APPLICATION OF THE PORTABLE PAVEMENT SEISMIC ANALYSER (PSPA) FOR PAVEMENT ANALYSIS

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ABSTRACT

The Portable Seismic Pavement Analyser (PSPA) is a non-destructive device used for the evaluation of the seismic stiffness of a pavement structure. The device can be used to obtain basic information on the condition of the pavement structure, including parameters such as the seismic stiffness of the combined layers, indications of layer thicknesses and indications of an-isotropy in the pavement. When monitoring a pavement over a period of time, changes in the pavement structure can become visible. This information is useful in developing an understanding of the changes occurring in a pavement with increasing traffic loading. In this paper the concept behind the PSPA is discussed, followed by information on a study conducted for the Gauteng Department of Public Transport, Roads and Works (GDPTRW). Data were collected from a range of pavement types, including Long-Term Pavement Performance (LTPP) sections and Heavy Vehicle Simulator (HVS) test sites. The data are analysed for repeatability, variability, isotropy, and ranges of seismic stiffness values. Information is provided on the protocol developed for using the PSPA and finally some conclusions and recommendations are provided.

1 INTRODUCTION

The Portable Seismic Pavement Analyser (PSPA) is a non-destructive device used for the evaluation of the seismic stiffness of a pavement structure (Figure 1). The device can be used to obtain basic information on the condition of the pavement structure, including parameters such as the seismic stiffness of the combined layers, indications of layer thicknesses and indications of an-isotropy in the pavement.

The Gauteng Department of Public Transport, Roads and Works (GDPTRW) procured a PSPA in an effort to obtain more detailed information on the behaviour in the upper layers (i.e. up to 300 mm) of pavement structures, specifically during research projects. The PSPA is thought to be able to provide more detailed information on the changes in pavement properties inside these upper layers during vehicular loading than devices such as the Falling Weight Deflectometer (FWD). It is currently specifically used on a Hot Mix Asphalt research project for GDPTRW. More detailed analysis of data obtained from this project will be presented when these studies are concluded.

In this paper the concept behind the PSPA is briefly discussed, followed by information on a study conducted for the GDPTRW. Data were collected from a range of pavement types, including Long-Term Pavement Performance (LTPP) sections and Heavy Vehicle Simulator (HVS) test sites. The data are analysed for variability, isotropy and typical ranges of seismic stiffness values. Information is provided on the protocol developed for using the PSPA and finally some conclusions and recommendations are provided. The aim of the paper is to provide the reader with a background on this new instrument that is available to improve the understanding of pavement behaviour.

It is important to realise that the focus of the paper is on the obtained data and the potential for using this data in pavement engineering. The principles behind the measurement of seismic stiffnesses are covered in much detail in various papers and dissertations (Celaya and Nazarian (2006); Nazarian et al (2002); Nazarian et al (2005); Taljaard (2006); Yuan and Nazarian (2002)) and are not covered in detail in this paper.

Figure 1: PSPA device in use.

2 BACKGROUND TO PSPA

2.1 Seismic analysis

Seismic analysis is the process through which the response of pavement layers to a stress wave applied to a pavement is recorded. Factors such as layer thicknesses, material type and material density affect the way in which such waves are reflected and attenuated in the pavement. The operating principle of the PSPA is based on generating and observing stress waves in the pavement layers. The Ultrasonic Surface Wave (USW) method is used for the calculation of the seismic modulus of the pavement material. Using the USW method, it is assumed that the properties of the upper-most pavement layers are uniform, and knowing that the velocity of propagation of surface waves is independent of wavelength for wavelengths less than the thickness of the uppermost pavement layer, the seismic modulus of the upper pavement layer can be calculated using the equation (Celaya and Nazarian, 2006):

$$E_{field} = 2\rho[(1.13 - 0.16\upsilon)V_R]^2 (1 + \upsilon)$$

Where
V_R – velocity of surface waves
ρ – mass density
υ – Poisson's ratio

It is important to appreciate that the frequency or energy of the applied load to the pavement will determine the depth to which the applied wave will penetrate into the pavement and the thickness of the pavement that can be evaluated using a specific frequency wave. In general, the lower the frequency of the wave, the deeper the layers that can be characterised, and the higher the frequency the shallower the layers that can be characterised. For pavement engineering applications it is thus important to use a source with a relatively high frequency, as the response from the upper layers of the pavement is vital.

