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Technical Memorandum: Instrumentation for APT and LTPP

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DOCUMENT RETRIEVAL PAGE			**Report No:** **CSIR/BE/IE/ER/2006/0001/B**
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Abstract:

The GDPTW makes extensive use of instrumentation in their Accelerated Pavement Testing (APT) and Long Term Pavement Performance (LTPP) programmes. In order to remain at the forefront of technology, this project investigates the available technologies to monitor these projects, identifies the most appropriate instruments to measure each of the relevant parameters and makes recommendations regarding instrumentation requirements for the GDPTRW.

This project has been performed in 3 phases. In these phases, the parameters to be monitored on APT and LTPP sections have been identified, appropriate instruments and sensors for monitoring these parameters have been identified, and recommendations made regarding new developments, required upgrading of sensors and instruments for the GDPTRW APT and LTPP programmes.

The following conclusions are drawn:

- There is a large range of potential parameters that can be monitored during APT and LTPP projects. However, the specific parameters required for each project should still be identified to ensure that parameters are not just monitored for the sake of monitoring them. A standard checklist can be used to ensure that relevant parameters are monitored using appropriate sensors and instruments;
- A variety of sensors and instruments exist for monitoring the identified parameters. However, while some of these sensors and instruments provide good data, others require improvements to enable reliable data to be collected consistently for APT and LTPP projects;
- Due to developments in electronics, smaller and improved sensors are constantly being developed. Some of these sensors may be appropriate for APT and LTPP once they are adapted to be used in the specific road material environment;
- There are specific requirements for new or upgraded sensors and instruments for the GDPTRW APT and LTPP programmes that need to be pursued. Some of these are already being addressed, while further research will be required for others.

The following recommendations are made:

- The checklist provided for the planning and execution for instrumentation on APT and LTPP projects should be used to ensure that appropriate parameters are being monitored using appropriate sensors and instruments;
- The current suite of sensors and instruments used on the GDPTRW APT and LTPP projects should be kept, with the focus on upgrading of the following instruments:
    - Wireless RSD and profilometer (currently being addressed at CSIR);
    - Wireless MDD (to be addressed once wireless RSD and profilometer has been completed);
    - Improved in situ moisture measurement sensors / instruments to be procured (not currently being addressed);
- A plan should be developed for a systematic approach towards addressing the potential development of nano- and micro-scale sensors and instruments for the measurement of stresses, strains, deformations and translations inside pavement layers, and
- The development of non-destructive thermography for pavement layer evaluation should be addressed to determine the feasibility of using this technology.

Keywords: Instrumentation, Accelerated Pavement Testing, Long Term Pavement Performance

Proposals for implementation:

It is proposed that the recommendations made in this report be followed to ensure that the GDPTRW remains at the forefront regarding instrumentation use in its APT and LTPP work.

Related documents:

None

Signatures:				
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DISCLAIMER

REVIEW STATEMENT

This report has been reviewed internally at CSIR Built Environment.

EXECUTIVE SUMMARY

The GDPTRW makes extensive use of instrumentation in their Accelerated Pavement Testing (APT) and Long Term Pavement Performance (LTPP) programmes. In order to remain at the forefront of technology, this project investigates the available technologies to monitor these projects, identifies the most appropriate instruments to measure each of the relevant parameters and makes recommendations regarding instrumentation requirements for the GDPTRW.

This project has been performed in 3 phases. In these phases, the parameters to be monitored on APT and LTPP sections have been identified, appropriate instruments and sensors for monitoring these parameters have been identified, and recommendations made regarding new developments, required upgrading of sensors and instruments for the GDPTRW APT and LTPP programmes.

The following conclusions are drawn:

- There is a large range of potential parameters that can be monitored during APT and LTPP projects. However, the specific parameters required for each project should still be identified to ensure that parameters are not just monitored for the sake of monitoring them. A standard checklist can be used to ensure that relevant parameters are monitored using appropriate sensors and instruments;
- A variety of sensors and instruments exist for monitoring the identified parameters. However, while some of these sensors and instruments provide good data, others require improvements to enable reliable data to be collected consistently for APT and LTPP projects;
- Due to developments in electronics, smaller and improved sensors are constantly being developed. Some of these sensors may be appropriate for APT and LTPP once they are adapted to be used in the specific road material environment;
- There are specific requirements for new or upgraded sensors and instruments for the GDPTRW APT and LTPP programmes that need to be pursued. Some of these are already being addressed, while further research will be required for others.

The following recommendations are made:

- The checklist provided for the planning and execution for instrumentation on APT and LTPP projects should be used to ensure that appropriate parameters are being monitored using appropriate sensors and instruments;

- The current suite of sensors and instruments used on the GDPTRW APT and LTPP projects should be kept, with the focus on upgrading of the following instruments:
    - Wireless RSD and profilometer (currently being addressed at CSIR);
    - Wireless MDD (to be addressed once wireless RSD and profilometer has been completed);
    - Improved in situ moisture measurement sensors / instruments to be procured (not currently being addressed);
- A plan should be developed for a systematic approach towards addressing the potential development of nano- and micro-scale sensors and instruments for the measurement of stresses and strains inside pavement layers, and
- The development of non-destructive thermography for pavement layer evaluation should be addressed to determine the feasibility of using this technology.

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1. INTRODUCTION

1.1. Introduction

The GDPTRW Heavy Vehicle Simulator (HVS) instrumentation is mainly used to measure the following properties of the pavement test section:

- Permanent surface deformation;
- Permanent in-depth deformation
- Elastic surface deflection;
- Elastic in-depth deflection
- Visual deterioration;
- Temperature, and
- Crack development and activity.

Each of the instruments used to measure these properties has been developed for specific use with the HVS and the data acquisition system currently used on the HVS. Most of these instruments have been used successfully over the last 15+ years. The protocols for measurements on the HVS have been adopted for these instruments, and the staff understands them well.

