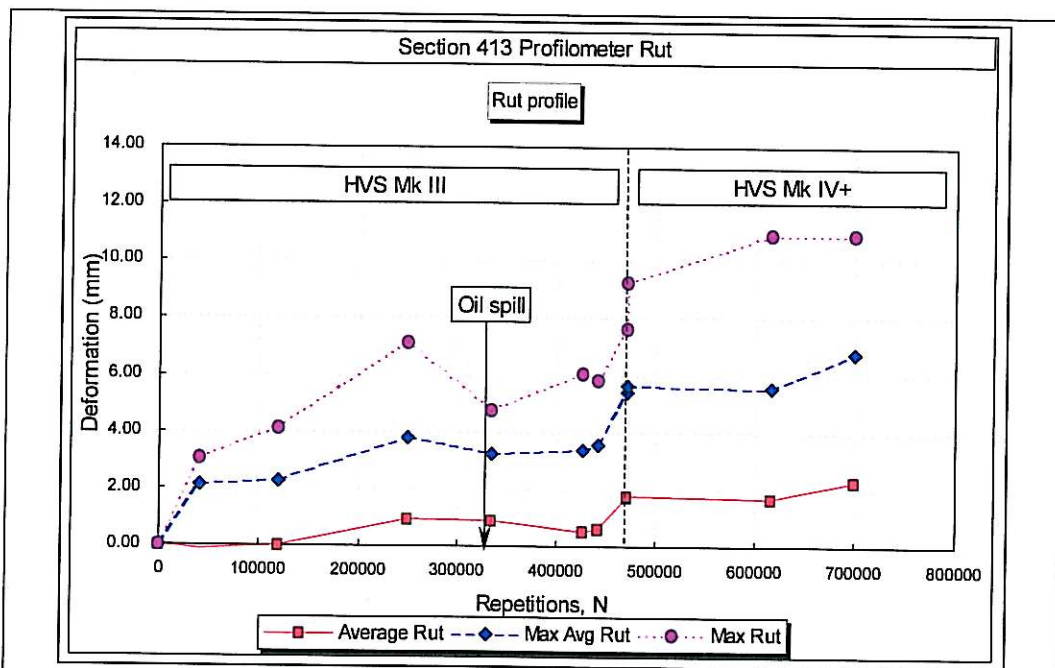
Figure 18 Centreline RSD deflection for test section 413A4/A5

**Straight edge and Laser Profilometer surface rut**

Figures 19 and 20 show the straight edge rut and Profilometer rut for test section 413A4/A5. It is noticeable that the oil leak had a significant effect on the asphalt layer, causing deformation of the layer and shoving under HVS trafficking. For this reason, straight edge and laser profilometer rut measurements were suspended after 575 000 repetitions since the results were not representative of the performance of an asphalt layer under HVS trafficking. The decrease in the maximum laser profilometer rut after the oil spill is due to the filling of the rut with fine sand put onto the section to absorb the oil.



**Figure 19 Average straight edge rut for section 413A4/A5**



**Figure 20 Average Profilometer rut for section 413A4/A5**



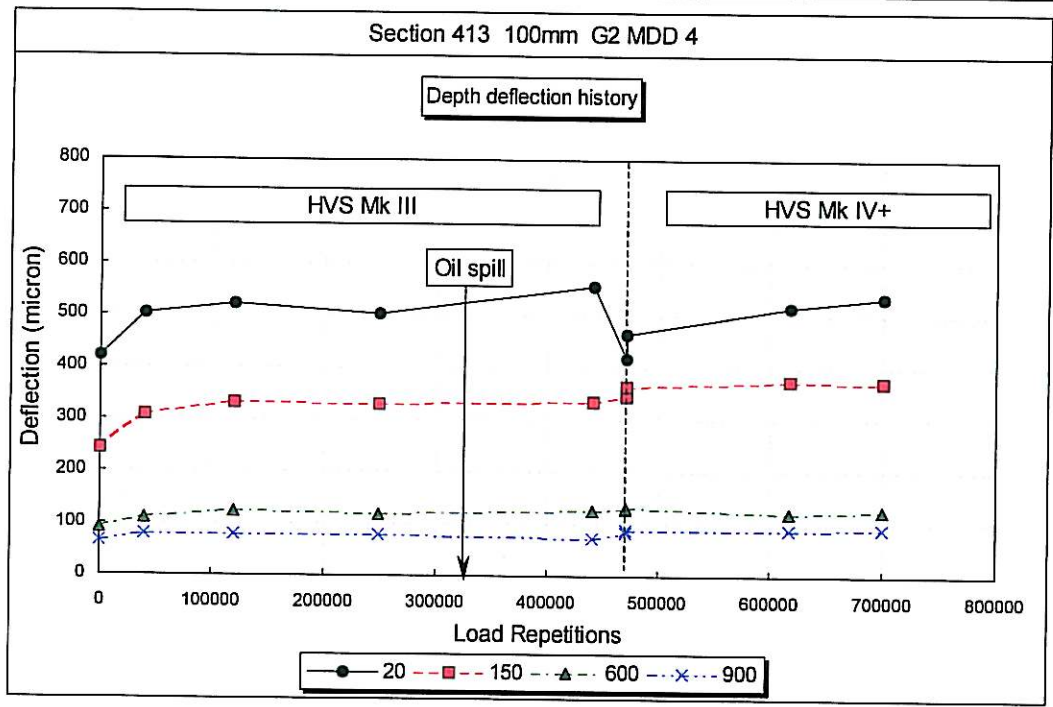
### 3.2.3 Depth response data

#### *Depth deflection data (MDD deflection data)*

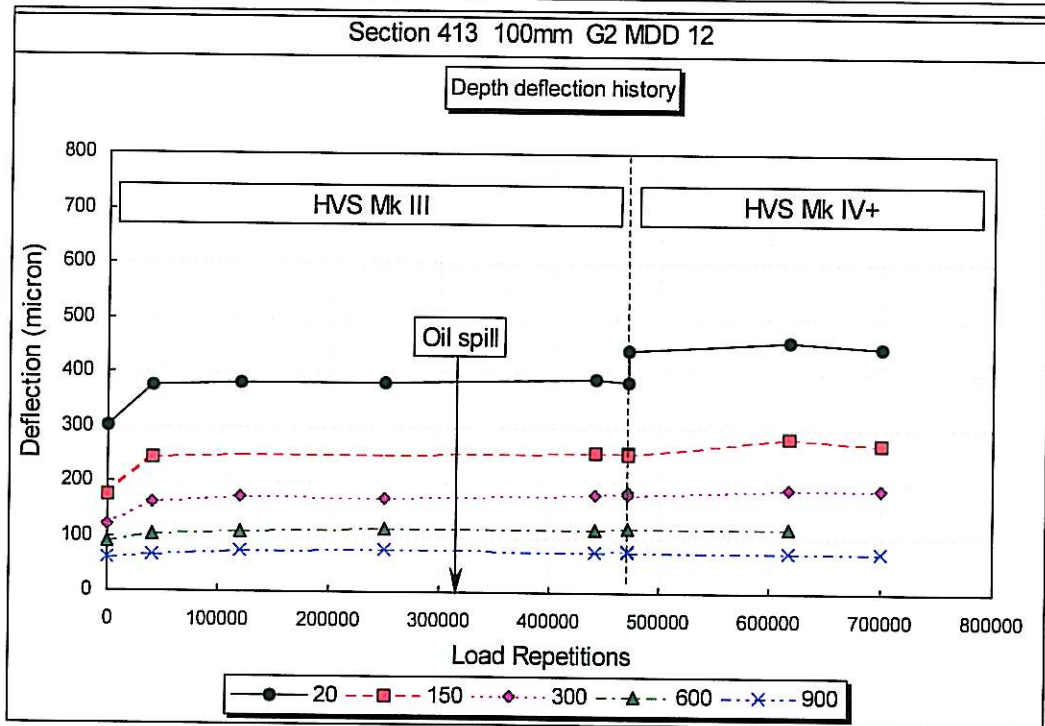
The detail of the MDD positions and module depths for section 413A4/A5 are shown in Figures 1 and 3 and the spreadsheet template that is used for processing the depth deflection data is discussed in Section 3.1.2. Figures 21 (a) and (b) show the depth deflection history for MDD4 and MDD12 plotted for the duration of the HVS test on section 413A4/A5. Figures 22 (a) and (b) show the depth deflection profile for MDD4 and MDD12 for test section 413A4/A5. MDD4 had a module installed at a depth of 300 mm but the data from this module was discarded because inspection of the data, a comparison with the deflection data from MDD12 and inspection of the permanent displacement data recorded by this module, indicated that the data was erroneous.

The deflection data in Figure 21 show the usual trend associated with MDD deflection data consisting of an initial rapid increase in deflection followed by a period during which the deflection remains constant or increases at a very low rate with increasing load repetitions. There was, however, a sudden decrease in the deflection at 20 mm depth at MDD4 prior to the changeover of the two machines. This sudden decrease may be explained by the fact that HVS III had to be stopped periodically to allow HVS Mk IV+ to reach the same number of load repetitions before the machines were swapped and the test section had the opportunity to recover.

The 20 mm deep deflection results from both MDDs consistently indicate an immediate increase in deflection the moment HVS Mk IV+ was put onto the section. This increase in deflection is even evident at a depth of 150 mm at MDD4. The increase in deflection cannot be ascribed to load damage as the deflection was measured immediately after the swap of the machines without applying additional load repetitions.

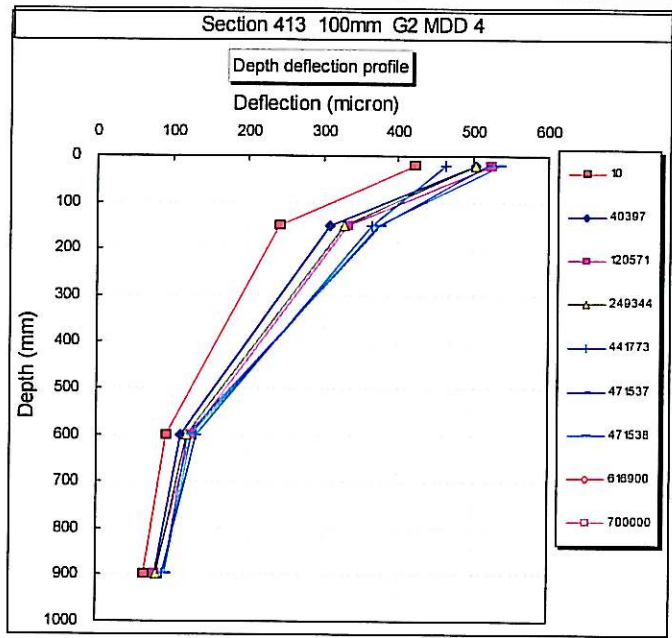


(a) 62 kN MDD deflection for the duration of test 413A4/A5 at MDD 4

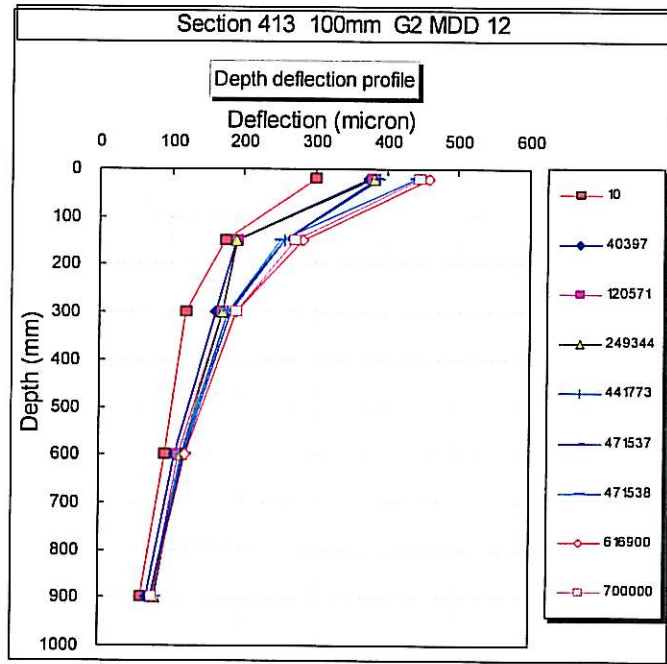


(b) 62 kN MDD deflection for the duration of test 413A4/A5 at MDD 12

Figure 21 MDD depth deflection history for test section 413A4/A5



(a) 62 kN MDD deflection profiles of section 413A4/A5 for MDD 4



(b) 62 kN MDD deflection profiles of section 413A4/A5 for MDD 12

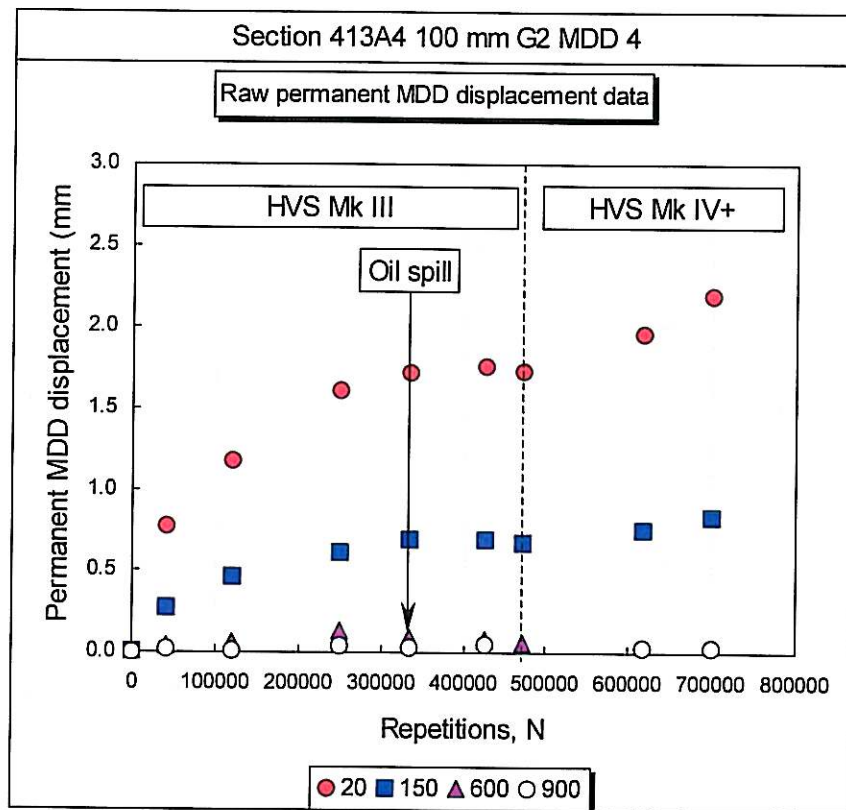
Figure 22 MDD deflection profiles for HVS test section 413A4/A5

### ***MDD permanent displacement data***

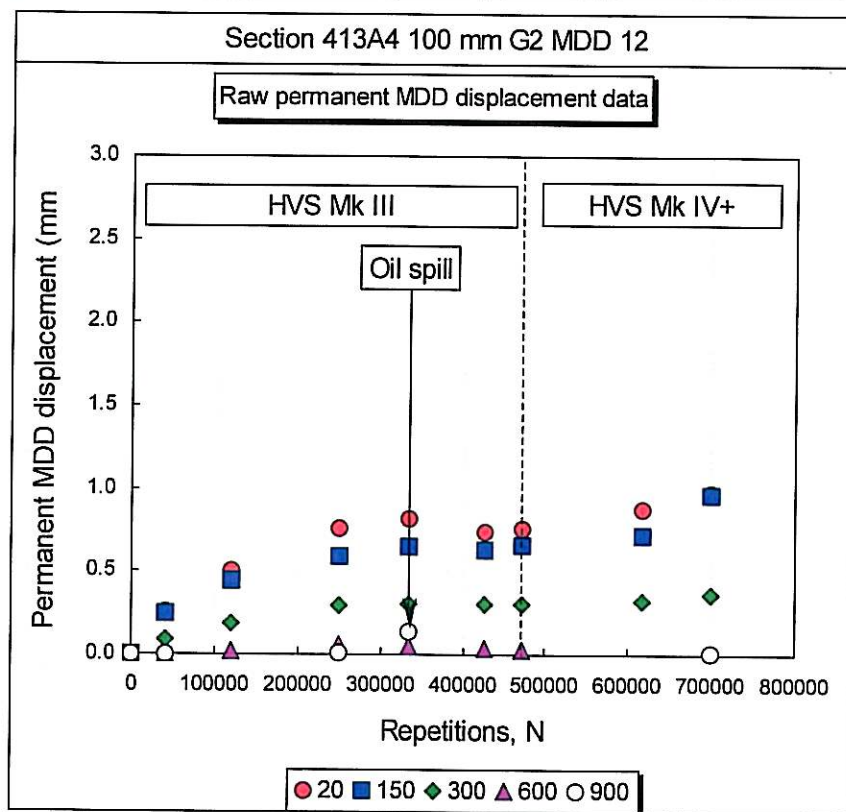
Figures 23 (a) and (b) show the permanent displacement data for MDD4 and MDD12 in test section 413A4/A5. Figure 23 (a) shows the permanent displacement increasing rapidly at the beginning of the test but then levelling-off before the changeover of the machines. The rate of permanent MDD displacement at depths of 20 and 150 mm increased under trafficking at both MDDs once HVS Mk IV+ was put onto the section.

A large portion of the total permanent deformation of the pavement occurred in the asphalt surfacing and base layer at MDD4. A significantly lower amount of permanent deformation occurred in the surfacing and base layer at MDD12 but the permanent MDD displacement at a depth of 150 mm is almost equal between the two MDDs.

Since the main objective of this document is to compare the pavement response under trafficking with the two HVS machines, no bearing capacity analysis of the pavement structure has been performed.



