APPLICATIONS OF OBSERVATIONAL TECHNIQUES IN PAVEMENT ENGINEERING

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ABSTRACT

Over the years the development of technology enabled an increase in the scope of potential observations that is spreading towards the larger and smaller realms of visibility. In this sense observations can be made on a scale from very large artefacts (such as the earth) to very small artefacts (such as nano-materials).

Although the available observational techniques are used in all aspects of life, this paper focuses on those aspects where the applications are specifically dedicated to pavement engineering. The objective of the paper is to demonstrate how the available range of techniques can be applied to improve the understanding of, and the design, construction and maintenance of pavements.

The paper starts with an introduction to the topic and some background information. This is followed by a discussion on the evaluation of material properties as an example for the rationale behind the work described in this paper. Next, a holistic view of a number of the observational techniques available to pavement engineers are provided, with a short discussion on each of these techniques. Finally, some conclusions and recommendations for further developments are made.

1 INTRODUCTION AND BACKGROUND

An image can contain a lot of information that are difficult to describe or explain. It can sometimes contain information that has not even been observed before, but when investigated in detail can become visible. The old adage of a picture being worth a thousand words has always been true. Road professionals (this term includes engineers, site agents, contractors, managers and anybody else that has a specific concern with roads and their functioning) has a daily requirement to record events on roads. These include the whole spectrum of the life of a road, starting with pre-construction investigations through construction, maintenance and evaluation and rehabilitation. Some typical applications where observational techniques can assist the pavement professional in improving the level of service that they render to the travelling public include the following:

- Visual evaluation of pavement condition as required for Pavement Management Systems (PMS) and rehabilitation evaluations;

- Forensic investigations of failures on pavements;
- Construction / as-built records during new construction and rehabilitation and maintenance actions to ensure that a valid record is kept of the proceedings on site;
- Recording pavement changes over time as per Long Term Pavement Performance (LTPP) experiments and Accelerated Pavement Testing (APT) experiments;
- Records of test pits to serve as visual evidence of layers in the pavement structure, and
- Records of borrow pits before and after excavation and rehabilitation.

The applications can be extended to more specialised applications too. During the application of observational techniques to pavement engineering, it is important to understand why these techniques can assist in performing tasks in pavement engineering and also where to apply the various techniques.

The objective of the paper is to demonstrate how the available range of techniques can be applied to improve the understanding of, and the design, construction and maintenance of pavements. In the paper an explanation on the rationale for applying specialised techniques to pavement engineering is provided, followed by a holistic view of a number of observational techniques available for use in South Africa.

2 EVALUATION OF MATERIAL PROPERTIES

Evaluation of pavement material properties can broadly be divided into three levels. The first being performance properties, the second engineering properties and the third fundamental properties.

On the most basic level the performance properties of a pavement material provide an understanding of the way the specific material will perform under specific conditions. It does not indicate why this specific behaviour occurs, or which properties of the material influence the performance. These are properties such as the permanent deformation of an asphalt material at a certain load, temperature and speed. Although the information is indicative of what can be expected from this specific material, no information is available of the changes that can be expected when the properties of the asphalt material change or when any of the loading parameters (load, speed and temperature) changes.

On a deeper level the engineering properties of a specific material provide a more detailed understanding of the material and its potential responses to loading conditions or changes. In this sense, a property such as the stiffness modulus of the material indicates a property of the material that remains constant for a wider range of parameters and will lead to an understanding of different types of performance, depending on the loading conditions applied to the material.

On the most detailed level the fundamental properties of a material are those properties that are not determined by external conditions (such as temperature or load) but which always remain the same and which directly influence the engineering and performance properties of the material. In this sense a simple example is the grading of a granular material. Based on the grading of the material, the expected performance of the material can be derived as well as the expected engineering properties. With the information on the grading of the material available, the expected performance at a range of densities, moisture contents and under a range of loads can be predicted.

In the same way certain of the advanced observational techniques (such as the Scanning Electron Microscope (SEM) and Atomic Force Microscope (AFM)) allow the measurement of fundamental properties of the material that can be used to derive expected performance of the material under a range of operational conditions. The understanding of the fundamental properties also allows explanations for the specific behaviour under specific operational conditions.

An example of this is where SEM images reveal that there is a clear difference in the grain size distribution between two different sand samples, although their engineering properties do not differ significantly. Their performance, when stabilised, shows significant differences. While the one sample Figure 1 (left) has a trace of smaller fractions on the surface of the grains, the second sample (Figure 1 (right) shows a significant presence of smaller fractions attached to the surface of the larger grains.

The rationale for the work that this paper is based on is thus to allow for an improved understanding of the fundamental properties of pavement materials through the application of more advanced observational techniques.