However, the science of measurement and instrumentation is continually evolving in conjunction with developments in electronics, and therefore improved instruments, refined measurements and more effective measurement techniques develop constantly. During the last few years, two significant new developments are the miniaturisation of electronic components and wireless data transfer systems. Both these developments can have a major impact on the way pavement instrumentation is used, as smaller instruments decrease the influence of the sensors on the pavement being studied, while wireless communication improves the reliability and efficiency of the whole system.

Apart from HVS related activities, Long Term Pavement Performance (LTPP) is also receiving increased attention, with most of the GDPTRW HVS test sites also being designated LTPP sites at the completion of the HVS test. As many of the parameters that are monitored on pavements are similar in both study types so that comparisons in performance can be made, LTPP parameters and instrumentation are included in this investigation.

This project has been divided into three phases to ensure that each aspect receives adequate focus and attention. The outcome of each phase will influence the methodology of the following phases:

- Evaluation of instrumentation needs;
- Evaluation of current and new instruments, and
- Recommendations for developments and / or procurement of instrumentation.

1.2. Structure of the report

The report consists of three main sections in which the three phases mentioned are discussed. At the end of each section, a summary and conclusions for the specific phase is provided, with the conclusions and recommendations for the project provided at the end of the report. In accordance with GDPTRW policy, the original project proposal is provided as Appendix A.

1.3. Objectives

The objectives for each of the three phases are described below:

Phase 1: Evaluation of instrumentation needs
Identify the specific parameters that need to be monitored / measured on APT and LTPP experiments and develop a standard specification for instrumentation and measurements on APT and LTPP test sections.

Phase 2: Evaluation of current and new instruments to meet needs
Develop a model list of instrumentation for APT and LTPP sites.

Phase 3: Recommendations for developments and / or procurement on instrumentation
Develop a plan to either procure or develop the required instrumentation where applicable.

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1.4. Methodology

The methodology for each of these three phases is described below:

Phase 1: Evaluation of instrumentation needs

- Identifies the specific parameters that need to be monitored / measured on APT and LTPP test sections through an analysis of pavement research needs (literature study, and survey of current international practice);
- Defines the measurement requirement for each of these parameters (i.e. resolution, accuracy, range, etc), and
- Develops a standard specification for instrumentation and measurements on APT and LTPP test sections.

Phase 2: Evaluation of current and new instruments to meet needs

- Identifies currently available instrumentation, both in South Africa and internationally, to measure the identified parameters (literature study and survey of current international practice);
- Matches the standard specification developed in Phase 1 with this instrumentation to identify the most appropriate instruments for the specific requirements;
- Identifies instances where instruments need to be either upgraded, modified or developed to fulfil the required role, and
- Develops a model list of instrumentation for APT and LTPP test sections.

Phase 3: Recommendations for developments and / or procurement on instrumentation

- Makes recommendations on the most appropriate suite of instruments for APT and LTPP studies;
- Provides guidelines on the availability and requirements for development of instruments, and
- Develops a plan to either procure or develop the required instrumentation where applicable.

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1.5. Project deliverables

The deliverables for each of the three phases are defined below. Although the deliverables are provided as three specific deliverables (one for each phase of the project), these deliverables are combined in this report to provide an integrated deliverable to the project.

Phase 1: Evaluation of instrumentation needs

A standard specification for instrumentation and measurements on APT and LTPP experiments, including the specific parameters that need to be monitored / measured and the measurement requirements for each of these parameters (i.e. resolution, accuracy, range, etc).

Phase 2: Evaluation of current and new instruments to meet needs

A model list of instrumentation for APT and LTPP experiments.

Phase 3: Recommendations for developments and / or procurement on instrumentation

Recommendations on the most appropriate suite of instruments for APT and LTPP experiments, including guidelines on the availability and requirements for development of instruments.

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1.6. Benefits to the Road Authority

The data obtained from an APT or LTPP section is probably the most important aspect in the pavement behaviour evaluation. These data are used to develop an understanding of the pavement behaviour, develop models and serve as input data for various analysis design processes.

Although current data generally provide good information for these processes, it is necessary to ensure that the data collection process is effective, economical and accurate, whilst opportunities should be sought to identify new systems that can be used to improve pavement design techniques. The outcome of this project will enable Road Authorities to better understand the quality of the data obtained from the HVS/LTPP programme, as well as potential enhancements to this data through the use of improved sensors and instruments.

HVS and LTPP projects represent major investments. The overall benefit of this study will be that data will be gathered more cost effectively and reliably, leading to a better understanding of the risk associated with various pavement structures. This should assist Road Authorities to improve the overall management of its assets.

2. PHASE 1: PARAMETERS

2.1. Introduction

The objective of Phase 1 is to identify the specific parameters that need to be monitored / measured on APT and LTPP test sections and to develop a standard specification for instrumentation and measurements on these experiments.

Phase 1 of the project focuses on the potential parameters that may be measured, and not on the instruments used. The list of parameters has been circulated for review by practitioners to ensure that all relevant parameters have been identified. As part of the investigation the typical accuracy and range that would be expected for each of these parameters are shown. In order to ensure that important parameters are not neglected, previous studies have also been reviewed in this phase of the project. The most important is the study conducted into the status of APT internationally (Hugo and Epps Martin, 2004).

2.2. Parameters to be monitored

The investigation identified appropriate parameters that can be monitored on APT and LTPP test sections. These are shown in Table 1 together with their relevance to APT, LTPP or both, and the typical accuracy and range for values. All potential parameters were considered, including environment, materials, pavement structure and traffic / load.

It is important to realise that the information in Table 1 focuses on those parameters that can potentially be monitored, and not only those that are currently monitored. Recommendations regarding the current parameters being monitored and any new parameters that should be included in the GDPTRW APT / LTPP monitoring programme are made in Section 4 of this report.