(a) Permanent displacement data for MDD 4



(b) Permanent displacement data for MDD12

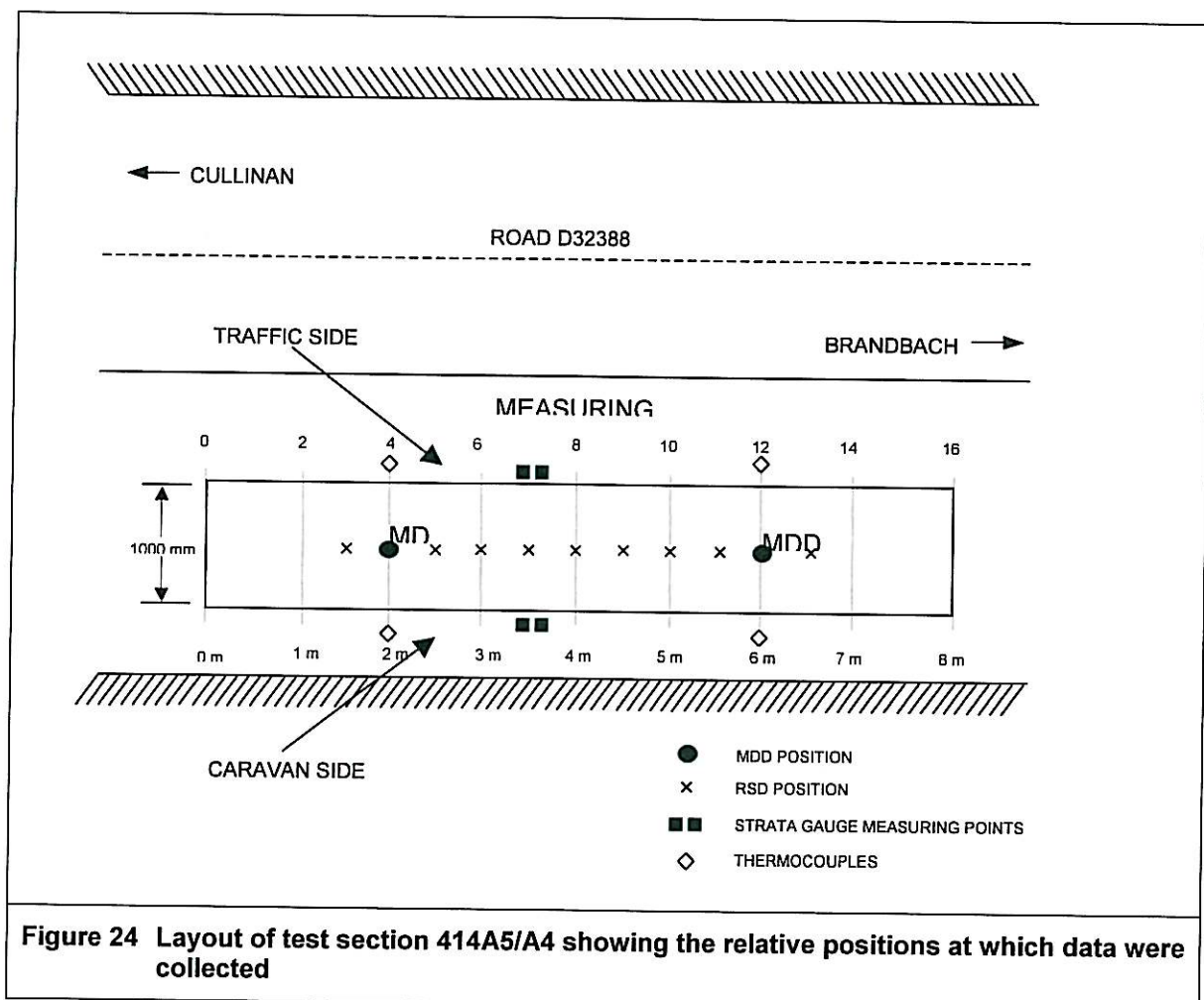
Figure 23 Permanent MDD displacement data for MDD 4 and MDD 12 on section 413A4/A5

### 3.3. Section 414A5/A4

The data presented in this section are grouped according to the same structure followed for section 413A4/A5:

- Operational and environmental data;
  - HVS tyre pressure data;
  - Pavement temperature data;
- Surface response data;
  - Visual distress;
  - Road Surface Deflectometer (RSD) data;
  - Manual and Laser Profilometer rut;
- Depth response data;
  - Depth deflection data (MDD deflections);
  - MDD Permanent Displacement (PD) data.

Figure 24 shows HVS test section 414A5/A4 and the relative positions at which data were collected.

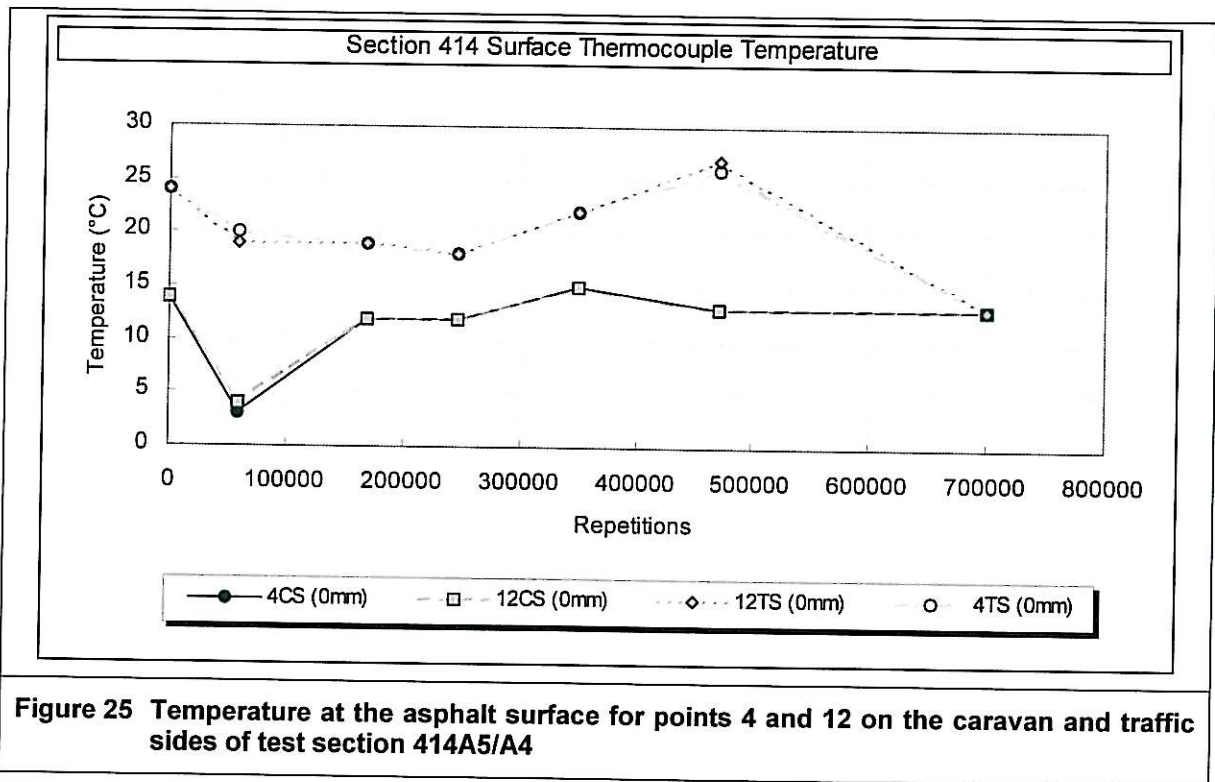


### 3.3.1 Operational and environmental data

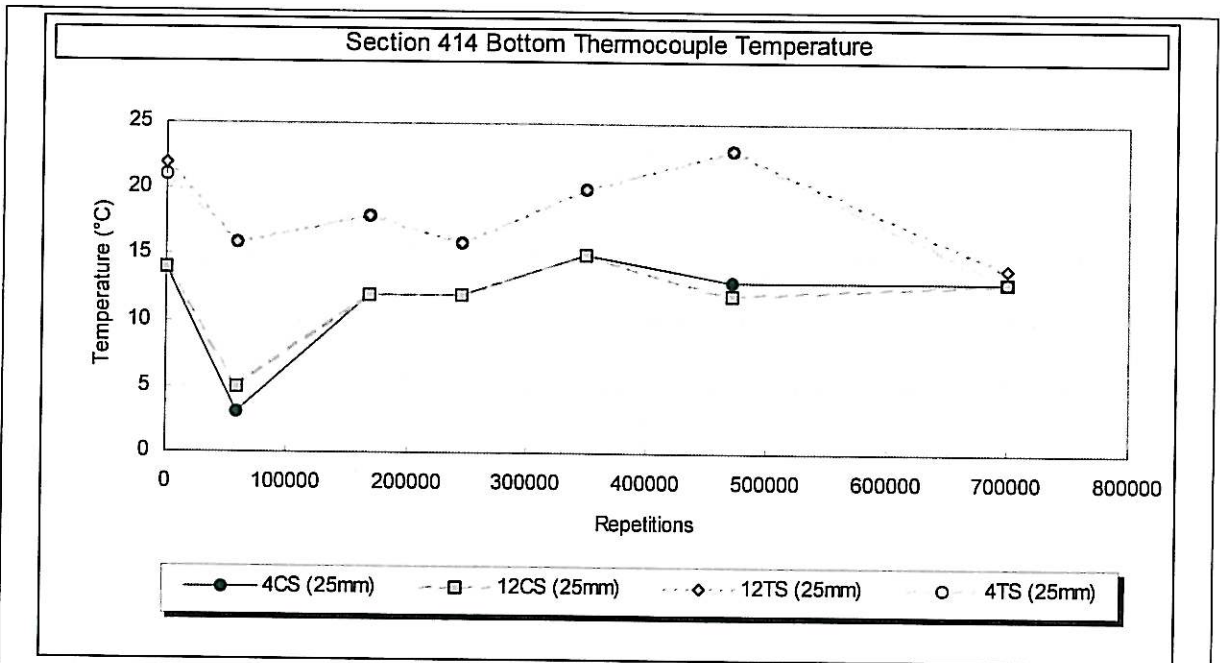
As with test section 413A4/A5, no rainfall data and limited temperature data was collected during the testing of HVS test section 414A5/A4.

#### *Pavement temperature data*

Pavement temperature data was collected from the thermocouples installed in test section 414A5/A4. Data collection was undertaken simultaneously with the deflection and rut measurements. Figure 25 shows the thermocouple temperature data of the surface of test section 414A5/A4, while Figure 26 shows the temperature at a depth of 25 mm in the asphalt concrete surfacing. The traffic side temperature consistently exceeded the caravan side temperature for both the surface temperature and the temperature 25 mm below the surface within the asphalt layer. Correspondence between the temperature points 4 and 12 (caravan or traffic side) was excellent, indicating that the temperature differential occurred transversely and not longitudinally.



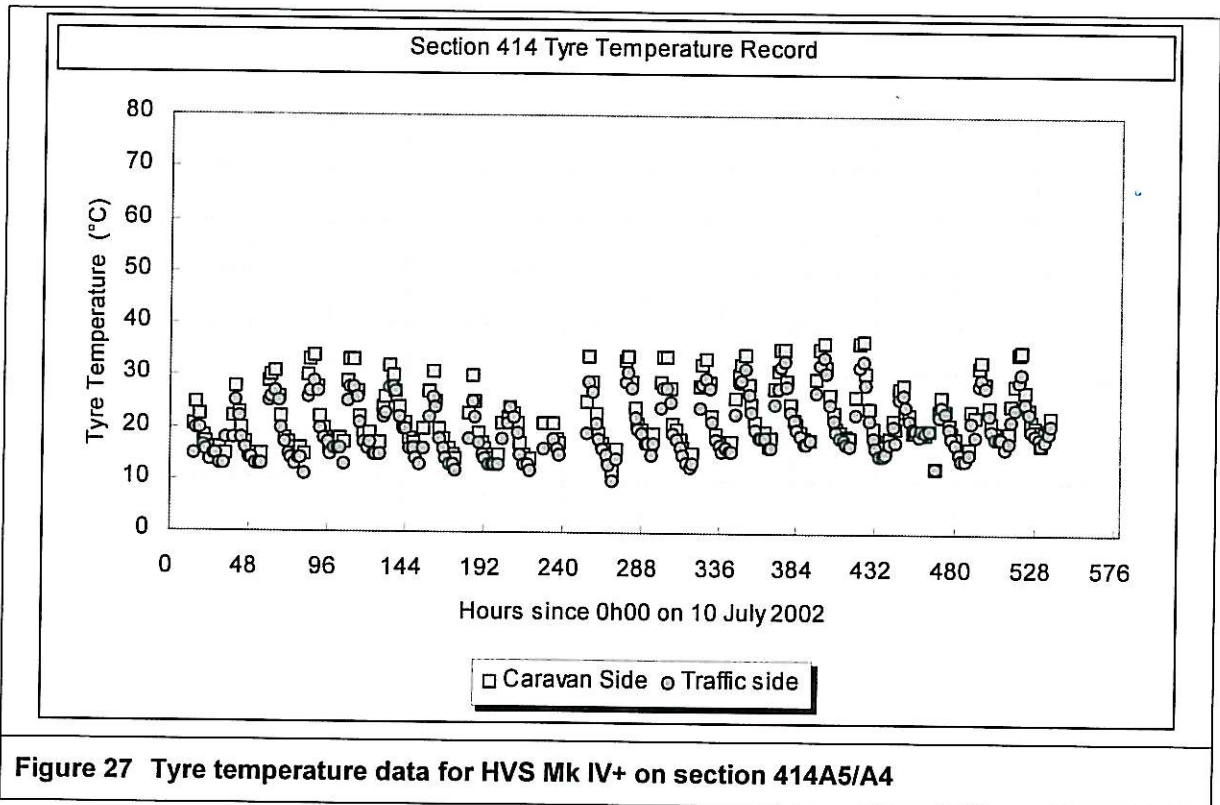
**Figure 25 Temperature at the asphalt surface for points 4 and 12 on the caravan and traffic sides of test section 414A5/A4**



**Figure 26** Temperature at 25 mm depth in the asphalt for points 4 and 12 on the caravan and traffic sides of test section 414A5/A4

**HVS tyre temperature and pressure data**

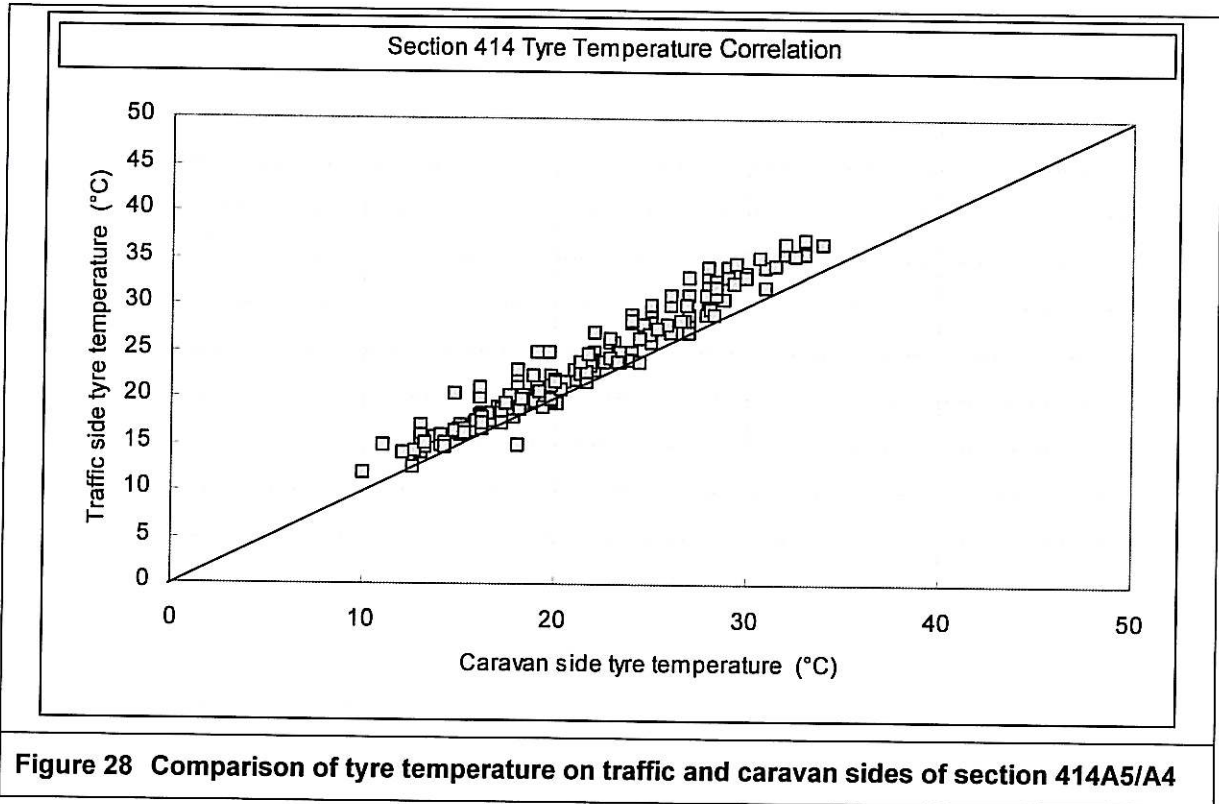
Figure 27 shows the tyre temperature record for the trafficking completed by the HVS Mk IV+ on test section 414A5/A4.



**Figure 27** Tyre temperature data for HVS Mk IV+ on section 414A5/A4



Figure 28 compares the tyre temperature on the traffic and caravan side tyres. The same trend in temperature variation, as observed on test section 413A4/A5, is also evident on test section 414A5/A4. The data in Figure 28 plots slightly above the line of equality indicating higher tyre temperature on the traffic side of the HVS and corresponding well with the trends in the thermocouple temperature readings.



**Figure 28 Comparison of tyre temperature on traffic and caravan sides of section 414A5/A4**

Figure 29 shows the tyre pressure data collected for the period during which the HVS Mk IV+ trafficked test section 413A4/A5. No tyre pressure and temperature data was collected for the testing completed by the HVS Mk III as the Mk III is not equipped with the necessary sensors. Figure 30 shows the relationship between the traffic and caravan sides tyre inflation pressures. The tyre inflation pressure varied over the duration of the testing conducted on test section 414A5/A4 by the HVS Mk IV+. The variation was caused by a slow leak on the traffic side rim at the location of the temperature gauge assembly unit. It was thus necessary to pump the tyres on a regular basis until the leak was found and repaired.