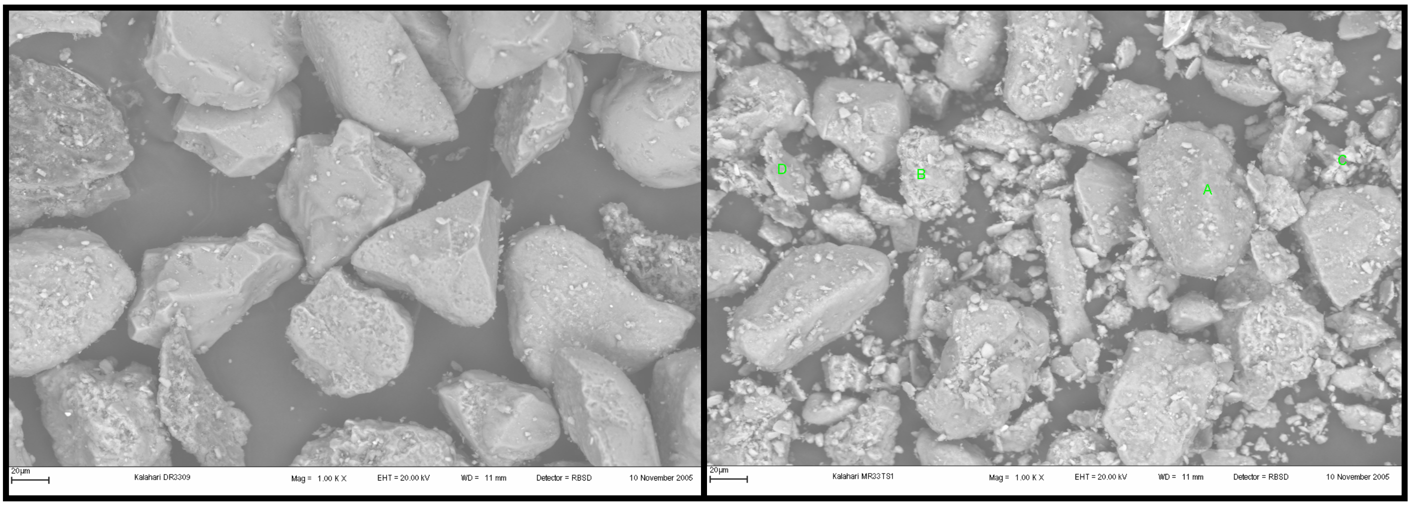

Figure 1: SEM images of two sands showing traces of small fractions (right) (Mgangira, 2007).

3 HOLISTIC VIEW

It is important to obtain a holistic view of the field of advanced observational techniques for pavement engineering, in order for the potential user of the various techniques to understand the available techniques, as well as the relation between the techniques and the benefits and limitations of each of the techniques. In order to do this, the summary shown in Figure 2 was developed. The information in Figure 2 indicates two main properties of the available techniques. On the horizontal scale the wavelength of interest for the images in the specific column is shown, while the vertical scale indicates the resolution of the images.

Figure 2 indicates that there are typically three wavelengths at which pavement engineering images are obtained. These are in the X-ray, visible and infrared wavelengths. The majority of the images fall in the visible waveband. In terms of resolution it ranges from images in the megameter (Mm) range (satellite images) down to the nanometer (nm) range (AFM images). Each of the images shown in Figure 2 can be obtained with equipment available at CSIR BE, or that the unit have relatively easy access to.