The Data Acquisition System (DAS) to be used when any of the parameters are being measured is specifically excluded from this initial phase of the study, as it is believed that the most appropriate DAS for a specific instrument should be used.

Table 1: Parameters identified to be monitored on APT and LTPP sections.

PARAMETER	APT	LTPP	ACCURACY	RANGE
ENVIRONMENTAL PARAMETERS				
Temperature air, surface, in-depth	x	x	± 0.5℃	-5℃ to 70℃
Humidity / Moisture air, surface, in-depth	x	x	±1%	0% to 100%
Rainfall	x	x	±1 mm	NA
Wind direction and speed	x		±1°, ±1 m/s	NA
Solar radiation (irradiance)	x		±10 W/m^2	0 to 1 000 W/m^2
Artificial wetting	x		±1 mm	NA
MATERIALS RELATED PARAMETERS				
In situ strength (DCP)	x	x	±0.1 mm/blow	NA
In situ density	x	x	±5 kg/m^3	NA
In situ moisture content	x	x	±5 %	0 to 100 %
Suction / Permeability	x	x	In accordance with standard test methods[1]	
Stiffness (field measured)	x	x		
Standard engineering and materials properties – laboratory tests[1]	x	x		
Coefficient of thermal expansion	x		0.1 x 10^{-5} mm/mm/℃	0.6 to 1.5 x10^{-5} mm/mm/℃
PAVEMENT STRUCTURE PARAMETERS				
Permanent surface and in-depth deformation	x	x	±0.1 mm	0 to 50 mm
Elastic surface and in-depth deflection	x	x	±0.01 mm	0 to 5 mm
Concrete shrinkage	x		±0.1 mm	0 to 5 mm
Concrete creep	x		±0.1 mm	0 to 5 mm
Crack / joint width	x	x	±0.1 mm	0 to 5 mm
Crack / joint activity / movement / joint faulting (before being visible)	x	x	±0.1 mm	0 to 5 mm
Visual condition	x	x	NA	NA
Water table	x	x	±0.1 m	0 to 2 m
Material loss		x	±1.0 mm	1 to 50 mm
Surface texture	x	x	±0.01 mm	NA
Riding quality		x	±1 mm/m IRI	1 to 16 mm/m IRI
Dust / spray		x	± 5% opacity	0 to 100 %
In situ stress	x	x	±0.01 kPa	NA
In situ strain	x	x	±100 με	NA

Table 1 (continued): Parameters identified to be monitored on APT and LTPP sections.

PARAMETER	APT	LTPP	ACCURACY	RANGE
TRAFFIC / LOAD RELATED PARAMETERS				
Wheel load	x		±1.0 kN	0 to 200 kN
Tyre inflation pressure	x		±1 kPa	0 to 1 500 kPa
Tyre-pavement contact stress	x	x	±0.1 MPa	0 to 2 MPa
Wheel speed	x		±0.5 m/s	0 to 10 m/s
Wheel position	x		±0.1 m	0 to 8 m
Traffic characterisation		x	WIM[2]	WIM[2]
Traffic noise (Pass-by for LTPP; Intensity for APT)		x	±5 dB	0 to 150 dB
Tyre temperature	x		±1 ºC	0 to 100ºC
Uni / Bi-directional	x		NA	NA

NOTES

Range – NA indicates that a specific range is not relevant (i.e. rainfall values).

1 – The standard laboratory tests to determine material and engineering parameters should be included in a programme.

2 – WIM indicates that typical Weigh-In-Motion type data need to be collected (i.e. speed, vehicle type, axle loads).

2.3. Discussion / Evaluation of parameters

The parameters identified in Table 1 are viewed as a standard set for APT and LTPP experiments. It should be clear that not all of these parameters will be monitored during every test, but that specific test requirements will dictate which parameters are monitored. The test should, however, always be planned in such a way that those parameters that could influence the outcome of the test are monitored.

The accuracy and range provided in Table 1 for each of the parameters are viewed as practical values. Most of the parameters can be measured at a much higher accuracy, or instruments with a much bigger range can be obtained. However, it should be realised that such higher levels of accuracy could require instruments that are much more costly, without necessarily improving the data that is to be used in the analysis of the specific pavement.

When starting to use wireless instrumentation the transmission range needs to be defined for specific instruments. This range should be adequate to ensure that the signal can be received outside the influence of traffic on the road, and also to ensure that the signal can penetrate the layers within which it is embedded (for embedded sensors).

2.4. Requirements for selection of sensors and instruments

As there are a variety of parameters that can be monitored on an APT and LTPP project, it is important to identify the relevant parameters and then select relevant sensors and instruments to monitor these parameters with. In this regard, the following checklist (adapted from Dunnicliff, 1988) can be of assistance:

- Predict mechanisms that will control the behaviour of the material being monitored;
- Define the questions (and thus the purpose of the instrument) that need be answered through the data obtained from the instruments;
- Select the parameters that should be monitored to answer the specific questions;
- Predict the magnitude of change to determine the range and accuracy required for the specific instrument;
- Assign the various tasks for design, installation and operation of the instrumentation;
- Select the appropriate sensors and instruments;
- Select the appropriate sensor and instrument locations;
- Devise a plan to record factors that may influence the measured data;
- Establish procedures for ensuring reading correctness;
- Develop an installation plan, including calibration and maintenance requirements;
- Develop a data collection, processing, presentation, interpretation and reporting plan;
- Procure, install and calibrate instruments in accordance with previous decisions;
- Collect, process, interpret and report data in line with previous decisions.