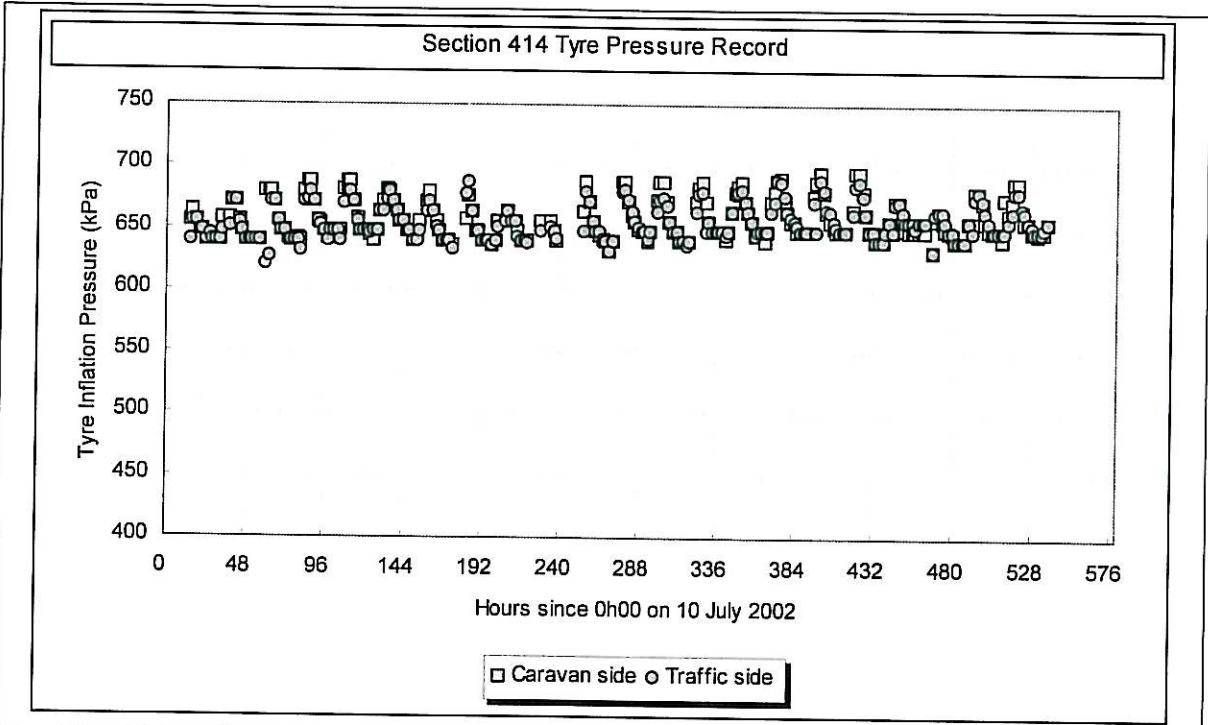


Figure 29 Tyre inflation pressure data for test section 414A5/A4

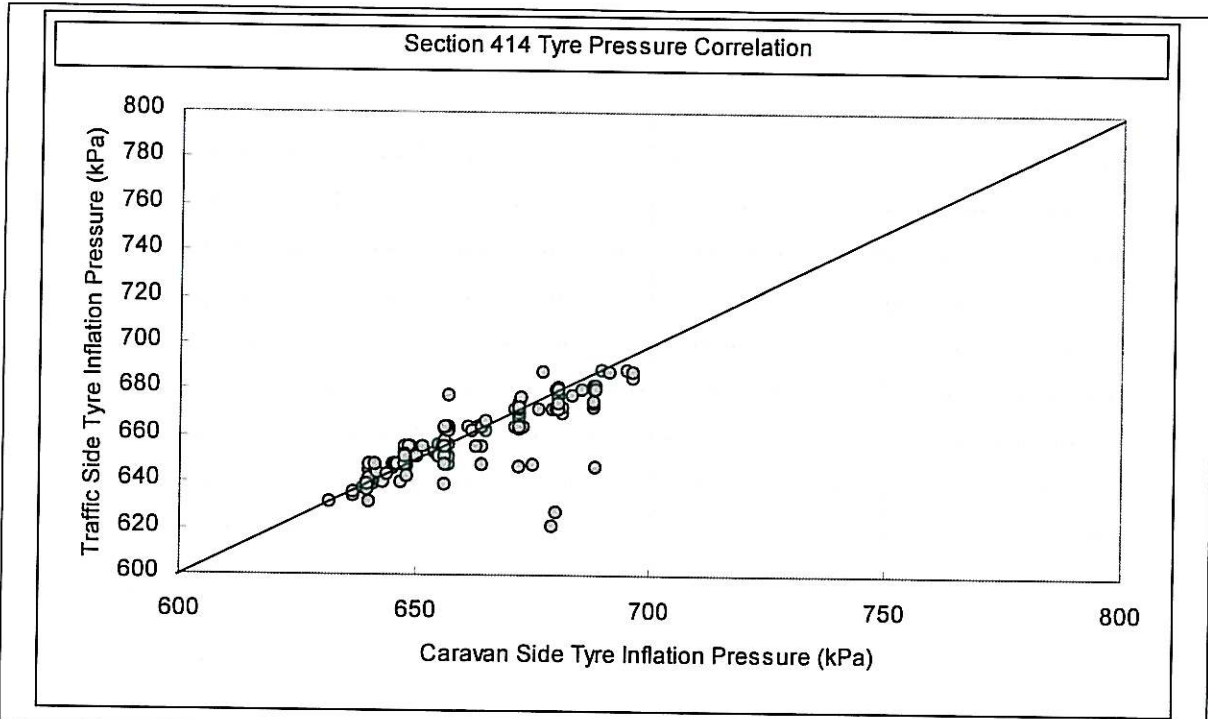
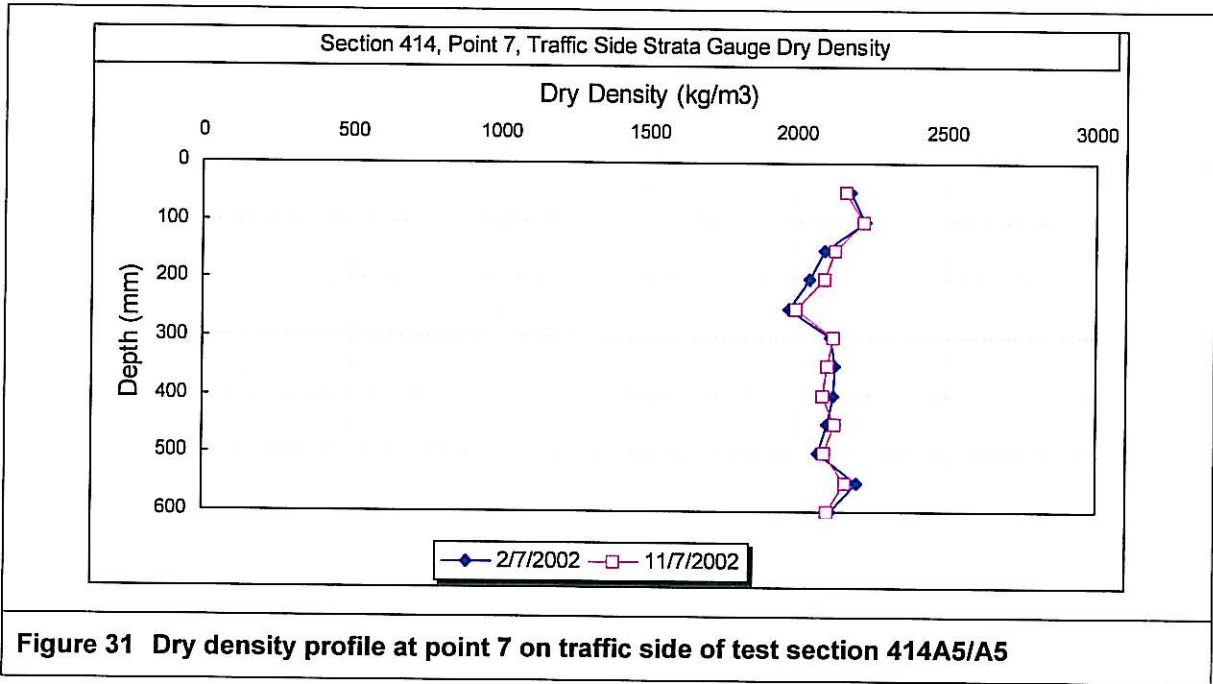


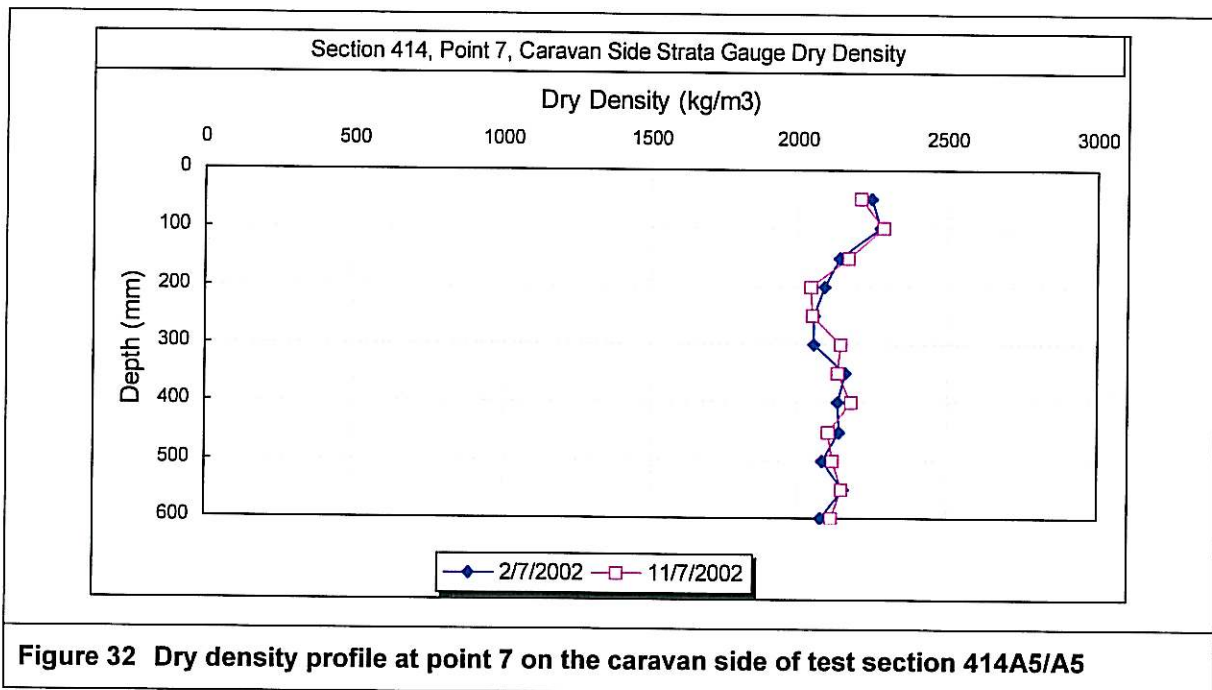
Figure 30 Comparison of tyre inflation pressure between the traffic and caravan sides on section 414A5/A4

**Strata gauge density and moisture content data**

Figures 31 and 32 show the dry density at point 7 on the traffic and caravan sides respectively for test section 414A5/A4. The data were measured using a Campbell strata density gauge.



**Figure 31 Dry density profile at point 7 on traffic side of test section 414A5/A5**



**Figure 32 Dry density profile at point 7 on the caravan side of test section 414A5/A5**

As with test section 413A4/A5, the dry density decreases with depth throughout the constructed pavement layers down to a depth of approximately 250 mm to 300 mm. Good correlation was found at point 7 between the dry density on the caravan and traffic sides.

Figures 33 and 34 show the moisture content profiles at point 7 for the traffic and caravan sides of test section 413A4/A5. The moisture content is generally high throughout the profiles, with relatively poor correlation evident between the traffic and the caravan sides.

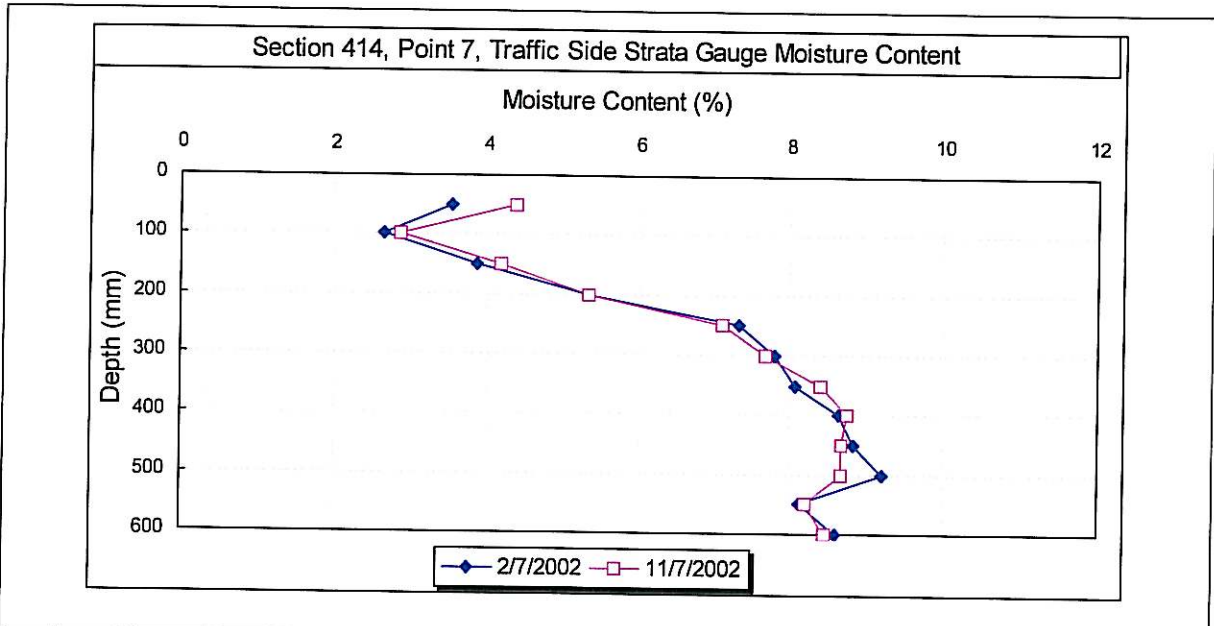


Figure 33 Moisture content profile at point 7 on the traffic side of test section 414A5/A5

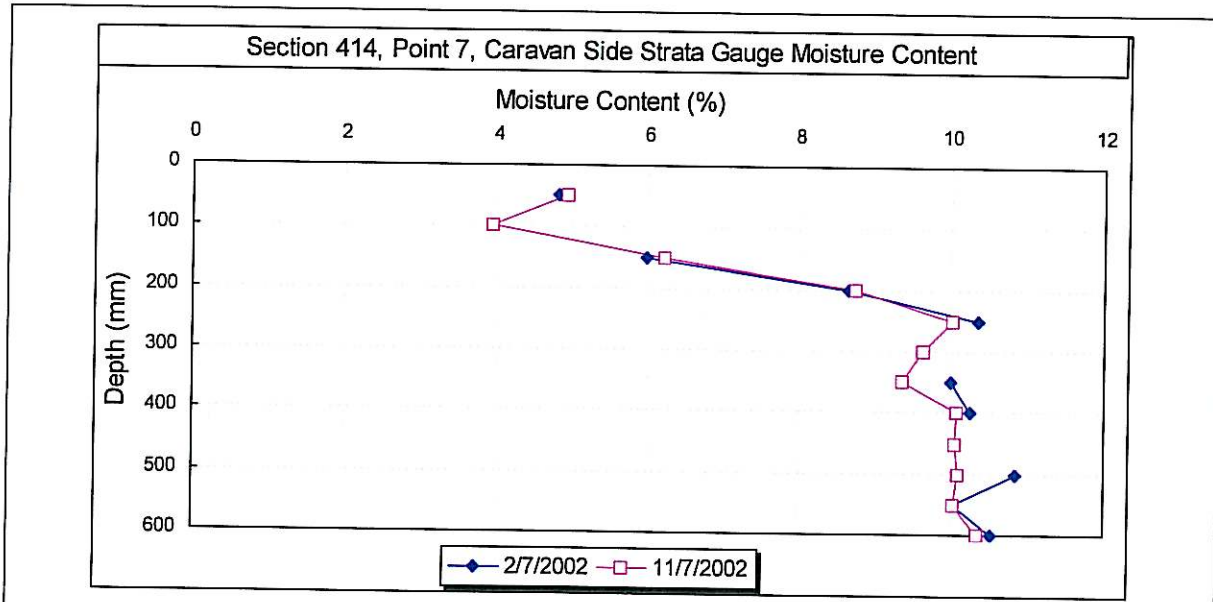


Figure 34 Moisture content profile at point 7 on the caravan side of test section 414A5/A5

### 3.3.2 Surface response data

#### *Visual distress*

Limited visual distress monitoring was performed on test section 414A5/A4 because of a diesel spill at 471 450 repetitions on 8 August 2002. This caused severe softening and, in certain cases, dissolution of the binder. Consequently, the visual distress monitored after the spill was not representative of the pavement performance under HVS trafficking due to the softening of the asphalt layer. As with test section 413A4/A5, very little visual distress was evident on the section prior to the diesel spill and the fine map cracks that were present prior to trafficking had disappeared under trafficking.

#### *Road Surface Deflectometer (RSD) data*

Figure 35 shows the average RSD centre line surface deflection for test section 414A5/A4. The test load and tyre pressure were set at the trafficking conditions given in Table 1. Taking into consideration the initial "bedding-in" phase, test section 414A5/A4 showed an approximate linear, gradual increase in deflections throughout the test.