2.2 Applications in engineering

Seismic analysis has been used in civil engineering for a long time. Typical applications of the technology can be found in the petroleum industry (locating sources of crude oil inside rock masses), geotechnical engineering (quantification of rock and soil (Wightman et al, 2003)) and pavement engineering (evaluating pavement layer properties).

Typical applications of the seismic technology in pavement engineering is to enable measurement of the seismic stiffness of the various pavement layers and to track changes in pavement layers over time due to vehicular and or environmental loading or to track construction practices to evaluate quality control (Celaya and Nazarian, 2006).

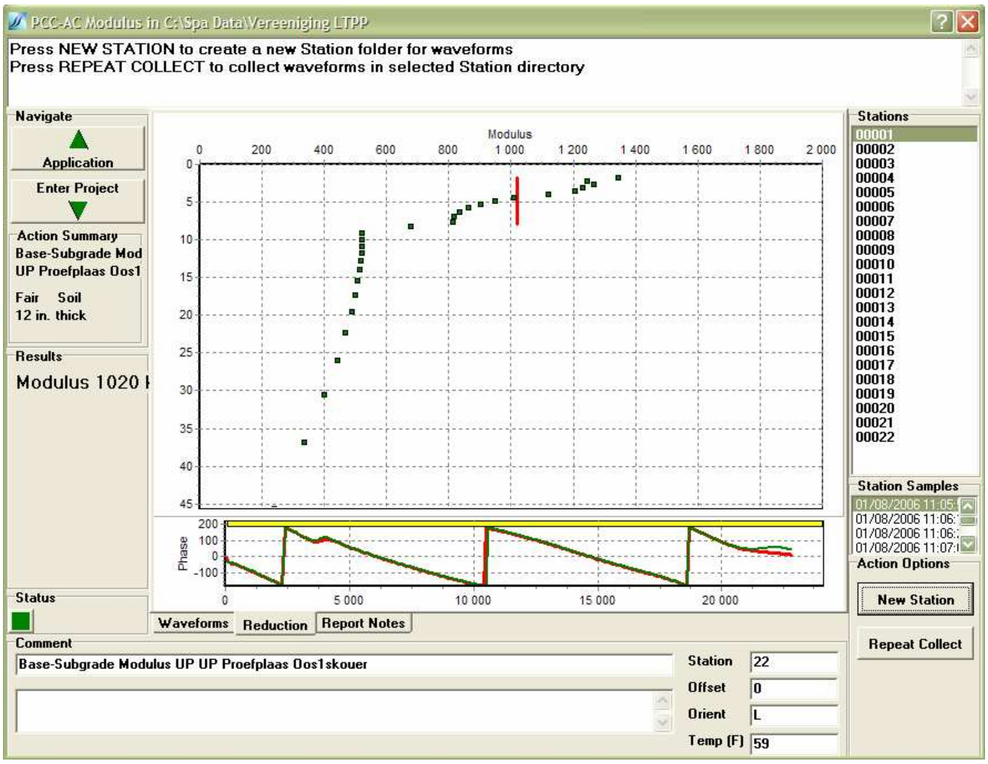
Nazarian et al (2002) conducted research using the PSPA for quality control during construction, and also developed a protocol for such quality control projects. Other field studies are also reported where the seismic moduli of pavement layers were measured and evaluated (Chen & Bilyeu, 2001). The Institute for Transport Technology (ITT) at the University of Stellenbosch has conducted several studies using the PSPA both in the laboratory and in the field. The purpose of these studies also focused on evaluating changes in pavement layer parameters during construction and vehicular loading.

2.3 Typical output from PSPA

The PSPA typically provides information on the seismic stiffness of the various pavement layers as output. Through a Fourier transform and spectral analysis of the time records obtained from the two sensors of the PSPA, the dispersion curve (Figure 2), indicating the moduli at the various depths are developed. These moduli are low-strain high-strain-rate moduli, and thus differ numerically from those obtained using a traditional deflection measurement (which causes high-strain deformation at low strain rates). It is not firstly the intention of the application of the GDPTRW PSPA to compare stiffnesses from different pavement response instruments with each other, but to obtain information on changes in pavement properties in the upper layers of the pavement that may occur before any visible deterioration (i.e. cracking) is observed.