2.5. Summary of Phase 1

The objective of Phase 1 of this project is to identify those parameters that require monitoring during APT and LTPP projects. These parameters have been listed in Table 1, together with proposed accuracy requirements and ranges for each of the parameters. The information provided in Table 1 also serves as the minimum requirement specifications for monitoring each of the various parameters in an APT / LTPP programme, dependent on the requirements of the specific project. A checklist of steps to be taken to ensure that the instrumentation to be used on a specific project is appropriate is also provided.

3. PHASE 2: INSTRUMENTATION

3.1. Introduction

The objective of Phase 2 of this project is to develop a model list of instrumentation for APT and LTPP sites. In Phase 1 (Section 2), the parameters that may require monitoring during an APT / LTPP project were identified and a standard minimum requirement for monitoring standards for each of the parameters developed. The following methodology was followed for identification of available instrumentation:

- Identify currently available instrumentation, both in South Africa and internationally, to measure the identified parameters;
- Match the standard specification developed in Phase 1 with this instrumentation and identify the most appropriate instruments for the specific requirements;
- Identify instances where instruments need to be either upgraded, modified or developed to fulfil the required role, and
- Develop a model list of instrumentation for APT and LTPP test sections.

3.2. Information collection

The process of collecting information on available instrumentation included discussions with the members of the Heavy Vehicle Simulator International Alliance (HVSIA), specific literature searches and evaluation of information provided by specific vendors of instrumentation. In these searches the objective was to find those sensors and instruments that could be used to monitor the parameters identified in Table 1.

During this process it was also decided to focus on the type of instruments that pavement engineers are familiar with, and keep introduction of new instruments until Phase 3 of the project. This was done in order to ensure that the initial match of instruments to parameters did not require a paradigm shift, and that any required changes can be accommodated relatively easily.

Further, it was also decided not to provide instrument details in terms of specific instrument models / manufacturers, but to make use of generic instrument descriptions. This was done as many companies offer similar instruments and sensors with small differences (if any) in the products, and the objective of this project is not to specify particular products from specific companies. Final selection of a brand for use on any project or programme will depend on issues such as the compatibility of the required sensors / instruments with the rest of the instruments, the availability of ranges of sensors and instruments locally and the specific experience with suppliers.

The information obtained from the HVSIA partners was limited and mostly similar to what was already available in the GDPTRW APT programme. Information from literature searches provided both generic information and product specific information. All this information has been archived for later use when required.

3.3. Match between parameters and instrumentation

In Table 2 an overview of the sensors / instruments identified for each of the various parameters identified in Table 1 is provided.

In terms of terminology used, it is important to distinguish between sensor and instrument. A sensor refers to a specific device that is used to convert a parameter (i.e. temperature) into an electric signal. This signal needs to be fed through a combination of signal conditioners into a system where the data can be collected, viewed and stored. The combination of all components is referred to as an instrument. In terms of the HVS instrumentation, the MDD modules are therefore sensors while the combined MDD installation and data acquisition system (DAQ) will be the instrument. In Table 2 an indication is provided of whether the device indicated is a sensor or an instrument. When it only indicates a sensor, an indication is provided of the type of DAQ required to operate the sensor. In terms of the GDPTRW instrumentation, the objective is to standardise on the Labview / National Instruments suite of conditioner units to enable all sensors to operate with the same DAQ.

In some cases there is more than one type of sensor or instrument that can be used to monitor a specific parameter. In such cases, the most applicable sensors / instruments are identified.

Table 2: Sensors and instruments identified to monitor pavement parameters.

PARAMETER	SENSOR	INSTRUMENT	DAQ	NOTES
ENVIRONMENTAL PARAMETERS				
Temperature air, surface, in-depth	Thermocouple	i-button Weather station	HVS NI[1]	These parameters are typically monitored using a dedicated weather station (excluding the pavement data)
Humidity / Moisture air, surface, in-depth	--	i-button Nuclear gauge Weather station	--	
Rainfall	--	Rain gauge	--	
Wind	--	Anemometer	--	
Solar radiation (irradiance)	Solar radiation sensor	Weather station	--	
Artificial wetting	--	Calibrated container	--	--
MATERIALS RELATED PARAMETERS				
In situ strength (DCP)	--	DCP	--	--
In situ density	--	Nuclear gauge	--	Sand replacement test can be used
In situ moisture content	--	Nuclear gauge	--	Gravimetric method should be used for calibration
Suction / Permeability	--	Tensiometer	--	--
Stiffness (field measured)	--	PSPA (Portable Seismic Pavement Analyser) Stiffness gauge FWD Deflectograph	--	--
Standard engineering and materials properties – laboratory tests	Standard tests as per specifications should be used for these parameters			
Coefficient of thermal expansion	--	Length and temperature measurement devices	--	Specific devices depend on the test method used

Table 2 (continued): Sensors and instruments identified to monitor pavement parameters.

PARAMETER	SENSOR	INSTRUMENT	DAQ	NOTES
PAVEMENT STRUCTURE PARAMETERS				
Permanent surface and in-depth deformation	Laser LVDT	Profilometer MDD Rut gauge	HVS NI[1]	--
Elastic surface and in-depth deflection	LVDT LVDT	RSD MDD FWD	HVS NI[1] HVS NI[1]	--
Concrete shrinkage	--	Extensometer	--	--
Concrete creep	--	Extensometer	--	--
Crack / joint width	--	Crack monitor	--	--
Crack / joint activity / movement / faulting	--	CAM	HVS NI[1]	--
Visual condition	--	Camera	--	--
Water table	--	Piezometer	--	--
Material loss	--	Rod and level	--	--
Surface texture	Laser	Generic vehicles	--	Standard sand patch test can be used
Riding quality	--	Generic high speed profilometer	--	--
Dust / spray	--	Dust meter Spray meter	--	--
In situ stress	Pressure cell Load cell	--	NI[2]	--
In situ strain	Strain gauge	--	NI[2]	--
TRAFFIC / LOAD RELATED PARAMETERS				
Wheel load	--	--	HVS system	These parameters are automatically monitored through the HVS control systems
Tyre inflation pressure	--	--		
Tyre temperature	--	--		
Wheel speed	--	--		
Wheel position	--	--		
Uni / Bi-directional	--	--		
Tyre-pavement contact stress	Strain gauges	SIM	SIM	--
Traffic characterisation	--	WIM	--	--
Traffic noise	Microphone	--	Dedicated test setup	Standard test methods exist that need to be followed

NOTES

1 – HVS NI indicates the current standard HVS DAQ based on National Instruments technology.