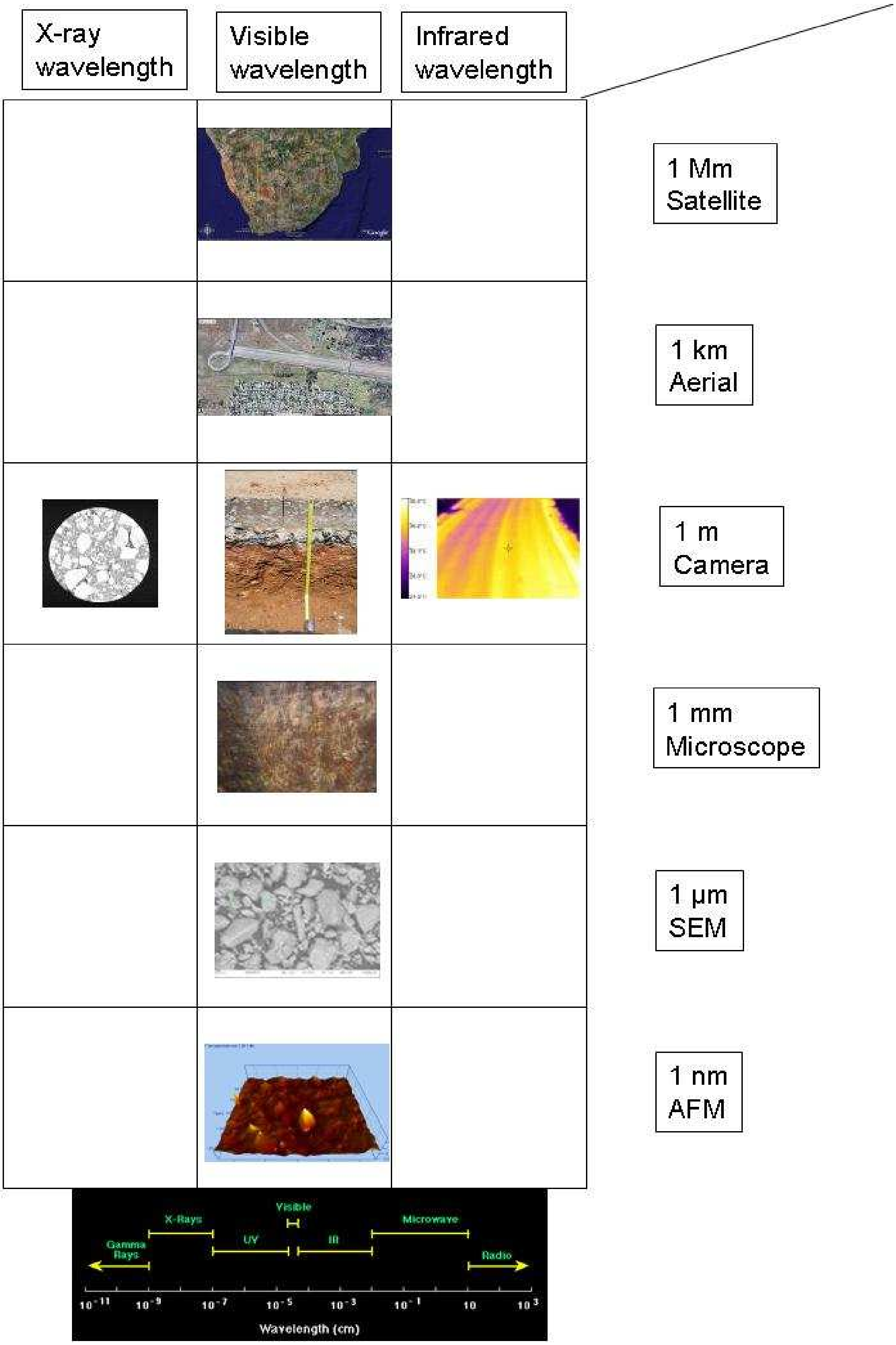

Figure 2: Holistic view of observational techniques for pavement engineering.

Some of the blocks in Figure 2 can be populated if access to the appropriate equipment is available (i.e. Mm X-ray and infrared images). However, the focus in this paper is on those images to which access is readily available at CSIR BE.

The technology used to obtain the images at each of the resolutions and wavelengths, as well as the benefits and limitations and typical applications of the groups of images are as follows:

3.1 Visible waveband, Mm resolution

Technology: Satellites are used for obtaining images at this resolution. At CSIR BE the Google Earth package (http://earth.google.com/) is mainly used to obtain the images.
Benefits: Satellite images of any location on the globe can be obtained at no cost and generally at a very high resolution. The information is available immediately and relatively accurate.
Limitations: Remote areas may have lower resolutions than metropolitan areas. The system is only available over the internet. Stand-alone systems such as Worldwind (http://worldwind.arc.nasa.gov/) is also available but takes up a lot of disk space and need to be updated regularly.
Applications: Overview of environmental features, overview of geographical features, information on remote locations, location of remote infrastructure (i.e. rural roads not shown on maps) etc.

3.2 Visible waveband, km resolution

Technology: Satellites are also used for obtaining images at this resolution. At CSIR BE the Google Earth package (http://earth.google.com/) is also used to obtain these images. Higher resolution images are available through the Agricultural Research Council (ARC) AGIS (Agricultural Geo-Referenced Information System) site. This site provides detailed information on soil, terrain, geology, climate, vegetation and near-real time data of veld fires in South Africa.
Benefits: Detailed information on specifically soils can be used in evaluating the available materials for road construction in a specific area, identify problem materials and obtain material properties in selected areas.
Limitations: Data are only available in areas where the ARC has populated the GIS system, remote areas may not have the level of detail available that is required for a specific study. A link to the internet is required.
Applications: Evaluation of geographical areas on a large scale for availability of specific materials, problem soils and potential problematic geographical features.