The relation between these values can be obtained through the development of master curves for the specific material (specifically when working with visco-elastic materials such as asphalts). The master curve relates a range of frequencies to the modulus of the material at that specific loading frequency (Figure 3), and when relating moduli measured at different load frequencies with each other for a specific material, this relation is thus applied. This is also the process followed to obtain design moduli for the specific material from the master curve. A master curve is selected for a reference temperature, after which a design frequency (based on vehicular speed) is selected. A design modulus is then obtained from the master curve for this specific frequency. It is recommended that this approach be investigated in more detail in South Africa to determine satisfactory relationships between the moduli obtained from the range of instruments used to measure pavement layer modulus with (e.g. deflectograph, FWD, PSPA etc).

It is important to realise that the relationship between load frequency and stiffness depends to a large degree on the material type, layer thickness and layer properties, and



thus a standard relationship can not be provided for all materials.

Figure 2: Seismic modulus output obtained from PSPA device – dispersion curve shown.

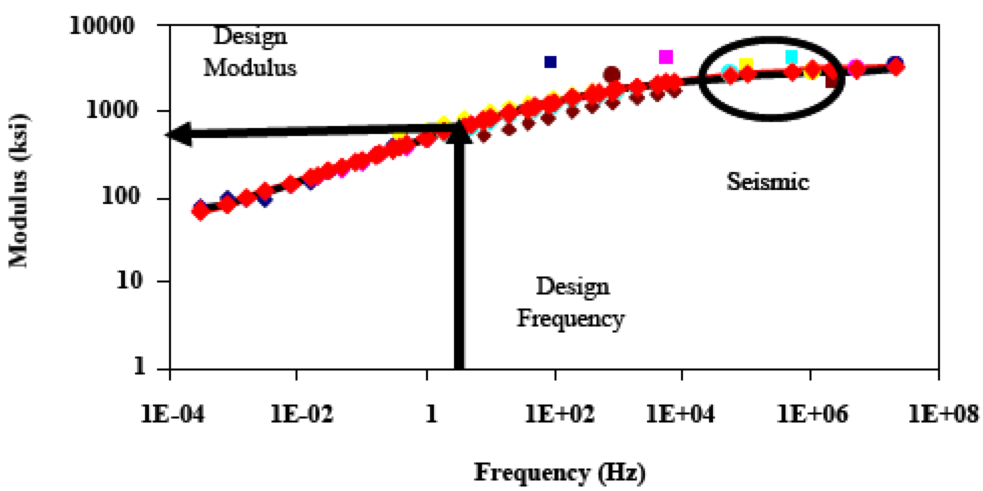


Figure 3: Schematic indication of the relationship between loading frequency and stiffness for pavement materials (Nazarian et al, 2005).

2.4 Availability of PSPA

There are currently three PSPA devices in southern Africa. These are owned by the Gauteng Department of Public Transport, Roads and Works (GDPTRW), ITT and ANE (Mozambican National Roads Administration). The devices are being used independently on projects for each of the three owners. These projects include both research and construction projects.

3 METHODOLOGY FOR TESTING WITH THE PSPA

3.1 Standard protocol

A standard protocol for the measurement of pavement seismic moduli using the PSPA was developed with the assistance of ITT at the University of Stellenbosch (US). This protocol provides guidelines for a uniform method for the use of the PSPA. It contains information on the following aspects:

- Test methodology;
- Site preparation;
- Calibration;
- Data analysis, and
- Reporting.

It has been proposed that this methodology be followed for all the PSPA devices in southern Africa, to ensure comparable outputs and studies of results. It is the intention that the protocol will be converted into a South African national standard over time.

3.2 Methodology for initial study

The initial study (reported on in this paper) focused on the verification of the capabilities of the PSPA device for the GDPTRW. As such, the study addressed the following four specific aspects:

- Repeatability of measurements;
- Variability of seismic moduli over a section of pavement;
- Isotropic behaviour of pavement materials, and
- Development of an initial database of typical seismic moduli for South African pavement materials.

The methodology thus included PSPA measurements on a range of pavement sites. These included mainly Heavy Vehicle Simulator (HVS) sites and Long Term Pavement Performance (LTPP) sites of the GDPTRW. The standard protocol was followed for the measurements and analyses. The detailed data analysis focussed on addressing the four aspects of the study. Currently, the PSPA is being used on the GDPTRW HMA project, and the results of this study will be reported at a later stage.

3.3 Analysis procedure

Data reduction and analysis included the verification of the collected data to ensure that the results obtained were reasonable, comparison of the data with published data to verify that the data linked with international experience with the PSPA and finally a statistical analysis to verify the repeatability, variability and isotropic behaviour of the pavement properties.

The analysed data are presented in this paper, with the detailed technical discussions and background in Steyn et al (2007).