2 – Standard National Instruments DAQ – not currently used in the HVS DAQ. Similar DAQ systems from other manufacturers also exist.

3.4. Proposed APT and LTPP instrumentation suite

One of the overarching objectives of this project is to identify the instrumentation suite that should be used on APT and LTPP projects. In Table 2, a generic list of sensors and instruments is provided for monitoring the various parameters identified. For specific application to the GDPTRW APT and LTPP programmes, it is recommended that the current suite of instruments be kept with the focus on National Instruments based hardware with Labview software to operate the instruments. The current GDPTRW APT instrumentation details are provided in Appendix A (part of the original proposal).

3.5. Development needs identified

The sensors and instruments shown in Table 2 typify those that are currently available for use without any major modifications. However, there are various sensors / instruments that, if they could be manufactured, would provide for improved monitoring of APT and LTPP parameter monitoring. In this regard, the following specific development needs are identified (requirements for developments in these areas are discussed in Section 4):

- Wireless instrumentation;
- Strain measurement in aggregate;
- Direct stress measurement in pavement layers;
- Nano- / micro-scale instruments;
- Particle location identification (translation and rotation under load and with time) for individual particles;
- Identification of cracks in pavements before they become visible through techniques such as Computed Tomography (CT) scans;
- Improvements to moisture content measurements, and
- Non-destructive testing using infrared thermography.

3.6. Sensors / instruments not currently evaluated

There are some sensors and instruments that were not evaluated specifically as potentially useful to monitor the parameters listed in Table 1. For others, there are some reservations when using them on typical APT and LTPP projects. These issues are listed with explanations below.

CTL SnapMDD

The CTL SnapMDD is a wireless device that is operated similarly to the CSIR MDD, although it is available in a wireless version. The main drawbacks for this system (in South African pavements) are the fact that the hole required for the device is bigger than the SA MDD (50 to 75 mm versus the current 38 mm) and that the upper-most deflection that can be measured is 170 mm from the surface of the pavement. For typical SA pavements, the first measurement that can thus be obtained is in the lower part of the base in stead of the surfacing as with the SA MDD.

Strain gauges

Although strain gauges are listed as sensors that can be used to measure strains in a pavement, recent experiences using these sensors on APT sections have not always been positive. Some of the reasons for this include the installation of the sensors, which needs to be performed during construction to enable an accurate indication of the actual stresses and strains to be made and the small area over which the strain gauge is physically taking its measurement, especially when using them in non-homogeneous and granular materials (it typically performs better in concrete and steel).

Sensors and instruments installed after construction

In both APT and LTPP applications, most of the sensors that are potentially used to measure stresses and strains need to be installed after construction of the test section if tests are being conducted on existing pavements. Even when dedicated test sections are constructed, detailed planning is required to ensure that sensors will be at the best locations after construction of the section, specifically when variability of the pavement section is taken into account when locating test sections.

When sensors for measuring stress and strain are installed after construction of the road, a problem develops in that the stresses and strains in the pavement will be directly affected by the installation of the sensor. This is the case whether the sensor (i.e. strain gauge) is fixed to a core of the pavement material that is being retrofitted into the pavement (i.e. with a concrete road) or when the sensor is installed and the volume filled with virgin material. Stress relaxation is bound to cause changes in the strains within the pavement layer that may overshadow the effects of the traffic that are being monitored.

Stresses conducted through materials that are compacted to different levels may also differ from those originally developed in the layer before disturbing the layer material. This is one of the problems that need to be addressed with new instrumentation development.

One option is to develop sensors as mimicking the particles (aggregate) in the pavement, This should ensure that the presence of the sensor should have a minimal influence on the parameter being observed.

Instruments that can easily be stolen / vandalised from LTPP sections

LTPP sites are by their nature typically located in rural areas and not tended to on a daily basis. This causes sensors and instruments on such sites to be prone to vandalism. Devices such as weather stations should thus be installed at a safe location close to the site and not necessarily on the site itself.

Nano- and micro-scale sensors and instrumentation

Various nano- and micro-scale sensors and instruments are becoming available as electronic components are being miniaturised. These include the devices used by Dust Networks to form a network of sensors that communicate wirelessly to enable data from a wide area to be collected. However, these devices are currently not viewed as practical alternatives for APT and LTPP due to the fact that the current sensors are not specifically those that monitor the parameters that pavement engineers are interested in (such as stresses and strains). These devices will become a possibility in future years and developments in these fields will be followed – as is the case with the i-buttons that are currently used on both APT and LTPP test sections to monitor temperature and humidity. Some of these developments are also discussed in Section 4.

3.7. Summary of Phase 2

In Phase 2 of this project the objective was to identify the typical instruments that can be used to monitor the various parameters identified in Phase 1 of the project. Such a summary is provided in Table 2 together with generic instrument and sensor information.

4. PHASE 3: RECOMMENDATIONS FOR INSTRUMENTS

4.1. Introduction

The objective of Phase 3 of this project is to develop a plan to either procure or develop the required instrumentation where applicable. Based on the information from Phases 1 and 2 a list of required instrumentation for monitoring the identified parameters has been developed. In this list there are a number of parameters for which the current available instrumentation is not necessary applicable, or where upgrades are required to the available instrumentation.