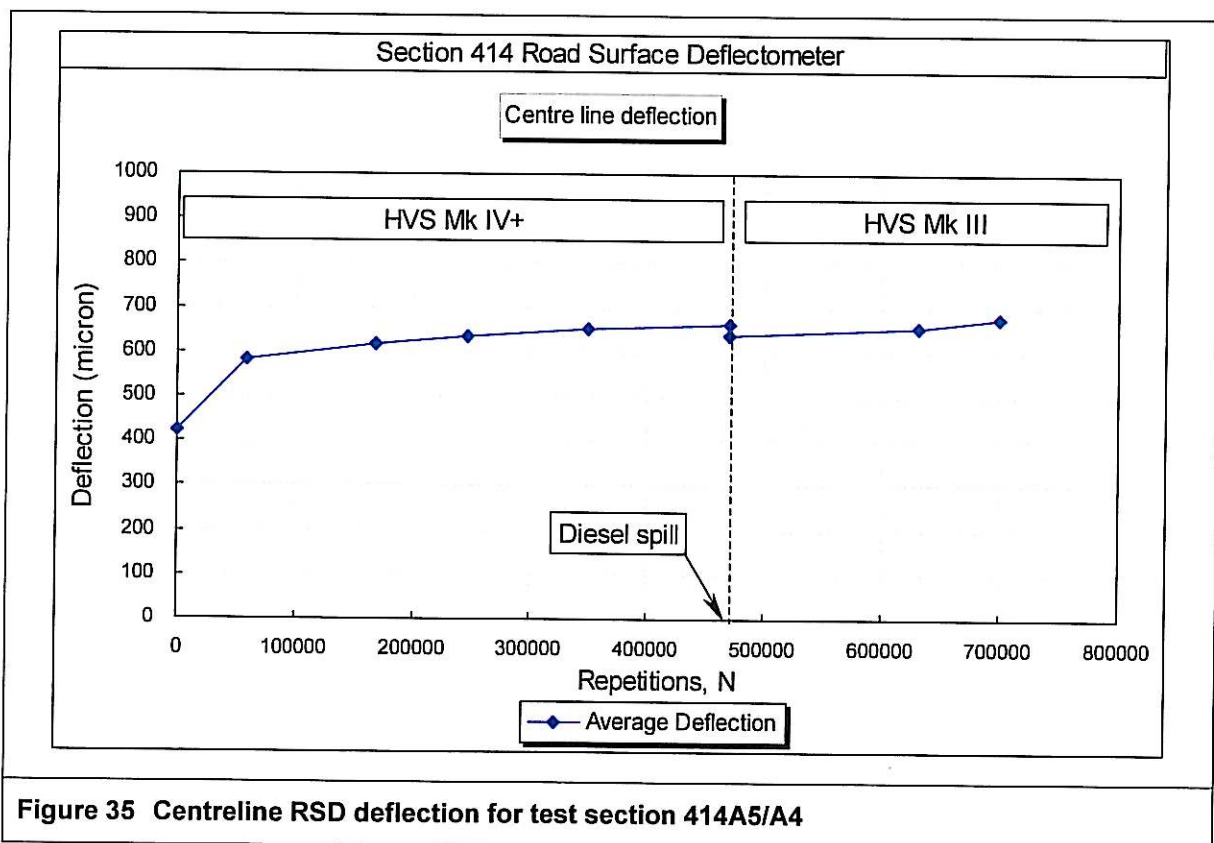


Figure 35 Centreline RSD deflection for test section 414A5/A4

#### *Straight edge and Laser Profilometer surface rut*

Figures 36 and 37 show the straight edge rut and Profilometer rut for test section 414A5/A4. The diesel spill had a profound effect on the measured rut. Severe deformation of the surfacing was experienced under trafficking. To counteract this deformation of the surfacing and to ensure that the pavement base layer remained intact and was not subjected to direct wearing as a result of the disintegration of the wearing course, a rubber mat 30 mm thick was placed on the section at 475 000 repetitions. Trafficking was performed on the rubber

mat, which was removed for deflection measurements. Since the rubber mat was only removed during instrument measurements, daily straight edge rut measurements were suspended at 475 000 repetitions.

As a result of the trafficking action the rubber mat 'bonded' to the softened asphalt layer and when the mat was removed the asphalt surfacing was removed in localised areas. Severe shoving of the asphalt was found at the outer extremities of the test section. The laser profilometer rut shown in Figure 37 indicates that the profile of the wearing course had been significantly altered due to the diesel spill and the subsequent dissolution of the binder. The rut decreased immediately after the spill because of fine sand that was placed on the section to absorb the diesel. This fine sand together with the diesel and dissolved binder formed a type of slurry that filled the rut. After this initial decrease in rut, the rut increased rapidly once trafficking resumed because of stripping and shoving of the surfacing layer.

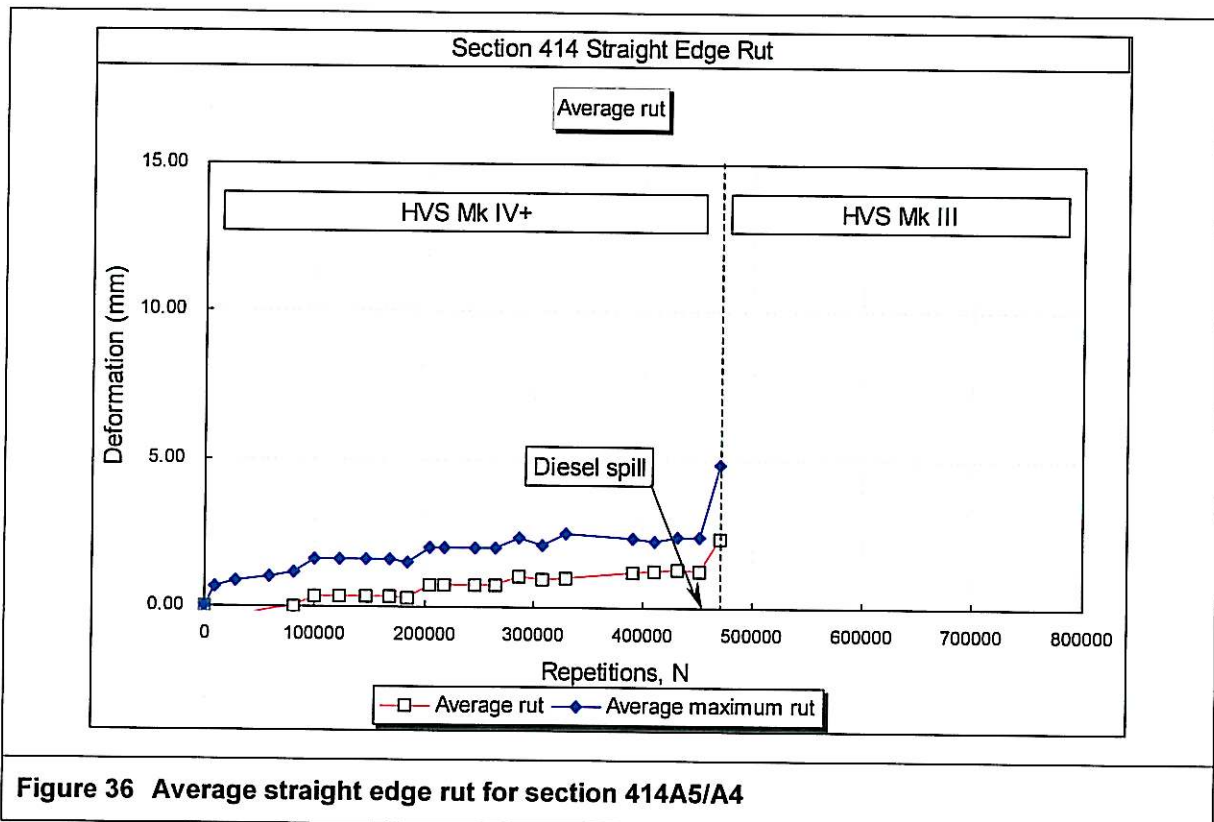


Figure 36 Average straight edge rut for section 414A5/A4

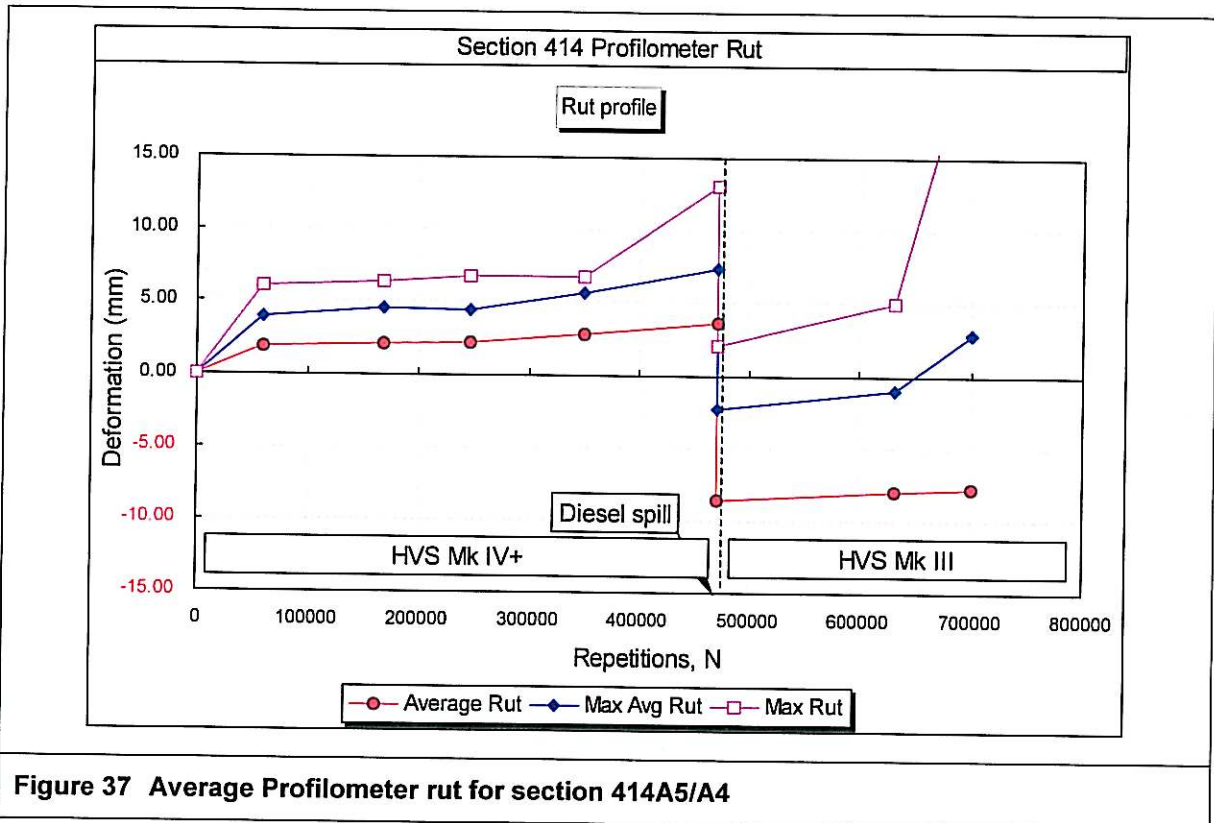


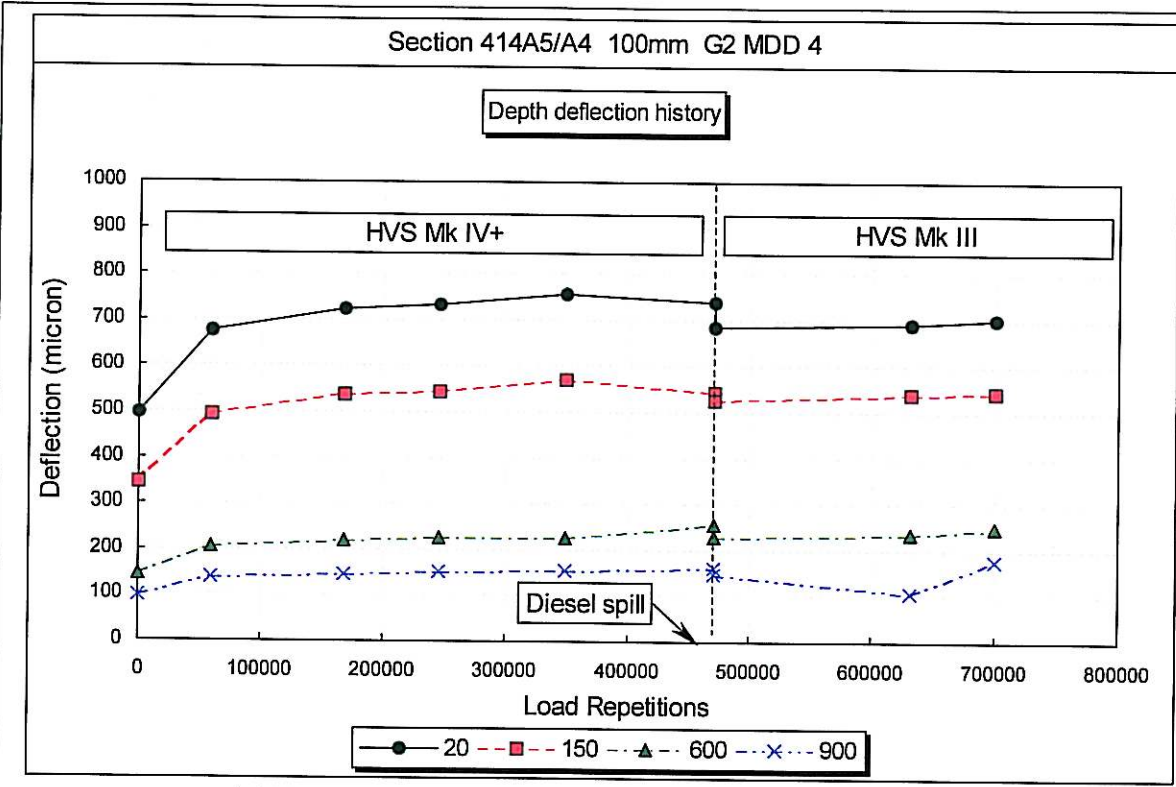
Figure 37 Average Profilometer rut for section 414A5/A4

### 3.3.3 Depth response data

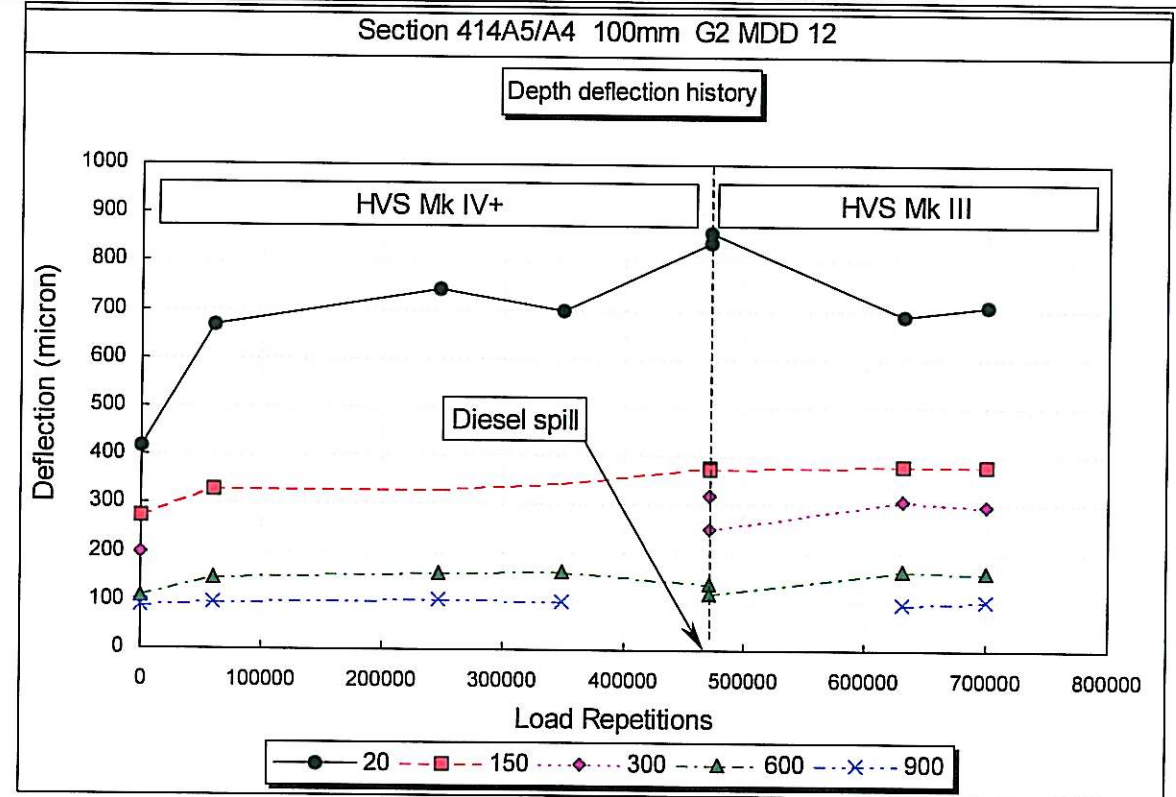
#### *Depth deflection data (MDD deflection data)*

The details of the MDD positions and module depths for test section 414A5/A4 are shown in Figures 1 and 4 and the spreadsheet template that is used for processing the depth deflection data is discussed in Section 3.1.2. Figures 38 (a) and (b) show the depth deflection history for MDD4 and MDD12 plotted for the duration of the HVS test on test section 414A5/A4. Figures 39 (a) and (b) show the depth deflection profile for MDD4 and MDD12 for test section 414A5/A4.

As with test section 413A4/A5, near linear increasing deflection trends with increased load applications were generally evident in all pavement depths, except at 20 mm at MDD12. The functioning of the top module at MDD12 could have been affected temporarily by the diesel spill. The deflection at all the modules (except the top cap at MDD12) decreased when HVS Mk III was put onto the section, compared to the deflection under HVS Mk IV+.