4 APPLICATIONS

4.1 Sample description

In Table 1 an indication is provided of the locations where the PSPA data used in this paper were collected as well as the specific analysis that the data were used for in this paper.

Table 1: Source and application of PSPA data.

SOURCE	APPLICATION			
	Repeatability	**Variability**	**Isotropy**	**Database**
Cullinan LTPP site	X	X	X	X
Vereeniging LTPP site	X	X	X	X
P159/1, R80 HMA site				X
Heidelberg TCC				X
Manhica				X

For each of the locations the data used in this paper consisted of the seismic moduli of the upper 600 mm of the pavement structure. The data obtained from the PSPA were analysed to provide seismic moduli output for similar depths for each of the stations where the data were collected. This information was then used in the detailed analyses.

4.2 Data analysis

Repeatability

Three repeats of the transverse measurements at the selected locations were compared using a one-way ANOVA and a correlation matrix to analyse the repeatability of the PSPA data, and to determine whether there was a significant difference between the three observations obtained at a specific location.

Variability

The variability analysis comprised the evaluation of the PSPA data measured along the length of a section of the LTPP sections. The objective was to verify whether or not the PSPA is sensitive enough to identify material / pavement layer variability along the length of the road. The analysis was based on a comparison between Falling Weight Deflectometer (FWD) maximum deflection data obtained for the same test sections on the same test locations and the PSPA longitudinal position moduli.

Isotropy

It is known that some pavement materials behave an-isotropically (i.e. the material parameters differ when measured in different directions (i.e. longitudinally and transversely)). In order to evaluate whether the PSPA could identify anisotropic behaviour from pavement layers, the PSPA measurements were conducted at 90° angles at the same location. An ANOVA test and correlation matrix was set up for each point to evaluate the isotropy of the moduli. Unfortunately, no comparative data (such as FWD data) were available to verify the PSPA-derived indications of anisotropic behaviour, but this would be a topic for further investigation.

Database

As the PSPA is a relatively new instrument and the seismic modulus an unknown material property in general pavement engineering practice, it is necessary to develop a database of typical seismic modulus values in order to develop a perception of the typical range of values for typical South African pavement materials. This process involved the analysis of the seismic modulus data from a range of test sections.

4.3 Data discussion

Repeatability

Statistically significant differences (all at 95 per cent confidence level) in the moduli obtained from the three repeat measurements were only found in limited cases (14 per cent of the 272 comparisons tested). An interesting trend was that where there was an error, it was mainly the first of the three measurements that did not correlate. Whilst 19 per cent of the correlations between the first and second measurement showed a statistically significant difference, and 21 per cent of the comparisons between the first and third measurement showed statistically significant differences, only 10 per cent of the comparisons between the second and third measurements showed statistically significant differences between the two measurements. This may indicate that the instrument had not been properly positioned for the initial reading and thus the repeatability error in these cases may have been due to instrument application error (it appears as if the sensors of the PSPA did not make good contact with the surface of the pavement in these cases). The PSPA was not physically moved between the three measurements. For the FWD it is standard practice to exclude the data from the first drop of the hammer from the analysis. It is not currently anticipated that this should affect the protocol, as the differences between the measurements are not significant in engineering terms.

The repeatability of the PSPA device has also been shown by other researchers to be good. Alexander (1996) found the repeatability of PSPA measurements performed at the same location to be better than those of traditional pavement layer strength tests.

Variability

In order to evaluate whether the PSPA could identify similar weaker and stronger areas along the pavement length than a traditional device such as the FWD, the PSPA-derived seismic moduli for the upper 300 mm of the pavements was compared to the Base Layer Index (BLI - difference between the FWD deflection at locations 0 mm and 300 mm). When comparing these data for the LTPP sections, the relationship indicated that as the BLI increase (weaker pavement structure) the PSPA moduli decrease (weaker pavement structure) (Figure 4). Although the correlation is relatively low for the data shown, this would probably improve when a more representative data set is used for this evaluation.