This section deals with the recommendations for developing / upgrading these instruments.

4.2. Identified requirements in new instruments

In Section 3.5 the following requirements for further developments in instrumentation for APT and LTPP were identified:

- Wireless instrumentation;
- Strain measurement in aggregate;
- Direct stress measurement in pavement layers;
- Nano- / micro-scale instruments;
- Improvements to moisture content measurements, and
- Non-destructive testing using infrared thermography.

Wireless instrumentation

Wires required to connect sensors and DAQs are a major nuisance factor in pavement engineering instruments. These wires need to be routed to enable sensors to be placed within the pavement and the DAQ to be placed out of the way of traffic using the pavement. Wireless communications would enable the user to install sensors in the pavement and locate the DAQ outside of the pavement, ensuring safe and convenient measurements.

The main drawback of wireless instrumentation is the need to supply electrical power to the sensor. This requires batteries located at the sensor, which typically increase the size of the sensor.

CSIR is currently busy with the upgrading of both the RSD and the profilometer to wireless formats. For both these instruments the provision of battery power is relatively straight forward, as there is enough space on the instrument to install batteries. Once these two instruments are operating in wireless mode, attention will be given to the development of a wireless MDD.

Strain measurement in aggregate

As Finite Element analysis Methods (FEM) become more sophisticated and the options of analysing the stresses and strains on an aggregate level become viable, the requirement to measure these stresses and strains also becomes apparent. The main obstacles in these measurements are installation of the sensors and supplying electrical power to the sensors. Various possibilities exist, including normal micro strain gauges, replacement of selected aggregate by specially constructed artificial aggregate with sensors embedded, and nano-scale sensors. The application of some of these instruments may assist in the development of subsurface crack maps.

Direct stress measurement in pavement layers

Stresses in pavement layers are typically back-calculated from the results of deflection measurements. Although various methods exist for the measurement of these stresses using pressure cells and load cells, difficulties exist regarding the installation of the sensors. Again, the focus for these developments should be on development of a stress sensor that can preferably become part of the pavement layer without disturbing the normally developed stresses and strains in the pavement layer. In this regard, artificial aggregate with embedded sensors (as for the strain measurements) again appears to be a potential option. Developments in nano- and micro-scale sensors will assist these potential developments.

Nano- / micro-scale instruments

A lot of attention is currently going to the field of nano- and micro-scale sensors and instruments, mainly in the biotechnical and medical fields. In terms of materials sciences, focus is being given to the embedment of various devices on a nano-scale that become part of the parent material but have the ability to convey information regarding the condition of the material to an external DAQ. CSIR has started to develop capacity in various nanotechnology fields, of which sensors is one. Developments in this field will be tracked and when suitable sensors become available, further investigations would follow.

Improvements to moisture content measurements

The accurate measurement of moisture content of a pavement material has always been a matter of contention. Various techniques are available for these measurements (i.e. nuclear, sand replacement, Time Domain Reflectometry (TDR) and others). However, each of these methods has its specific drawbacks when attempts are made to monitor the in situ moisture content of a non-saturated material. Some of these include the effect of bituminous matter on the measured values, the requirement to saturate the sensor to obtain correct data, the requirement to accurately determine the density (which often changes during an experiment) to obtain accurate moisture content values, and the requirement to measure the moisture content over a large volume of material and not only at the sensor. This is another area where the lessons learned in other fields of science should be investigated to see whether different methods exist to accurately determine the moisture contents.

Non-destructive testing using infrared thermography

One of the objectives of monitoring parameters during an APT or LTPP project is that the monitoring should preferably be a non-destructive type of activity. As these projects typically run over a number of months or even years, destructive tests tend to enlarge the required area for the test, and also prevent the behaviour of a specific location in the test area to be tracked over time. Infrared thermography has been used in the composite materials industry to gain information on the condition of the materials. Adoption of the techniques for bituminous and concrete layers should be possible, providing possible additional non-destructive testing techniques for pavements. However, some ground work is required to determine in what way the current techniques would need to be adopted to enable these measurements to be made. The use of 'near-infrared' technology to potentially study the orientation of aggregate in bituminous mixtures will form part of these studies. CSIR is currently busy with some preparatory work in this regard.

4.3. Identified requirements in upgraded instruments

Although it has been covered in various parts of the report, the following requirements for upgrading of current APT and LTPP instrumentation for the GDPTRW programmes are summarised as follows:

- Wireless mode for RSD and profilometer – currently being addressed by CSIR;
- Wireless mode for MDD – will be addressed once wireless RSD and profilometer has been successfully developed;
- Current DAQ – no specific upgrades are required as the current Labview / National Instruments system is providing good service;
- In situ moisture measurements – attention is required to obtain an improved sensor – not currently part of any project;
- Remaining current sensors and instruments – no specific current developments required.

In terms of upgraded and new instruments, the procurement of the Portable Seismic Pavement Analyzer (PSPA) should be mentioned. This device is due to start service early in 2006. Initially, an evaluation programme will be set up to develop a standard protocol for use of the device, as well as use of the data obtained from the device. Once these have been completed, the device will form part of the standard APT / LTPP instrumentation suite for The GDPTRW.