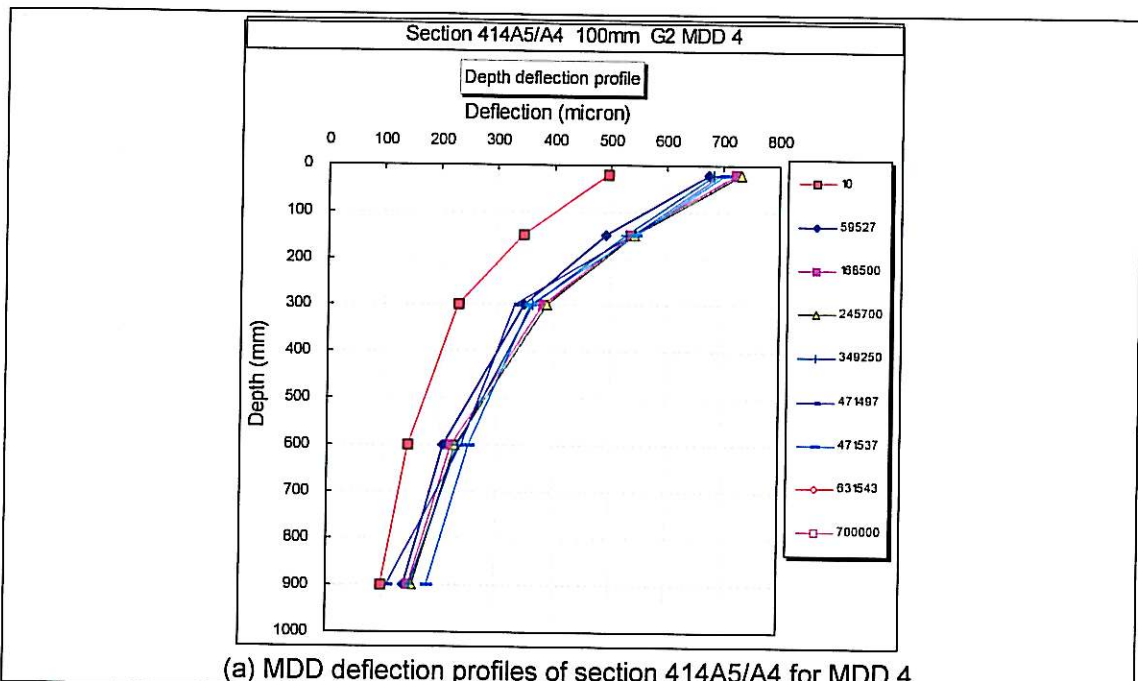
(a) MDD deflection for the duration of test 414A5/A4 at MDD 4



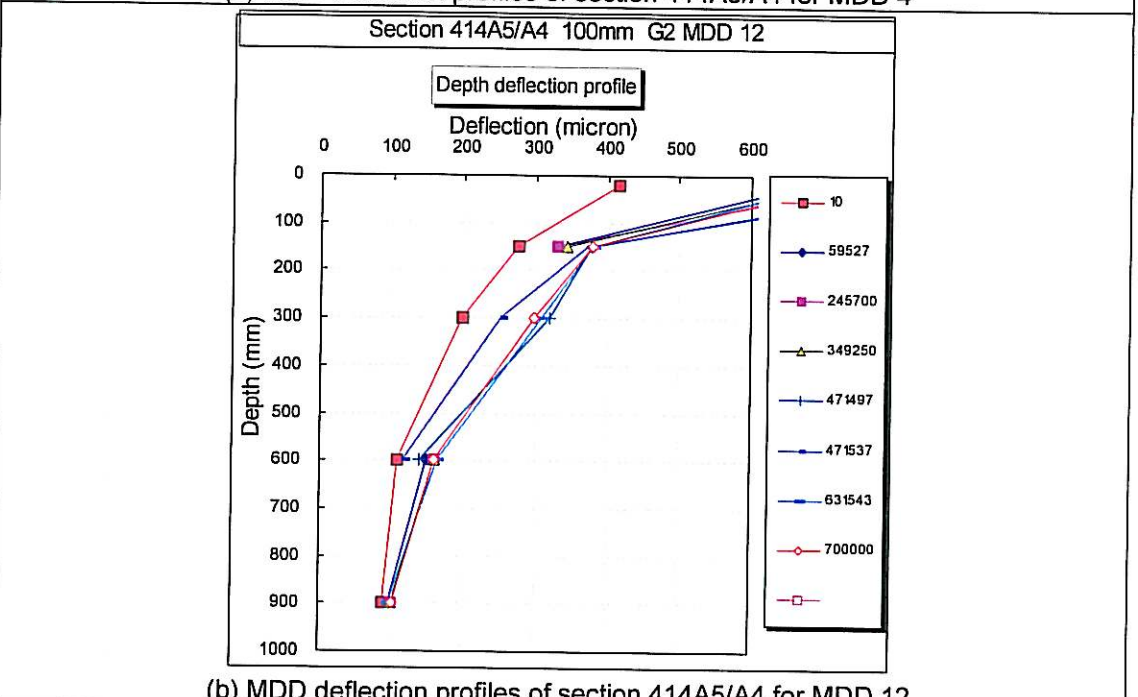
(b) MDD deflection for the duration of test 414A5/A4 at MDD 12

Figure 38 MDD depth deflection history for test section 414A5/A4





(a) MDD deflection profiles of section 414A5/A4 for MDD 4

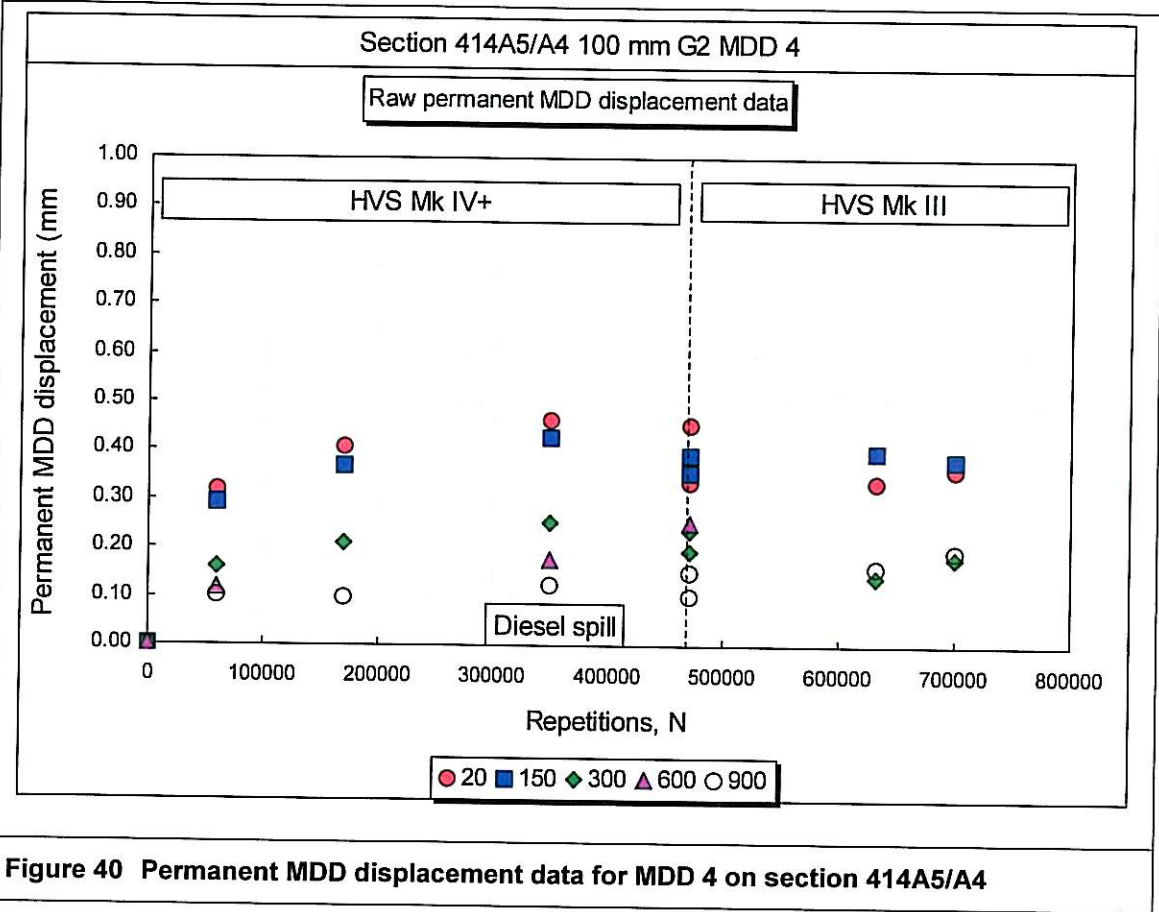


(b) MDD deflection profiles of section 414A5/A4 for MDD 12

**Figure 39 MDD deflection profiles for HVS test section 414A5/A4**

***MDD permanent displacement data***

Figure 40 shows the permanent displacement data for MDD4 of test section 414A5/A4. The diesel spillage on section 414A5/A4 affected the permanent displacement data from MDD12 to such an extent that the data had to be discarded. The permanent displacement data from MDD4 do, however, show that the increase in permanent deformation levelled off once HVS Mk III was put onto the section in contrast to Section 413A4/A5 where the permanent deformation increased for the second stage of the test under the HVS Mk IV+.



## 4. ASSESSMENT OF THE COMPARATIVE TEST RESULTS

HVS tests 413A4/A5 and 414A5/A4 were completed as part of the comparative testing of the pavement response under trafficking by the HVS MK III and HVS Mk IV+. The testing was completed at a uniform load and tyre pressure for each machine irrespective of the test section under trafficking. The HVS Mk III initially applied 471 497 load repetitions to test section 413A4/A5, while HVS Mk IV+ trafficked test section 414A5/A4. At 471 497 load applications on each test section, the two machines were swapped and trafficking continued (HVS Mk III on test section 414A5/A4 and Mk IV+ on test section 413A4/A5) until 700 000 load repetitions had been applied to both the test sections. Table 1 contains a summary of the traffic load and tyre pressure variables during all trafficking completed on test sections 413A4/A5 and 414A5/A4. This chapter contains a summary of the performance of HVS test sections 413A4/A5 and 414A5/A4.

### 4.1. Summary of Laser Profilometer Rut

Figure 41 shows the average laser profilometer rut for test sections 413A4/A5 and 414A5/A4. Limited rutting was present during the first phase of testing. The damage caused to the asphalt surfacing of both test sections at about 470 000 repetitions because of the oil and diesel spills precludes any assessment being made of the results obtained from data collected subsequent to 471 450 load repetitions.

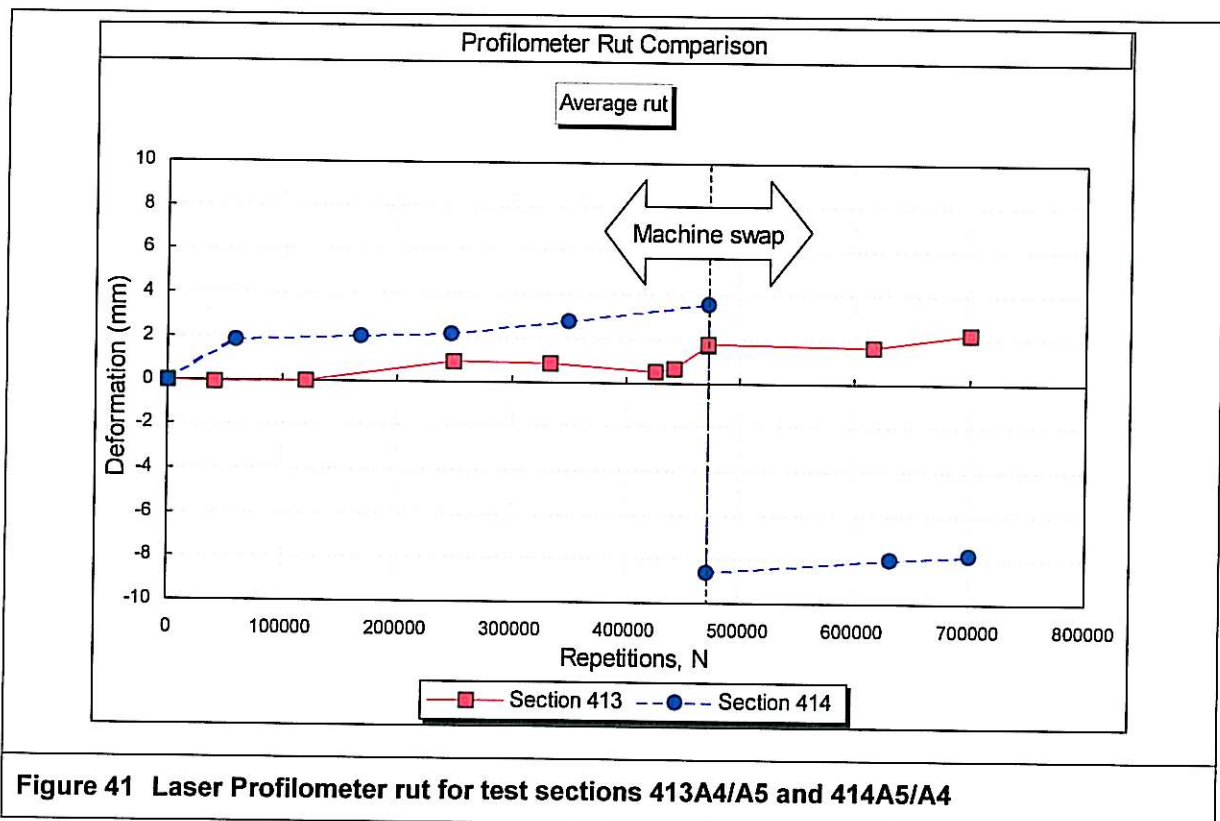


Figure 41 Laser Profilometer rut for test sections 413A4/A5 and 414A5/A4

From the initial data it is evident that test section 413A4/A5 experienced slightly less surface deformation than test section 414A5/A4. Since rutting is load dependent, it should be noted that test section 414A5/A4 was trafficked during the 1<sup>st</sup> stage of testing by HVS Mk IV+.

which was set at a load of 66 kN compared with the 62 kN load setting on HVS Mk III on test section 413A4/A5. This factor, in combination with the variation in tyre type could have resulted in the slightly higher surface deformation measured on section 414A5/A4 compared to that on section 413A4/A5. The magnitude of the surface deformation and the difference in surface deformation are, however, very small.

#### 4.2. Summary of Straight Edge Rut

Figure 42 shows a summary of the average straightedge rut for HVS test sections 413A4/A5 and 414A5/A4. Although the initial rut on section 414A5/A4 (HVS Mk IV+) during the 1<sup>st</sup> stage of testing is lower than that of section 413A4/A5 (HVS Mk III), the rate of increase in rut on section 414A5/A4 seems to be higher than that of section 413A4/A5.

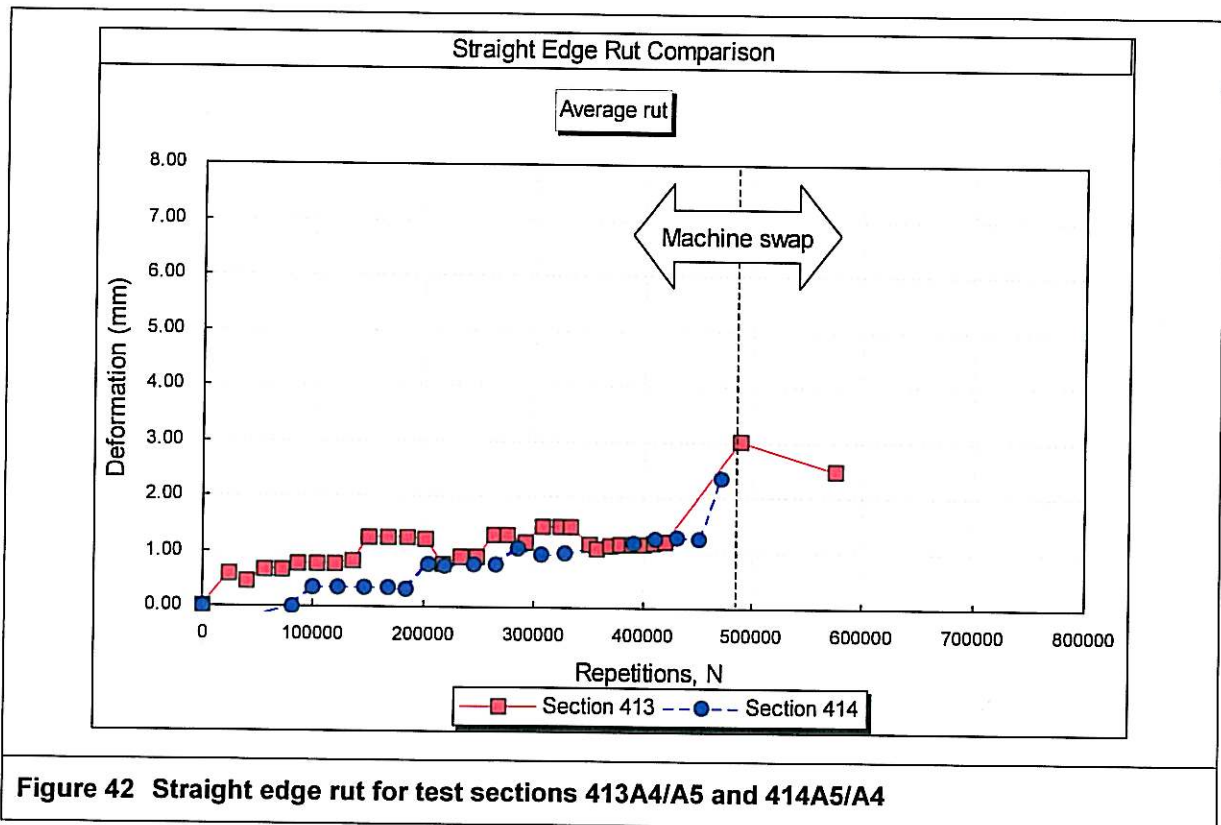


Figure 42 Straight edge rut for test sections 413A4/A5 and 414A5/A4

#### 4.3. Summary of Road Surface Deflectometer (RSD) Results

Figure 43 shows the combined RSD data for test sections 413A4/A5 and 414A5/A4. Both test sections show a linear increase in RSD deflection with increased repetitions. The deflections measured on test section 413A4/A5 are approximately 60% of those collected from test section 414A5/A4. Although only very slight, there was an increase in deflection on section 415A5/A4 at the changeover of the machines.