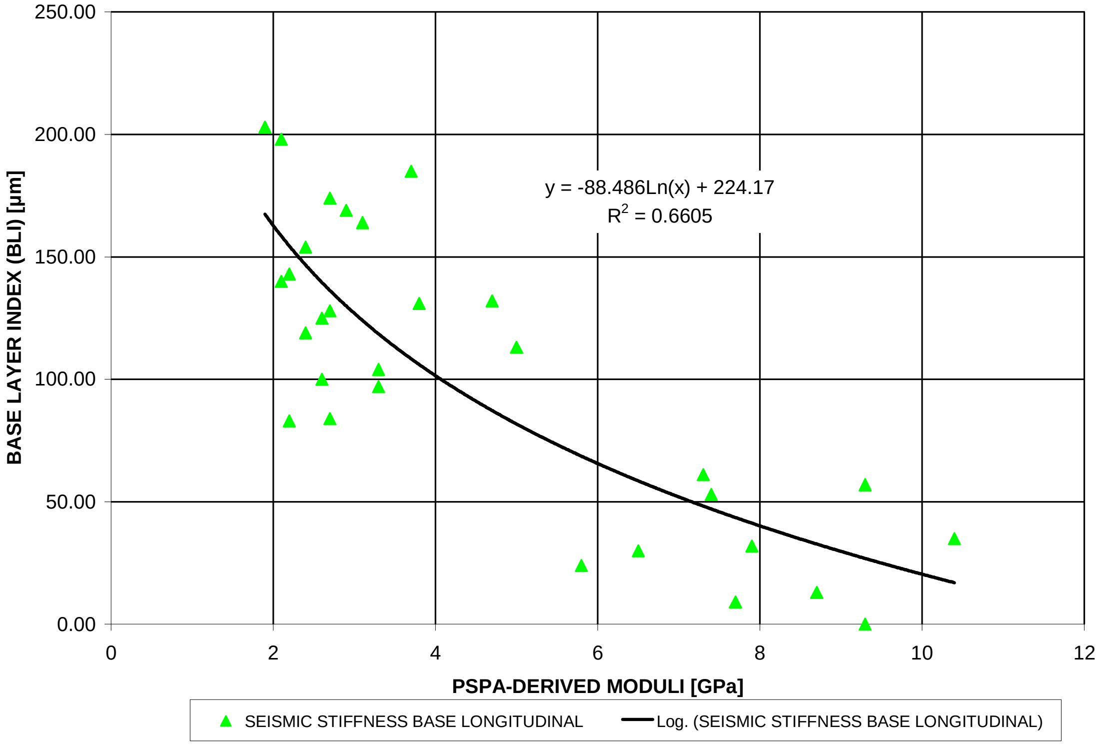


Figure 4: Comparison between FWD-measured deflection data and PSPA-derived moduli for the LTPP sections.

Isotropy

Different outputs were obtained from the statistical analysis of the data from the Vereeniging and Cullinan LTPP sites (Table 2).

Table 2: ANOVA analysis outputs and Correlation matrix outputs for tests of isotropic behaviour.

	ANOVA analysis at 95 per cent confidence limit		Correlation matrix	
	Significant difference	**Not significant difference**	**Correlation < 95%**	**Correlation < 85%**
Cullinan	2.5%	97.5%	20%	10%
Vereeniging	18%	82%	32%	14%

Whilst the Cullinan data showed no significant difference (95 per cent confidence limit – ANOVA analysis) between the longitudinal and transverse PSPA-derived moduli (thus indicating isotropic behaviour) for 97.5 per cent of the locations measured, the Vereeniging data showed significant differences from the ANOVA analysis at 18 per cent of the locations.

On the Cullinan site there were also 20 per cent of the locations where a correlation of less than 95 per cent was obtained, while 32 per cent of the locations showed a correlation of less than 95 per cent on the Vereeniging site.

These differences are probably due to the difference in materials at Cullinan and Vereeniging. These locations where significant differences occurred were not spatially connected, and occurred along the length of the test section at random locations. The possibility of operator error during one of the measurements is excluded as this should have randomised the Cullinan measurements as well. Further investigation of this phenomenon is recommended.

Database

In Figure 5 an indication is provided of typical seismic moduli as measured during this project. The moduli are shown in an increasing order, with the material types on the x-axis. Evaluation of the data in the figure indicates that the trend is as expected with the sand on the one extreme and the concrete on the other extreme of the range. The order of materials between these two extremes is generally acceptable, although the specific properties of any of these materials will influence the absolute position of the material in the trend. More detailed analysis of these data is required to obtain a closer relationship between the various materials and their seismic moduli. It was indicated earlier in the paper that each material will have a unique master curve (that will be dependent on the specific properties of the material) that will has to be developed if absolute comparisons between the seismic modulus and moduli obtained at other frequencies are required.