4.4. Summary of Phase 3

Phase 3 focused on the requirements for upgrading and development of new instruments and sensors. In this regard, six areas of new developments have been identified and some information provided on the current steps being taken to address these issues. An indication was also provided of the status of the current GDPTRW APT and LTPP instrumentation suite and required upgrading of these devices.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Based on the findings from the study, the following conclusions are drawn:

- There is a large range of potential parameters that can be monitored during APT and LTPP projects. However, the specific parameters required for each project should still be identified to ensure that parameters are not just monitored for the sake of monitoring them. A standard checklist can be used to ensure that relevant parameters are monitored using appropriate sensors and instruments;
- A variety of sensors and instruments exist for monitoring the identified parameters. However, while some of these sensors and instruments provide good data, others require improvements to enable reliable data to be collected consistently for APT and LTPP projects;
- Due to developments in electronics, smaller and improved sensors are constantly being developed. Some of these sensors may be appropriate for APT and LTPP once they are adapted to be used in the specific road material environment;
- There are specific requirements for new or upgraded sensors and instruments for the GDPTRW APT and LTPP programmes that need to be pursued. Some of these are already being addressed, while further research will be required for others.

5.2. Recommendations

Based on the information provided in this report, the following recommendations are made:

- The checklist provided for the planning and execution for instrumentation on APT and LTPP projects should be used to ensure that appropriate parameters are being monitored using appropriate sensors and instruments;
- The current suite of sensors and instruments used on the GDPTRW APT and LTPP projects should be kept, with the focus on upgrading of the following instruments:
    - Wireless RSD and profilometer (currently being addressed at CSIR);
    - Wireless MDD (to be addressed once wireless RSD and profilometer has been completed);
    - Improved in situ moisture measurement sensors / instruments to be procured (not currently being addressed);

- A plan should be developed for a systematic approach towards addressing the potential development of nano- and micro-scale sensors and instruments for the measurement of stresses and strains inside pavement layers, and
- The development of non-destructive thermography for pavement layer evaluation should be addressed to determine the feasibility of using this technology.

6. REFERENCES AND BIBLIOGRAPHY

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Hugo, F, and Epps Martin, A.L. 2004. Significant findings from full-scale accelerated pavement testing. NCHRP Synthesis 325, TRB, Washington D.C.

APPENDIX A. PROJECT PROPOSAL.

PROJECT PROPOSAL: PP/2005/04

May 2005

Version 2.0

APT AND LTPP INSTRUMENTATION INVESTIGATION

CSIR
TRANSPORTEK

Contact persons

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BACKGROUND, MOTIVATION AND PROBLEM STATEMENT

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The GDPTRW HVS instrumentation is mainly used to measure the following properties of the pavement test section:

- Permanent surface deformation;
- Permanent in-depth deformation
- Elastic surface deflection;
- Elastic in-depth deflection;
- Temperature, and
- Crack activity, etc.

Each of the instruments used to measure these properties has been developed for specific use with the HVS and the data acquisition system currently used on the HVS. Most of these instruments have been used successfully over the last 15+ years. The protocols for measurements on the APT have been adopted for these instruments, and the staff understands them well. (The current instrumentation are shown in Appendix A).

However, the field of measurement and instrumentation develops and evolves as it is supported by electronic developments, and therefore improved instruments, refined measurements and more effective measurement techniques develop constantly. With this in mind, a specific project is being motivated to enable the HVS instrumentation package to be of world standard. During the last few years, two of the major new developments included the miniaturisation of electronic components and wireless communication developments. Both these developments will have a major impact on the way the pavement instrumentation is being used, as smaller instruments decrease the effect of the sensors on the pavement being studied, while wireless communication improves the reliability of the whole system.

There are also aspects of the current HVS instrumentation that have been identified over the years as possibly affecting the measurements. This includes an issue such as the effect of the hole required for installation of the MDD modules on the performance of the pavement structure.

This project is divided into three phases to ensure that each of the different aspects receives adequate focus and attention, and as the outcome of the first two phases will influence the details of the following phases:

- Evaluation of instrumentation needs;
- Evaluation of current and new instruments to meet needs, and
- Recommendations for developments and / or procurement on instrumentation.

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OBJECTIVES

The objectives for each of these three phases are described below:

Phase 1: Evaluation of instrumentation needs

The objective of Phase 1 is to:

- Identify the specific parameters that need to be monitored / measured on an APT test section and develop a standard specification for instrumentation and measurements on APT sites.

Phase 2: Evaluation of current and new instruments to meet needs

The objective of Phase 2 is to:

- Develop an ideal list of instrumentation for APT sites.

Phase 3: Recommendations for developments and / or procurement on instrumentation

The objective of Phase 3 is to:

- Develop a plan to either procure or develop the required instrumentation where applicable.

METHODOLOGY

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The methodology for each of these three phases is described below:

Phase 1: Evaluation of instrumentation needs

The methodology for Phase 1 includes to:

- Identify the specific parameters that need to be monitored / measured on an APT test section through a analysis of pavement research needs (literature study and survey of current international practice);
- Define the required measurement parameters for each of these parameters (i.e. resolution, accuracy etc), and
- Develop a standard specification for instrumentation and measurements on APT sites.

Phase 2: Evaluation of current and new instruments to meet needs

The methodology for Phase 2 includes to:

- Identify the currently available instrumentation – both in South Africa and internationally – to monitor the identified parameters (literature study and survey of current international practice);
- Match the standard specification developed in Phase 1 with these instrumentation and identify the most appropriate instruments for the specific requirements;
- Identify instances where instruments need to be either upgraded or developed to fulfil the required role, and
- Develop an ideal list of instrumentation for APT sites.

Phase 3: Recommendations for developments and / or procurement on instrumentation

The methodology for Phase 3 includes to:

- Make recommendations on the most appropriate suite of instruments for the HVS;
- Provide guidelines on the availability and requirements for development of instruments;
- Develop a plan to either procure or develop the required instrumentation where applicable.

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PROJECT DELIVERABLES

The deliverables for each of the three phases are defined below.

Phase 1: Evaluation of instrumentation needs

A standard specification for instrumentation and measurements on APT sites, including the specific parameters that need to be monitored / measured on an APT test section and the required measurement parameters for each of these parameters (i.e. resolution, accuracy etc).

Phase 2: Evaluation of current and new instruments to meet needs

An ideal list of instrumentation for APT sites, indicating both locally available and internationally used instruments.