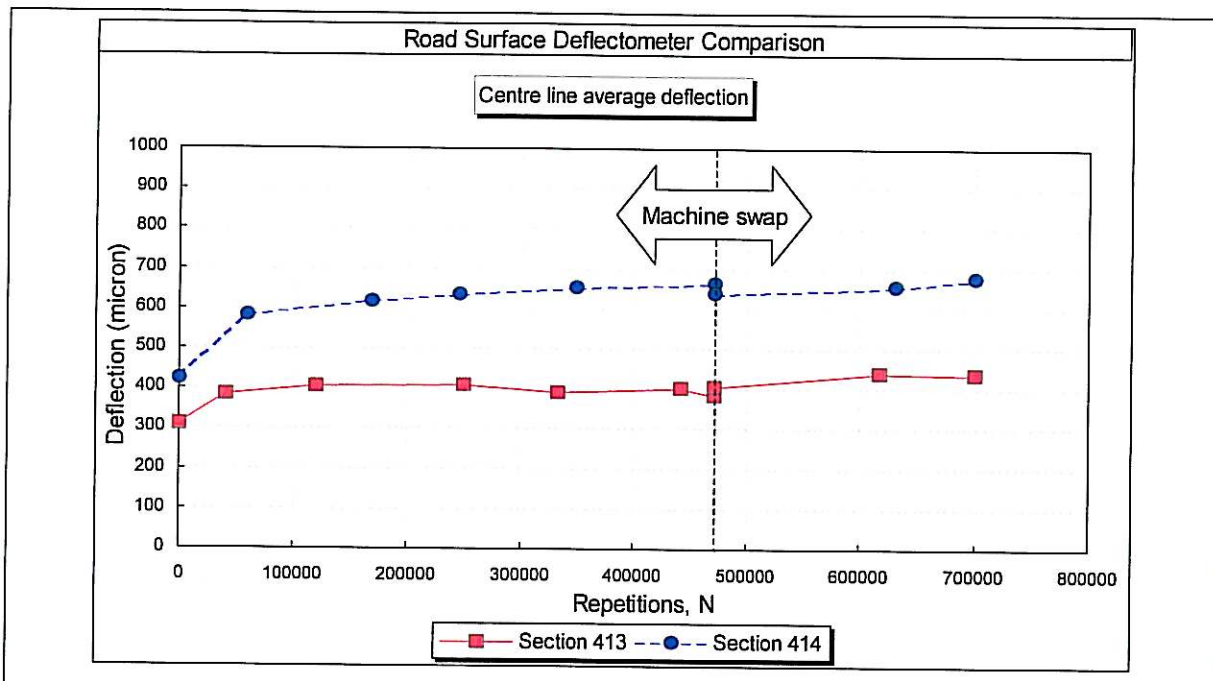
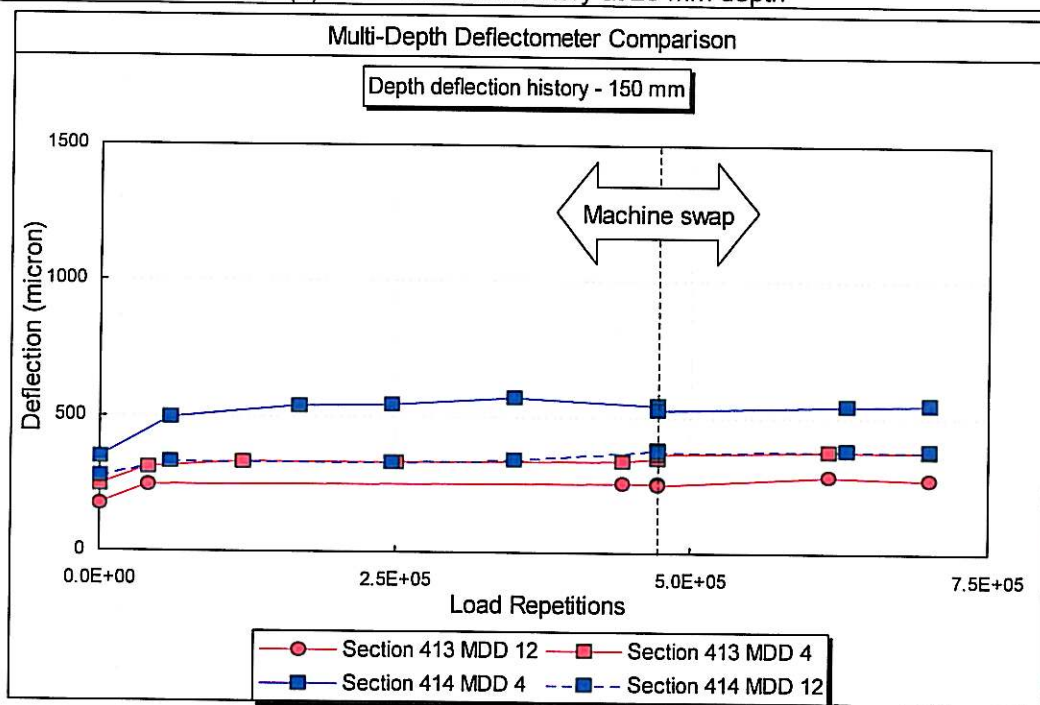
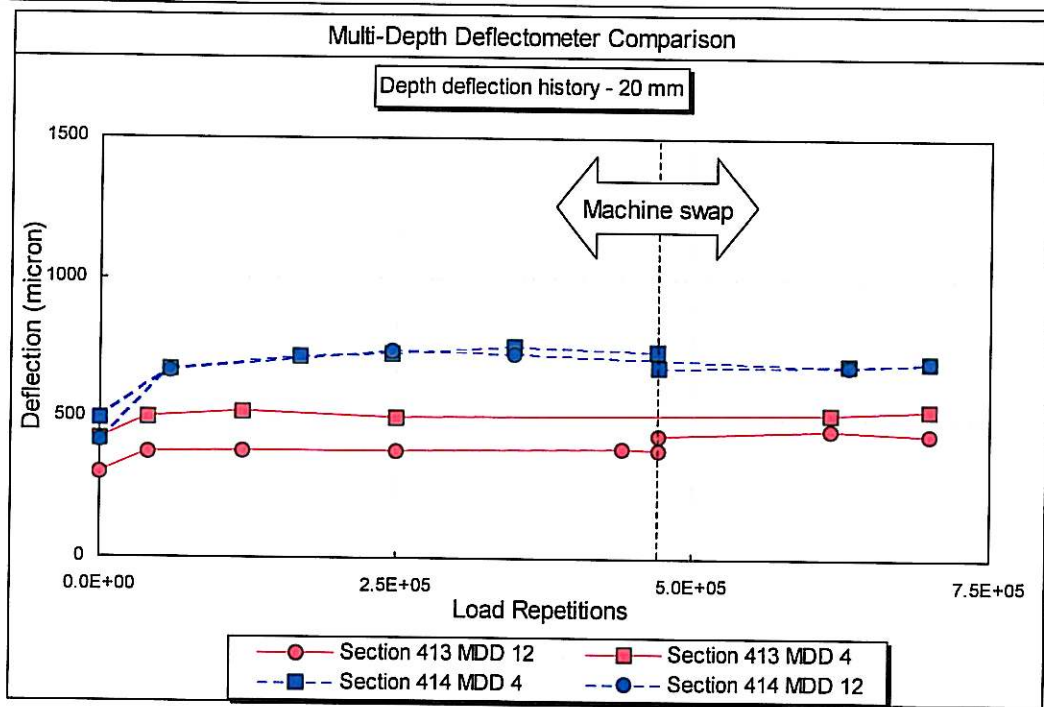


Figure 43 Average RSD centre line data for test sections 413A4/A5 and 414A5/A4

#### 4.4. Summary of Multi-Depth Deflectometer (MDD) results

Figure 44 (a) and (b) show the peak deflections at 20 mm and 150 mm for the load history of test sections 413A4/A5 and 414A5/A4. Linear pavement response trends were established in the depth deflection history of the MDDs in the all pavement layers, with slight variations in these linear trends evident after 471 497 load repetitions, when the two HVS machines were swapped.

Figures 44 (a) and (b) support the RSD results showing lower deflection results in test section 413A4/A5, which indicates higher pavement strength in this test section. Excellent correlation is evident between the RSD and the MDD results at 20 mm (Topcap) on test section 414A5/A4. Good correlation is present between the RSD and MDD results at 20 mm for test section 413A4/A5. The top cap MDD deflection on both test sections confirms the observation from the RSD deflection that the deflection slightly increased on section 413A4/A5 and decreased on section 414A5/A4 at the swap of the machines.



**Figure 44 Multi-Depth Deflectometer (MDD) results at 20mm and 150 mm for test sections 413A4/A5 and 414A5/A4**

## **5. COMPARISON OF HVS MK IV+ AND HVS MK III**

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### **5.1. Background**

This chapter is a deviation from the standard 1<sup>st</sup> level analysis reporting. It is however included to discuss the main objective of the project, namely the comparison of the pavement response under trafficking with the HVS Mk III and HVS Mk IV+. At the outset of testing it was envisioned that the two HVS machines would be compared with respect to surface and in-depth pavement response. The damage caused to the test section as a result of a hydraulic oil leak (test section 413A4/A5) and the diesel spill (test section 414A5/A4), prevents a fair comparison being made as to the change in permanent surface deformation under trafficking with the two machines. Thus, the permanent surface deformation comparison will be based on comparison of the results of test sections 413A4/A5 and 414A5/A4 up to 471 450 load repetitions. The surface deflection response and the in-depth pavement response and performance will be compared on a test section basis, showing the change, or lack thereof, in response to the two machines. In addition to the pavement response comparison, a brief comparison will be included on the productivity of the two machines.

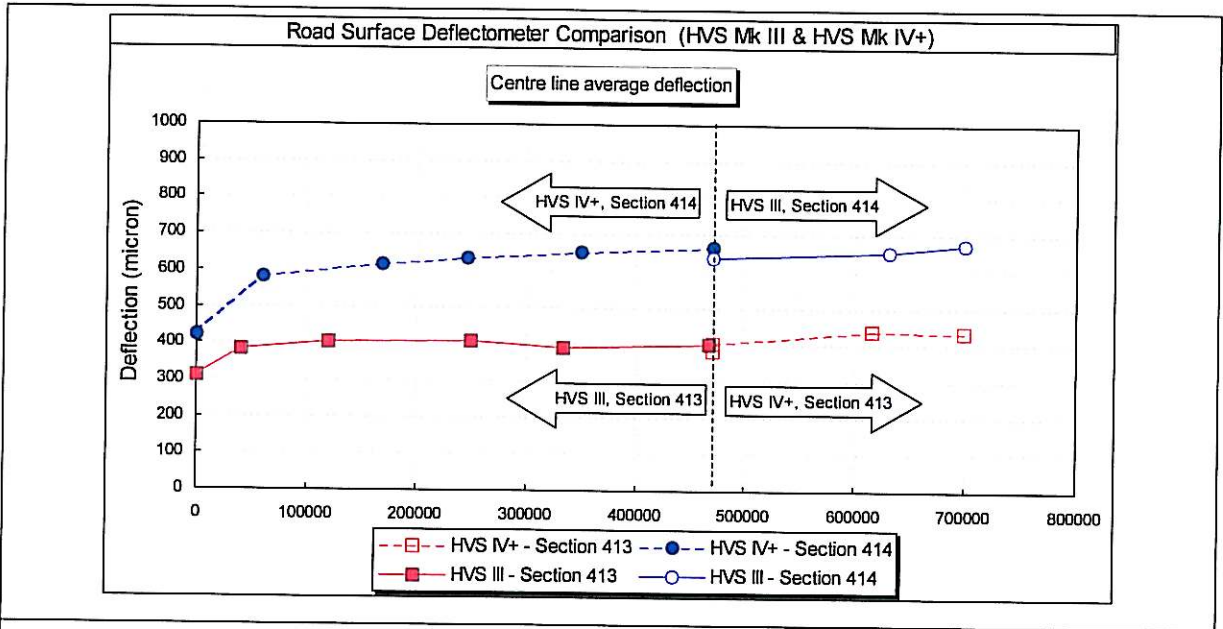
It should be noted that during the collection of this data, the same data acquisition system was utilised on both test sections 413A4/A5 and 414A5/A4, irrespective of the machine trafficking the section. This negated the possibility of any variation in results being caused by variation in the data collection process.

### **5.2. Surface Response Comparison**

#### **5.2.1 Road Surface Deflectometer (RSD) comparison**

Figure 45 shows the RSD results for test sections 413A4/A5 and 414A5/A4, as well as the load repetitions at which the machine swapped sections. Apart from the initial "bedding-in" phase during the first 50 000 load repetitions, the RSD results show a linear trend in pavement response with deflection increasing with increased trafficking. The swapping of the machines at 471 497 load repetitions resulted in a slight change in measured deflections on both test sections 413A4/A5 and 414A5/A4.

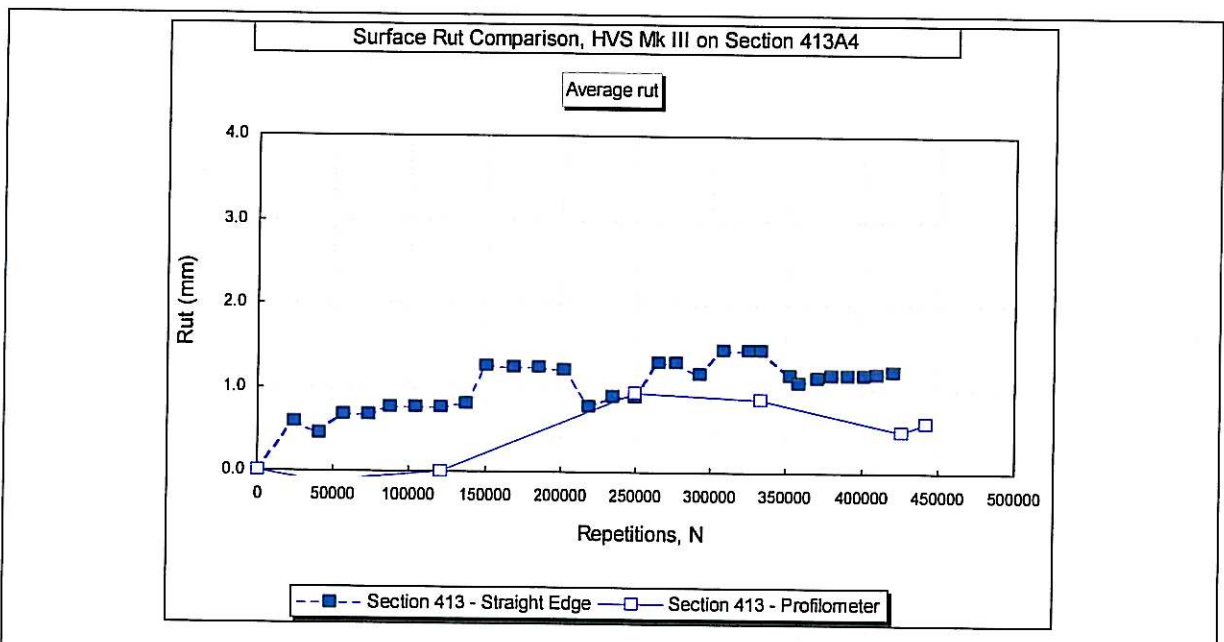
The swap from HVS Mk III to HVS Mk IV+ trafficking resulted in a very slight increase in the measured deflection, as was evident in the results for test section 413A4/A5. The swap from HVS Mk IV+ to HVS Mk III resulted in a decrease in deflection measured on test section 414A5/A4. The probable cause of this variation is the differences between the HVS Mk III and the HVS Mk IV+ with regards to applied load, tyre size and inflation pressure. The rate of pavement deterioration during the two phases of testing (slope of the average deflection line) is similar for both test sections .



**Figure 45 Comparison of RSD results for HVS Mk III and HVS Mk IV+**

**5.2.2 Straight edge and Laser Profilometer surface rut comparison**

Figures 46 and 47 show the surface rut for sections 413A4 and 414A5 up to 471450 load repetitions before the oil and diesel spills occurred. The data collected after the oil and diesel spills are not reliable and were therefore omitted for the comparison of the surface rut under HVS Mk III and Mk IV+. Although the magnitude of the average rut calculated from the straight edge and laser profilometer differs, both instruments indicate the same pattern regarding the rate of increase in surface rut. The rut levelled off on section 413A4/A5 under HVS Mk III towards the end of the 1<sup>st</sup> stage of testing while the rut on section 141A5/A4 under HVS Mk IV+ kept on increasing at a linear rate towards the end of stage 1. This observation is supported by the MDD permanent displacement data.



**Figure 46 Average surface rut data for test section 413A4 under HVS Mk III**



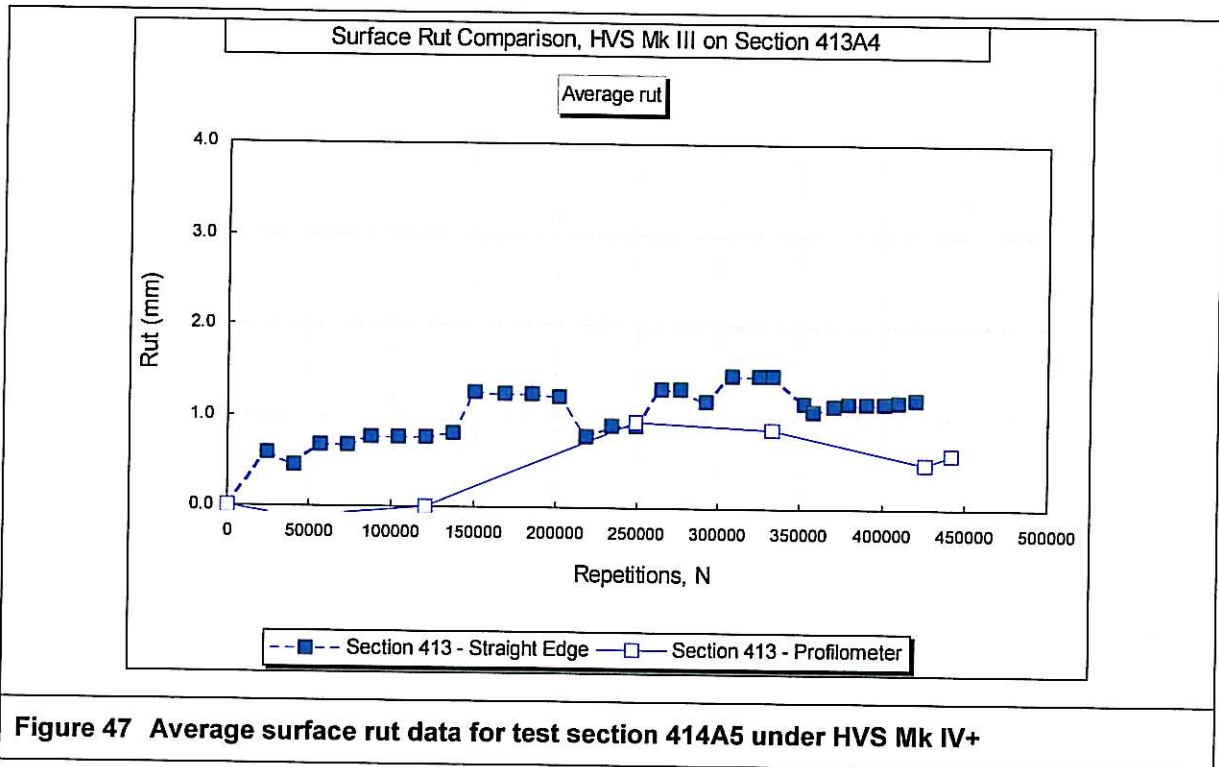


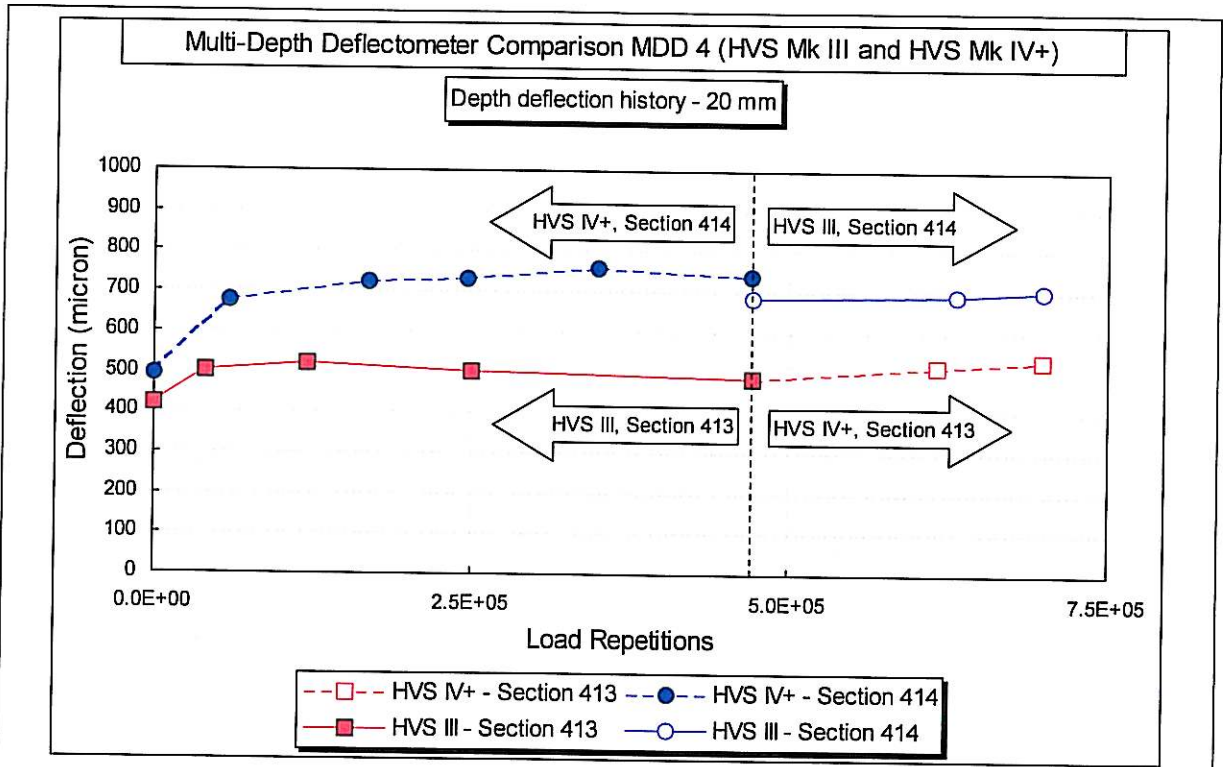
Figure 47 Average surface rut data for test section 414A5 under HVS Mk IV+