3.3 Visible waveband, m resolution

Technology: Standard digital cameras and video cameras.
Benefits: Images provide a permanent record of the status of affairs on a specific site when the image was obtained. It provides information to users that can not access a site.
Limitations: Images may not always be well referenced and thus the links to physical sites and / or the time at which the image was obtained may be lost. Unacceptable quality of images (out of focus, no scale indication, wrong colours, etc) may affect the usefulness of images. A database of images needs to be kept up to date.
Applications: General views of infrastructure, in situ conditions at site, forensic evidence of failures, history of deterioration of infrastructure, record of construction / rehabilitation procedures, training material, etc.

3.4 Visible waveband, mm resolution

Technology: Digital cameras with microscopes, dedicated systems connected to a microscope. Digital camera linked to hand-held microscopes.

Benefits: Shows images of microscopic details of materials, observations of cracks and features not visible to the naked eye.

Limitations: Require microscopes and dedicated equipment.

Applications: Evaluation of grain sized properties of sandy materials, observation of cracks in pavement surfaces.

3.5 Visible waveband, μm resolution

Technology: Scanning Electron Microscopy (SEM) equipment available at the National Metrology Institute (NMI).

Benefits: Evaluation of micron level features of materials.

Limitations: Require high-tech equipment, only small samples can be scanned, specialised techniques are required for scanning and interpretation.

Applications: Evaluation of cementation behaviour, observation of clay particles in materials, chemical analysis of materials.

3.6 Visible waveband, nm resolution

Technology: Atomic Force Microscope (AFM) equipment available at the National Metrology Institute (NMI).

Benefits: Evaluation of sub-micron surface properties of materials.

Limitations: Small samples, only surface properties evaluated, very rough samples excluded, specialised techniques are required for scanning and interpretation.

Applications: Evaluation of ageing effects on bituminous binders.

3.7 X-ray waveband, m resolution

Technology: CT scanning equipment (X-ray based medical device) available for use at the Pretoria Academic hospital.

Benefits: Evaluation of the internal packing and features of pavement samples (i.e. voids, stone-on-stone contact). Indication of density variations (Hounsfield scale).

Limitations: Require highly specialised equipment and trained personnel, specialised techniques are required for interpretation, size limit on samples. Laboratory sized equipment is available, however, the prices are in the range of R 2 million per scanner.

Applications: Evaluation of aggregate packing inside asphalt samples, evaluation of voids location and features (interconnectedness etc), evaluation of density gradients inside samples due to compaction equipment variations, etc (Steyn, 2007).

3.8 Infrared waveband, m resolution

Technology: Infrared wavelength camera (thermal camera) available at CSIR BE.

Benefits: Evaluation of the effects of temperature on infrastructure, indications of material differences due to different thermal properties.

Limitations: Require specialised equipment, externalities may affect measurements (i.e. the location of the sun and shadows).

Applications: Direct measurement of temperature over a wide area, observation of differences in thermal behaviour between different materials, evaluation of potential for temperature-related deterioration of pavements, experimental evaluation of asphalt layer thickness (Steyn, 2005).

4 DISCUSSION

The information provided in the previous section summarises a wide range of applications of observational techniques in a short space. It is important to realise that the correct application of these various techniques typically require highly skilled and experienced personnel who understands both the engineering aspects of the evaluation of the images and the aspects specifically related to the type of image evaluated.

In this sense the evaluation of the various types of images should not be performed without such experience, as incorrect conclusions can easily be drawn from images where either the image itself was not correctly obtained or where the specific interpretation skills lack.

In this regard simple issues such as provision of scale on digital images as well as ensuring that the colours shown on the image are correct are very important to ensure that any interpretation of the image afterwards (especially if such interpretations are made by personnel who were not present on the site where the images were obtained) are performed correctly. Wrong colours or a lack of clarity between different colours on an image of a test pit may for instance cause specific layers in the test pit not to be visible on an image afterwards. Similarly, the lack of a scale shown on an image of cracks can cause the level of fatigue on a pavement to be either under- or over-estimated.

A further aspect that requires attention during the process of obtaining the images for observational analysis is to ensure that all images are clearly identifiable through a system that would lead to clear descriptions of each image. Without such a system images quickly becomes history of events with no links to places or times, and this only cause frustration and does not assist the road pavement professional at all in application of these techniques.

5 CONCLUSIONS AND RECOMMENDATIONS

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

- Observational techniques can be used effectively in pavement engineering to ensure that the pavement professional can provide a superior service to his clients;
- A large range of observational techniques that ranges from macro to nano level are available to the pavement professional, and
- Experience and knowledge are required to ensure that the interpretation of images is performed correctly.

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

- Pavement professionals should make ample use of the available observational techniques to improve their understanding of the fundamental properties of materials and their applications in pavements.

6 REFERENCES

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