Phase 3: Recommendations for developments and / or procurement on instrumentation

Recommendations on the most appropriate suite of instruments for the HVS, including guidelines on the availability and requirements for development of instruments.

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BENEFITS TO THE ROAD AUTHORITY

The data obtained from an APT section is probably the most important aspects of the study. This data are used to develop an understanding of the pavement behaviour, to develop models from and as input data in various analysis processes.

Although the current data mostly provide good information for these processes, it is necessary to ensure that the data collection process is effective, economical and accurate. The outcome of this project will enable the road authority (owner of the HVS) to understand the quality of the current data that emerge from the APT programme, and the available improvements that can be made to this data through improved sensors and instruments.

The overall benefit will be more cost effective and reliable data emerging from a major investment, causing a better understanding of the risk associated with various pavement structures. This should assist the road authority to improve the overall management of its assets.

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IMPLEMENTATION

The findings of this project will be implemented through the use of improved instrumentation on all APT projects, as well as other related pavement studies (i.e. LTPP studies) where applicable.

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COST

The estimated cost of this project is shown in Table 1. This cost is based on the current proposal and will be affected by any changes to the proposal. It does not include the development or procurement of any new instrumentation at this stage, as these steps will be dependent on the outcome of the project.

Table 1: Estimated cost.

PHASE	HR	HRS	RATE	TOTAL
1	WS	24	R 600	R 32 084.00
	LDP	24	R 690	
	CF	4	R 407	
2	WS	12	R 600	R 16 856.00
	LDP	12	R 690	
3	CF	4	R 407	R 12 912.00
	WS	12	R 600	
	LDP	12	R 690	
SUBTOTAL				R 61 852.00
VAT				R 8 659.28
TOTAL				**R 70 511.28**

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PROJECT TEAM

Principle Investigator (PI): WJvdM Steyn

Technical support: L du Plessis, D Jones, C Fisher, W du Preez

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SCHEDULE

The provisional schedule is project is shown in Table 2. This schedule is based on the current proposal and will be affected by any changes to the proposal. Based on this schedule the anticipated completion date for the project is 3 months after acceptance of the proposal.

Table 2: Approximate Gantt chart

TASK	Month 1	Month 2	Month 3
1	XXX		
2		XX	
3			XX

PROJECT MANAGEMENT AND PAYMENT SCHEDULE

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Payment will be made based on detailed monthly invoices. The progress of the project will be measured against the Gantt chart shown in Section 9. Progress will be presented and discussed at monthly technical meetings.

After Phase 1 a meeting will be held with the client to agree on the properties identified to be measured.

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APPROVAL OF PROJECT

I ………………………………………….. hereby accept the content of the proposal "APT AND LTPP INSTRUMENTATION INVESTIGATION" and the conditions of contract on behalf of

…………………………………. (GAUTRANS)

Signed at ……………………… on this ….. day of ………………. 2005.

………………………………….

As witness:

1.

2.

I ………………………………………….. hereby undertake on behalf of CSIR Transportek (CONTRACTOR) to complete the work set out in the proposal "APT AND LTPP INSTRUMENTATION INVESTIGATION" under the conditions of contract.

Signed at ……………………… on this ….. day of ………………. 2005.

…………………………

As witness:

1.

2.

Appendix A: Current instrumentation.

Gautrans / Transportek
Accelerated Pavement Testing
Instrumentation and Data Acquisition System

Instrumentation / System	Use	Notes	Links / Suppliers
Thermocouple Wire	Type K thermocouple wire for general purpose temperature measurements in concrete, asphalt and ambient air	The wires are twisted together at one end and a plug (Part No. 4559764 - Type 'K' mini T couple) are attached to the other end of the wire.	RS Components SA www.rssouthafrica.com
Temperature buttons (i-buttons)	Programmable to measure temperatures within a pavement structure or ambient air.	Thermochron i-buttons temperature / humidity buttons	Fairbridge Technologies Po. Box 865 Wendywood 2144 S.A. http://www.ibuttons.com
Linear Vertical Displacement Transducers. (E300)	Measurements of Permanent Deformation and Elastic Deflection within a pavement structure	LVDT's LUCAS Schaevitz Sensors E300	Accutronics PO.box 4211 Rivonia 2128 South Africa www.schaevitz.com
Linear Vertical Displacement Transducers. (E300)	Measurements of Permanent Deformation and Elastic Deflection within a pavement structure	LVDT's MACRO Sensors E 750 /300 (larger centre hole)	Accutronics PO.box 4211 Rivonia 2128 South Africa www.schaevitz.com
Multifunction Data Acquisition System. National Instruments (PC card PCI-MIO-16E-1)	Logging of temperature and LVDT data.	Easy to setup extra modulus, Software written in Labview (pc card)	http://sine.ni.com/nips/cds/view/p/lang/en/nid/1045
SCXI Modular Data Acquisition and Signal Conditioning System. National Instruments	Single system for the integration of temperature, load, acceleration, LVDT, etc.		http://sine.ni.com/nips/cds/view/p/lang/en/nid/1604 / 1663
Temperature Data acquisition. (TC-2095) National Instruments	Connecting thermocouples.	Plug in the thermocouples.	http://sine.ni.com/nips/cds/view/p/lang/en/nid/1676
Laser Profilometer System	Measures the profile of the pavement surface.	Built by the CSIR.	Transportek (CSIR)
RSD (Road Surface Deflectometer)	Measures the surface deflections of a pavement.	Built by the CSIR.	Transportek (CSIR)
LabVIEW Data acquisition and Control Software. National Instruments	Collecting, filtering, logging and display of data.	Software written by Peter Westwood / Jeremy Lee.	http://sine.ni.com/nips/cds/view/p/lang/en/nid/1382