### 5.3. Depth Response Comparison

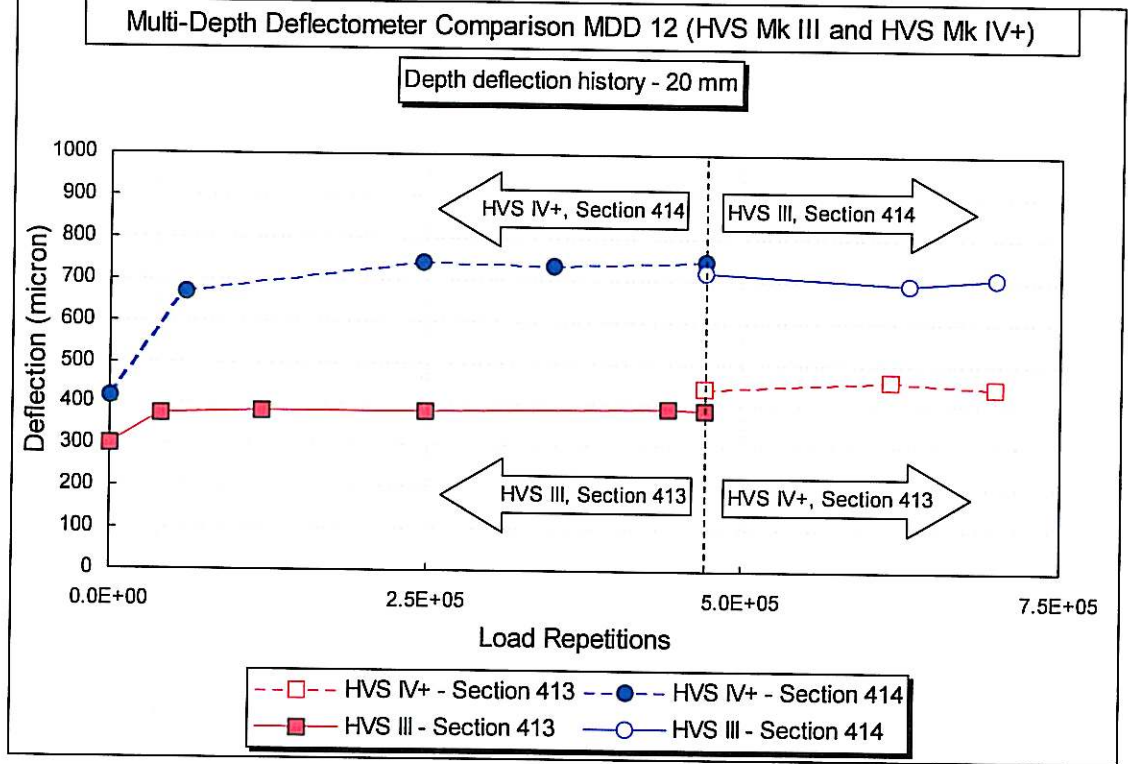
#### 5.3.1 Depth deflection comparison (MDD deflection data)

Figures 48 (a) and (b) show the depth deflection comparison at 20 mm for MDD4 and MDD12, respectively. MDD4 in test section 413A4/A5 shows very good correlation between the results measured before and after swapping of the machines. The other MDDs exhibited the same variation in results when the machines were swapped, as identified in the RSD results. As with the RSD the general trend was for the results to decrease slightly with the change from trafficking with HVS Mk IV+ to HVS Mk III, and to increase with the change from HVS Mk III to HVS Mk IV+. Constant deflection trends were established by all MDDs in both phases of testing.

Figures 49 (a) and (b) show the depth deflection comparison at 150 mm for MDD4 and MDD12, respectively. At 150 mm the deflection results show a linear trend. The linear performance trend is significantly better at 150 mm than what was observed at 20 mm. Furthermore, the slight variations found between results surrounding the changing of the machines (at 20 mm depth) is not prominent. This points to the variation in results being controlled by differences in tyre size and inflation pressures. Surface deflection results (20 mm) are more tyre contact stress sensitive than deflections at deeper depths (150 mm), which are more load sensitive.

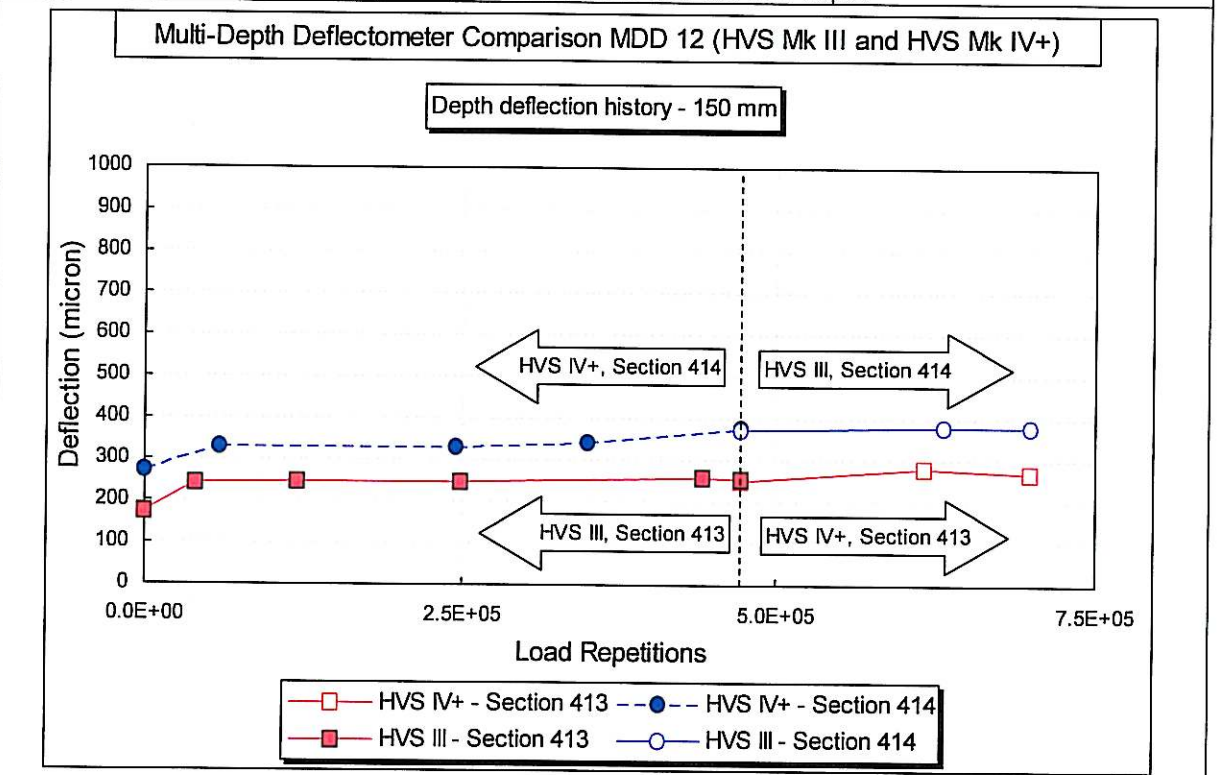
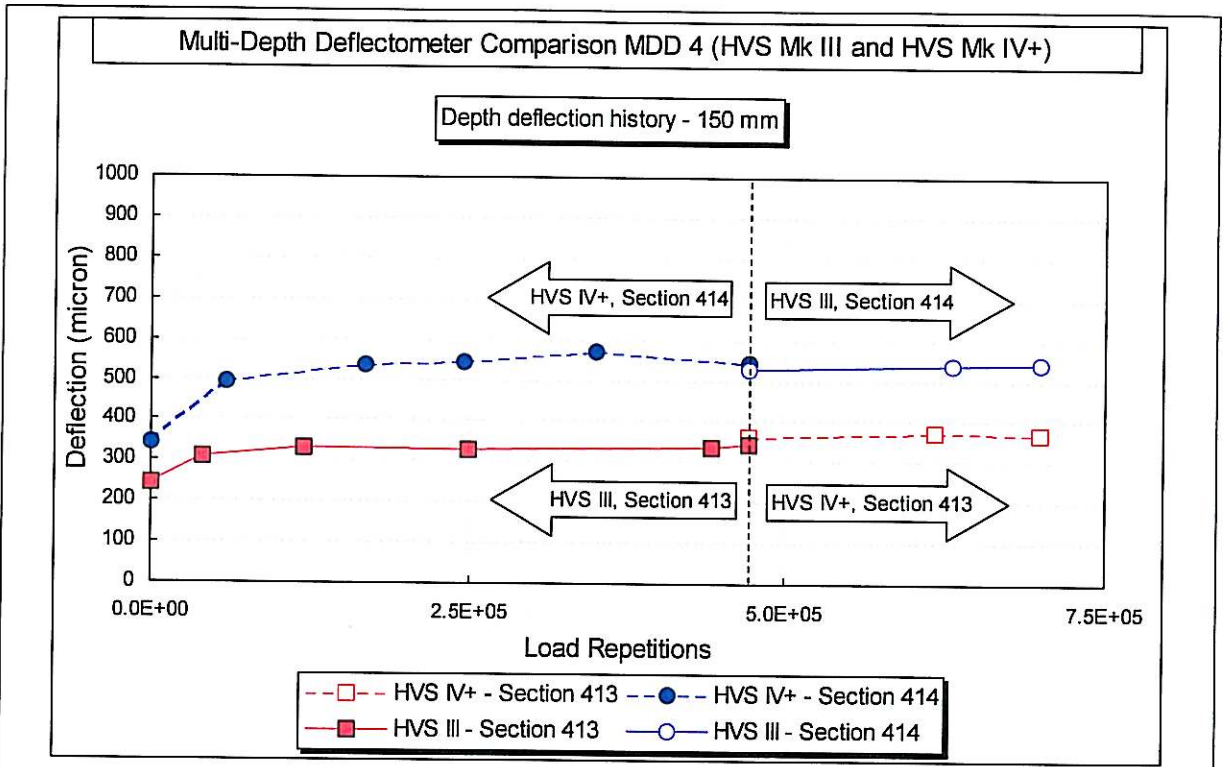


(a) Comparison for MDD 4 at 20 mm depth



(b) Comparison for MDD 12 at 20 mm depth

Figure 48 Comparison of MDD results at 20 mm for HVS Mk III and HVS Mk IV+



**Figure 49 Comparison of MDD results at 150 mm for HVS Mk III and HVS Mk IV+**

#### **5.4. Productivity Comparison**

The productivity of the two machines was monitored throughout the testing. Due to breakdowns and the resultant delays caused by the hydraulic oil leak and the diesel spill a direct comparison of the performance of the machines cannot be fairly made from their productivity over the entire test period. However, the productivity of the best week of operation of the machines has been compared.

The HVS Mk III achieved a maximum productivity of 110 219 load repetitions in a week, which relates to 15 745 repetitions per day. The maximum productivity of the HVS Mk IV+ was 159 073 over a 6.5 day period, which relates to 24 475 repetitions per day. Thus, based on the comparative testing project, the HVS Mk IV+ provides a 55% improvement in productivity. This increased productivity corresponds closely with the increased trafficking speed (60%).

## 6. CONCLUSIONS AND RECOMMENDATIONS

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Analyses of the comparative results presented in this report indicate that the differences in the induced pavement response under the two HVS machines are small and of the magnitude of the variation normally associated with HVS testing. Although these differences were small, the consistency with which the pavement response, as measured with different instruments, changed from one machine to the other on both test sections, indicates that these changes may not be ascribed to random variation and are therefore ignored.

### 6.1. Conclusions

Taking into account the variation between the initial pavement strength in test sections 413A4/A5 and 414A5/A4, the performance of the two test sections under HVS trafficking exhibited good correlation between sections. The rate of increase of deflection and permanent deformation is comparable, and a linear trend was established in surface response and depth response in both the test sections.

The damage caused to the asphalt surfacing of the test sections negates the possibility of coming to any significant conclusion with regards to the permanent surface deformation of test sections 413A4/A5 and 414A5/A4 after the oil and diesel spills. The rut developed prior to the damage was relatively small, representing approximately 30% of the maximum allowable rut to failure of the pavement. There were, however, indications that the rut rate on section 414A5/A4 (trafficking by HVS IV+) was higher than the rut rate on section 414A4/A5 (trafficked by HVS III) during the first stage of testing.

Surface deflection increased on section 413A4/A5 once HVS IV+ was put onto the section while the surface deflection on section 414A5/A4 decreased when the machines were swapped. The changes in surface deflection were, however, small. These changes in the surface deflection were confirmed by the MDD top cap deflections.

Whereas the changes in elastic response were consistent but small, the difference in the rate of permanent deformation measured by the MDD system under the two HVSs caused more concern. The higher rate of permanent deformation is even reflected by the MDD modules at a depth of 150 mm on section 413A4/A5. The rate of surface rut measured by the straight edge and laser profilometer for the first stage of testing confirms this observation made from the MDD data.

These differences in pavement response to the two HVS machines may be attributed to:

- Differences in the frequency at which the pavement is loaded because of the higher trafficking speed of HVS Mk IV+. This will result in shorter rest periods under HVS Mk IV+ and less opportunity for the pavement to recover, hence the higher permanent deformation;
- Differences in the total load applied by the two machines although an attempt was made to eliminate this effect through calibration of the load settings on the machines;
- Differences in the contact stress distributions applied by the two different tyre brands and widths used on the two machines.

The difference in trafficking speed cannot explain the changes in the elastic response of the test sections. It is therefore not likely that the difference in trafficking speed is the cause of

the differences in the observed behaviour of the test sections. The difference in the observed behaviour is more likely to be related to the total applied load or the contact stress distributions.

Increased productivity of the HVS Mk IV+ compared to the HVS Mk III is a significant improvement. Under optimal conditions it could result in a 50% increase in productivity. This results in a substantial saving in terms of the time and cost of testing. The advantages that the HVS Mk IV+ therefore has over the HVS Mk III are increased productivity and associated reduction in cost, as well as certain automated measurement capabilities and improved safety and control aspects.

## **6.2. Recommendations**

Tests conducted by the HVS Mk III and HVS Mk IV+ exhibited similar rates of increase of pavement deflection response parameters (MMD and RSD results). Thus, use of the HVS Mk IV+ for all subsequent HVS testing in South Africa will provide close to identical deflection results to those that would be obtained from using the HVS Mk III.

The differences in permanent deformation response, however, cause concern as these differences could lead to different conclusions regarding the permanent deformation bearing capacity of the pavement depending on which HVS is used for testing. The differences in the permanent deformation behaviour of sections 413A4/A5 and 414A5/A4 were most likely caused by differences in the total load or differences in the magnitude and pattern of the contact stresses. An attempt was made to eliminate differences in the total applied load by developing load calibration curves for the two machines and then adjusting the load settings on the machines so as to ensure an equal total applied load. This calibration was, however, done at creep speed. The total load at operational speed may be quite different from the total load at creep speed. An investigation of the contact stresses and total load at operational speed is therefore required. It is recommended that a stress-in-motion (SIM) survey should be conducted for the two machines at operational speed. A proposal for such work will be prepared.

## 7. REFERENCES

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**Appendix A:  
Proposal**

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**PROJECT PROPOSAL GAUTRANS/PP/2002/02**  
27 June 2002

**COMPARATIVE TESTING BETWEEN  
HVS Mk III AND HVS Mk IV+**



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The content of this document is confidential

## 1 BACKGROUND

After many years of owning and operating a HVS Mk III, Gautrans recently acquired a HVS Mk IV+. In addition to the advanced features of this machine compared to the HVS Mk III, the Mk IV+ has certain operational advantages as well that will make it more efficient than the Mk III.

## 2 PROBLEM STATEMENT

Gautrans will use the Mk IV+ machine on their APT project in future. The differences between the Mk III and Mk IV+ machines may lead to differences in pavement response and test results. Although there are many mechanical differences between the machines, the variables that could influence the HVS test results are:

- The total load applied by the Mk III and Mk IV+ machines. Although this should not be a problem if both machines are properly calibrated, the load control system of the Mk III machine is not as accurate as that of the Mk IV+. The load of the Mk III HVS is manually set based on a hydraulic oil pressure reading while for the Mk IV+, the load is constantly monitored electronically and adjusted by a hydraulic servo-valve;
- The speed of operation and number of loads applied per time period of the Mk IV+ is significantly higher than that of the Mk III. The maximum speed for the Mk III HVS is 6,5 km/h and that of the Mk IV+ is 12,8 km/h;
- The contact stress distribution patterns will differ between the two machines as the tyres are different. A pair of 279 mm wide tyres can

be fitted to the Mk III HVS while the Mk IV+ can be fitted with either a pair of 304 mm or 315 mm wide tyres.