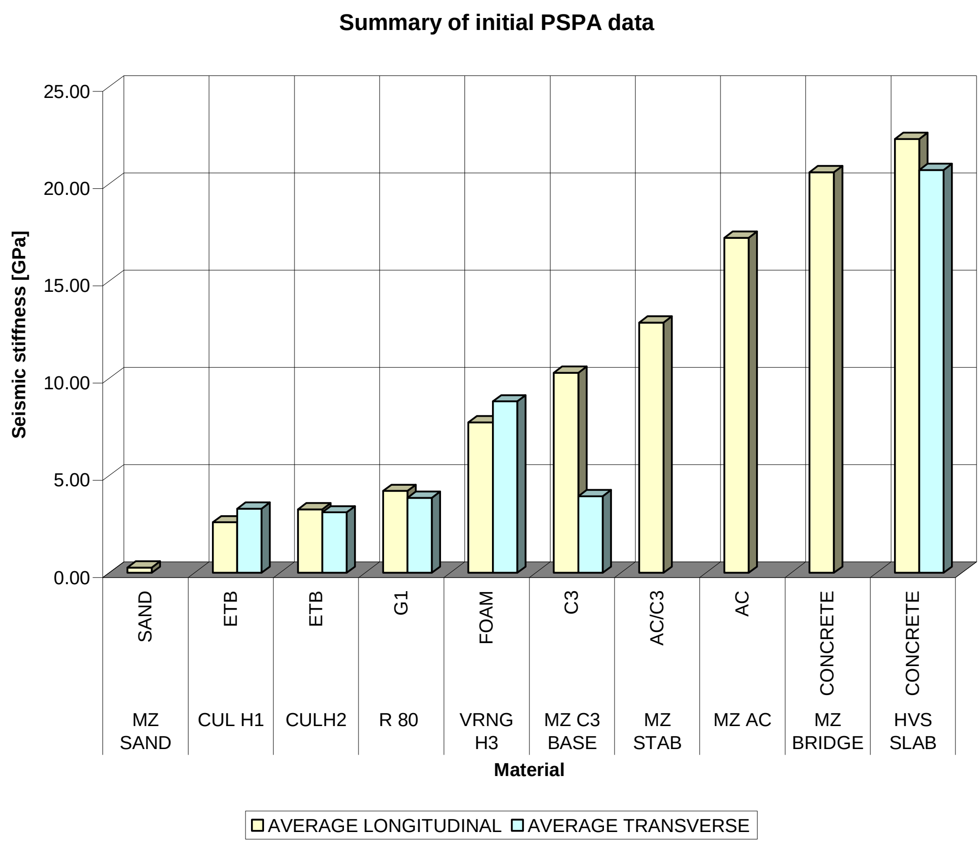


Figure 5: Seismic moduli of a range of typical pavement materials as determined using the PSPA.

5 OUTSTANDING ISSUES

The PSPA is still a relatively new instrument in pavement engineering and there are still a lot of questions regarding the applicability of the data obtained from the device in traditional pavement engineering. Research is being conducted in these areas, and it is currently expected that the device will become a standard pavement evaluation device. Some of the aspects that are being researched or that require further research are:

- Evaluation of the applicability of the PSPA to identify changes in the condition of an HMA layer with increasing loads during HVS testing;
- Development of master curves for typical South African pavement materials;
- Investigation into the use of master curves to relate moduli obtained from various modulus-measuring instruments in South Africa;
- Comparison of PSPA moduli with moduli obtained from the FWD and Light FWD;
- Expansion of the database of typical PSPA- derived moduli for South African pavement materials;
- Development of relationships between fundamental material properties and seismic moduli obtained from the PSPA;
- Evaluation of the effects of parameters such as temperature, moisture content and layer thickness on the PSPA-derived moduli for South African pavement materials.

6 CONCLUSIONS AND RECOMMENDATIONS

Based on the information discussed in this paper, the following conclusions are drawn:

- The PSPA can provide valuable insights into the behaviour of pavement layer properties;
- There is still further work required to ensure that the relationships between moduli obtained from the various modulus-measuring devices can be related to each other with confidence, and
- The PSPA appear to provide good input regarding parameters such as the variability, isotropy and repeatability of seismic moduli for pavement layers.

Based on the information discussed in this paper, the following recommendations are made:

- Further evaluation should be conducted on the issues identified in this paper (i.e. evaluation of thin HMA condition, master curves for SA materials, effects of parameters such as moisture and temperature, etc);
- The database of PSPA-derived moduli for South African pavement materials should be expanded in conjunction with data from other instruments in order for an improved understanding of the fundamental behaviour of pavement materials to be achieved.

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