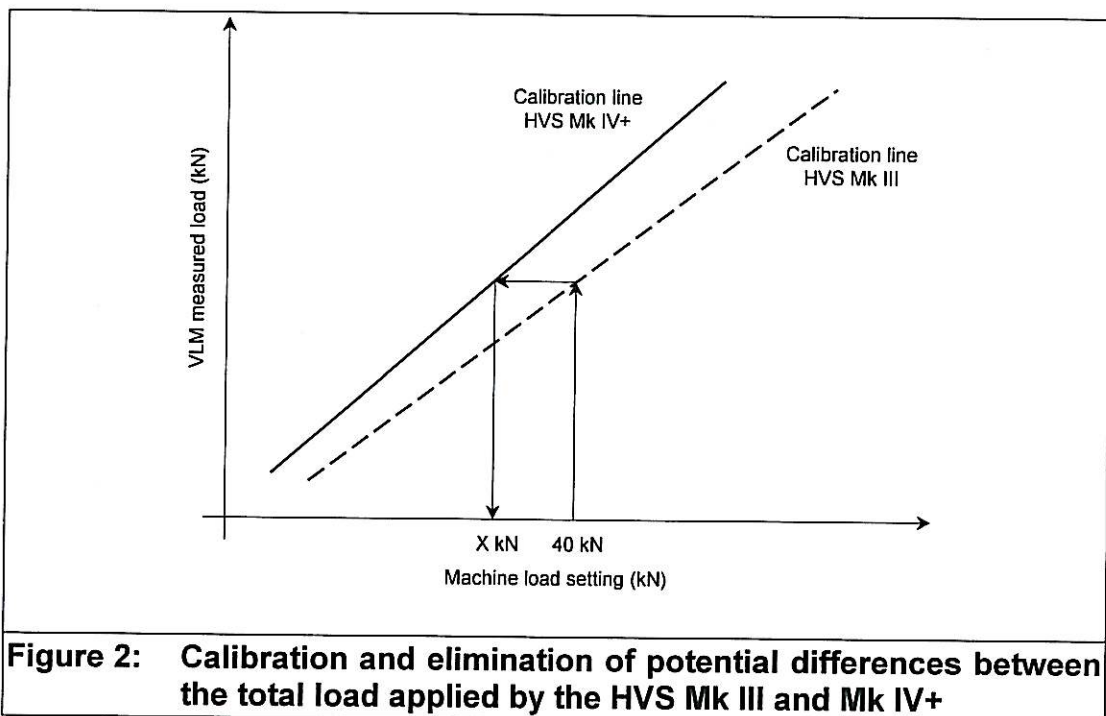
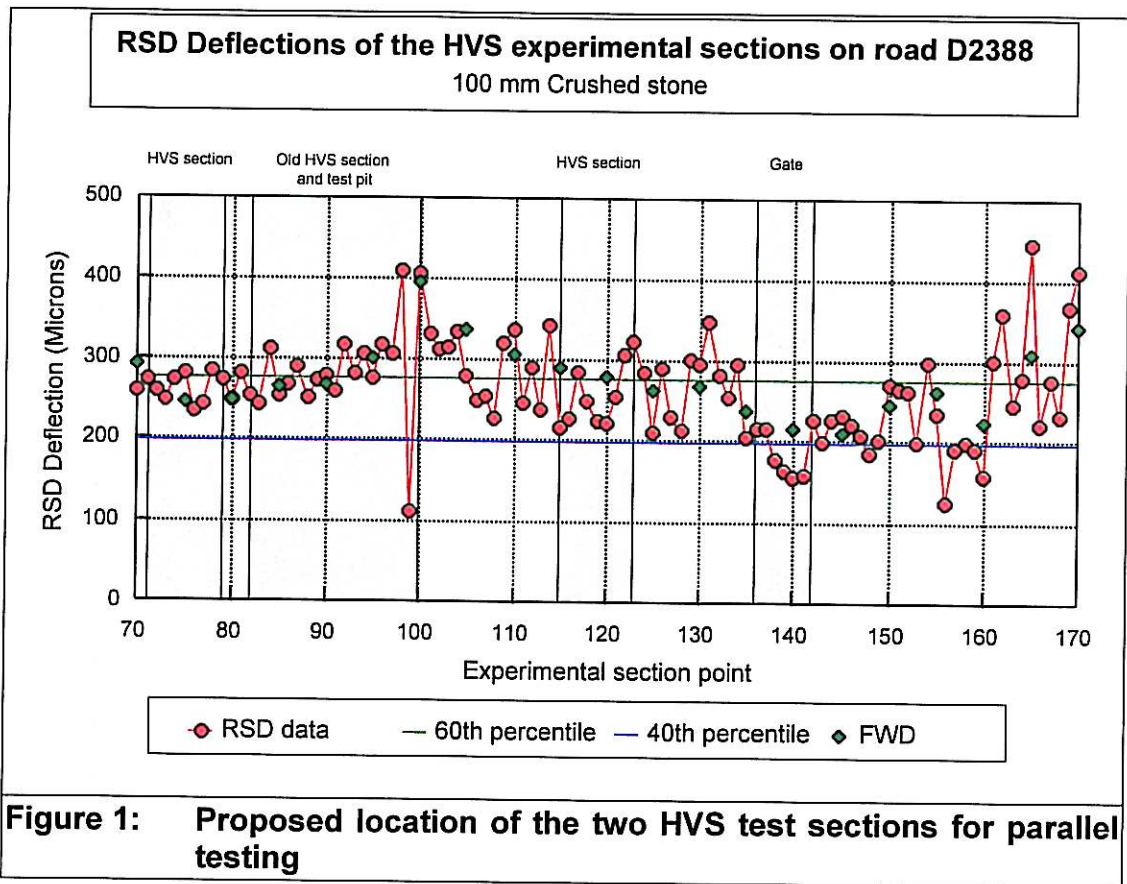
### 3 METHODOLOGY

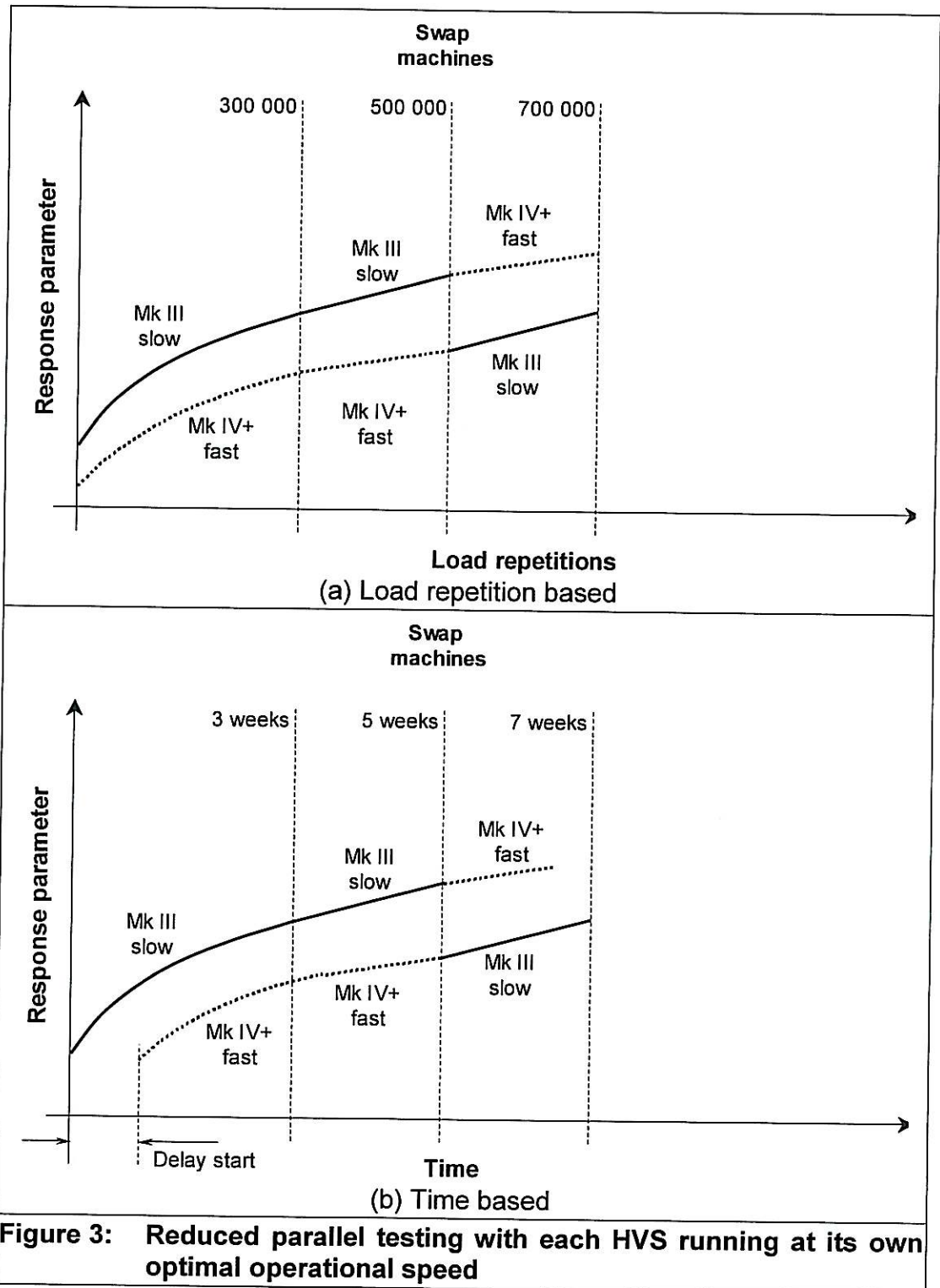
The process that is recommended is aimed at investigating the differences between the machines and their effect on pavement behaviour under accelerated testing. Essentially, the project consists of parallel testing between the two machines on two test sections on one of the experimental road sections on road D2388 near Cullinan. The 100 mm thick crushed stone experimental section on road D2388 was selected for the comparative tests. The 100 mm thick emulsion treated gravel section was also considered but not selected because of deterioration of the section from 1998 to date without any trafficking. The two HVS test sections were selected based on deflection data and practical limitations such as the location of the previous HVS test. Figure 1 shows the proposed location of the two test sections.

The comparative test program consists of three tasks, the first two tasks are covered by this proposal but because of its specialised nature, a separate proposal will be prepared for the third task:

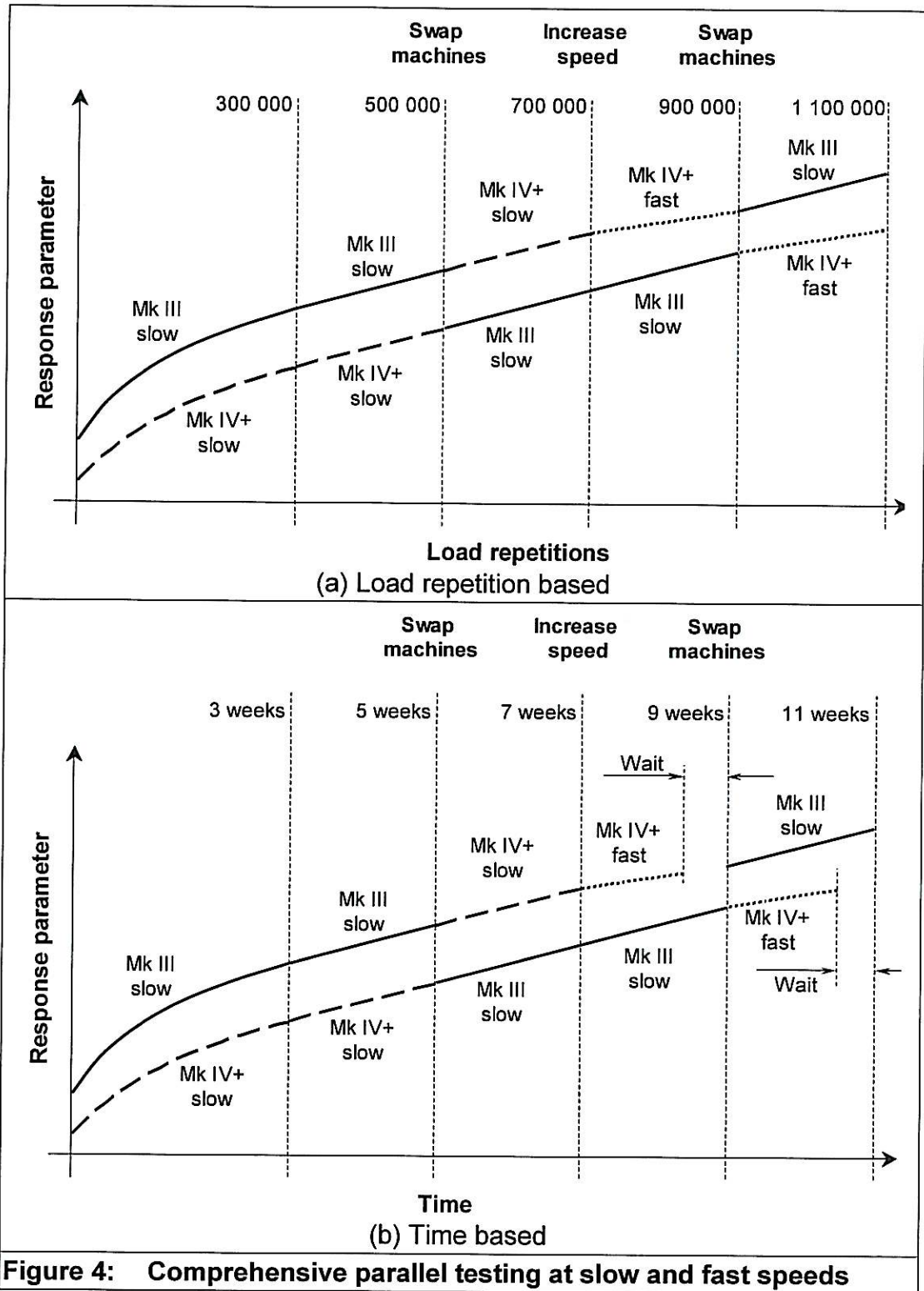
- The first task will be to develop total load calibration curves for both machines. This will be done prior to the two machines moving onto the site. The Vehicle Load Monitor (VLM) will be used as the calibration device. The procedure illustrated in Figure 2 will be used to eliminate potential differences in the total load applied by the two HVSs. The intention is to eliminate the total load as one of the potentially different variables during parallel testing on the road D2388.
- The second task consists of parallel testing on two test sections on the 100 mm thick crushed stone portion of the Cullinan site. The total load will be eliminated as a variable during the parallel tests by using the load calibration curves developed set an equal load on the two machines. There are two options for the second task:
  - The simplest option would be to operate the Mk IV+ HVS at a fast speed from the onset of the parallel tests while HVS Mk III runs at the normal operating speed used during previous HVS tests. Once the linear response patterns are established for both machines, each on a particular test section, the two machines are swapped. A hypothetical illustration of this option is shown in Figure 3 plotted against load repetitions and time.

- The second option is to let the two HVSs operate at the same slow speed of which the HVS Mk III is capable. Once the linear response patterns at a slow speed are established for both machines, each on a particular test section, the two machines are swapped and testing continues at a slow speed to establish the linear response pattern for each machine on the new test section. After this, the speed of the new machine is increased for a sufficient number of load repetitions to establish the linear response pattern. The machines are then swapped again and the linear response patterns determined for the last time. A hypothetical illustration of this option is shown in Figure 4 plotted against load repetitions and time.
- The third task involves the investigation of the differences in the contact stress patterns for the HVS Mk III and IV+ machines. This task will be addressed in a separate proposal.





**Figure 3: Reduced parallel testing with each HVS running at its own optimal operational speed**



**Figure 4: Comprehensive parallel testing at slow and fast speeds**

**4 PROJECT DELIVERABLES**

The deliverable from the project will be a report comparing the pavement response of two test sections under loading by the HVS Mk III and Mk IV+. Possible explanations for any significant differences in the response of any of the test sections under the two HVS machines will be investigated.

## 5 PROJECT PLAN

The project plan is already reflected in Figures 3 and 4 depending on the option that is selected. Loading will be in wandering mode at 70 kN. A final test plan will be developed before testing commences. Readings will be taken twice a week and should include digital photographs, nuclear density and moisture content readings, RSD, rut, laser profilometer, MDD deflections and MDD permanent displacement. DCP and test pit data are regarded as optional as these tests will only be done at completion of the parallel HVS tests. These tests will not be able to differentiate between the two HVS machines.

The cost set out in the table below only serves as an estimate because the HVS test plan may be adjusted during testing.

<b>Comprehensive parallel testing option</b>			
Task	Activities included	Duration	Cost
Load calibration	1. Load measurements 2. Data processing	1 week	R 12 764,00
Deflection testing	1. Deflection tests 2. Data analysis	2 days	R 6 985,00
Parallel testing	1. Operation 2. Supervision and management	11 weeks	R 825 510,94 R 88 768,30
Data analysis	1. Visual data 2. Temp, density and MC 3. RSD data 4. Manual rut 5. Profilometer data 6. MDD deflection 7. MDD PD data	9½ weeks	R 99 300,00
Report		4 weeks	R 64 480,00
Total duration and cost (excluding VAT)		25½ weeks	R 1 097 808,24
		(VAT 14 %)	R 153 693,15
		<b>Total cost</b>	<b>R 1 251 501,39</b>

<b>Reduced parallel testing option</b>			
Task	Activities included	Duration	Cost
Load calibration	3. Load measurements 4. Data processing	1 week	R 12 764,00
	3. Deflection tests 4. Data analysis	2 days	R 6 985,00
Parallel testing	3. Operation 4. Supervision and management	7 weeks	R 507 455,49
Data analysis	8. Visual data 9. Temp, density and MC 10. RSD data 11. Manual rut 12. Profilometer data 13. MDD deflection 14. MDD PD data	7 weeks	R 63 107,10
Report		3 weeks	R 80 800,00
Total duration and cost (excluding VAT)		18 weeks	R 54 080,00
		(VAT 14 %)	R 725 191,49
		<b>Total cost</b>	<b>R 101 526,81</b>
			<b>R 826 718,30</b>

The project team will consist of the following individuals with their responsibility as indicated:

W Diedericks	Operation, execution of test plan
L du Plessis	Operational management
C Fisher	Instrumentation, data processing, associated testing
M Muthen/B Morton	Data analysis, technical management, reporting
H L Theyse	Technical review, project management

## 6 SCHEDULE

The reduced parallel testing option was selected. The project schedule is shown in the table below. This schedule is only an estimate as the HVS test plan may change during testing.

	Schedule					
	5/2002	6/2002	7/2002	8/2002	9/2002	10/2002
Load calibration						
Parallel testing						
Data analysis						
Report						



