MOISTURE RELATED TEST PROTOCOLS FOR HVS TESTING

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ABSTRACT

Accelerated Pavement Testing (APT) aims to evaluate pavement sections under a range of loading and environmental conditions in order to improve the knowledge of the potential performance of the pavement layers and structure under a full range of operational conditions. Using this philosophy it is standard APT practice to select a range of vehicular loading conditions (i.e. load levels and tire inflation pressures) as well as environmental conditions (i.e. temperatures and moisture conditions) for different tests and obtaining the response of the pavement under the specific selected conditions. The outputs of these tests are then combined to develop a model of pavement response under expected field conditions.

The selection and application of load conditions is a well-known and documented process for most APT devices. However, the selection and application of environmental conditions still requires some clarification as this is not one of the standard options on the APT device, but rather an action to prepare and condition the pavement before and during the APT test.

In order to provide guidance on the possible methodologies for evaluating specifically moisture related pavement response using the Heavy Vehicle Simulator (HVS), this paper describes the objectives, potential effects and available methods for performing HVS tests on pavements where the moisture condition of the pavement is a major parameter in the experimental design test matrix. It starts with background on the objectives of these types of tests, followed by typical outcomes and potential outcomes of HVS tests where the moisture condition of the pavement or specific layers in the pavement is under investigation for a specific test. Practical guidance is then provided on the potential systems (how to manage the moisture – hardware) as well as the methods (when to manage the moisture – test program) that can be employed. Attention is also given on the monitoring of moisture condition before and during the test and the relevance to practical field conditions where seasonal moisture changes occur.

INTRODUCTION

Accelerated Pavement Testing (APT) is a technology that is used to simulate the effect of mainly accelerated loading conditions on a pavement structure in an attempt to determine the expected failure mechanisms and life for the specific pavement structure under the simulated conditions. However, wheel loading is only one part of the loading that is applied to real-life pavements and in order to obtain a realistic understanding of the performance of the pavement, the environmental loading should ideally also be considered. The temperature and moisture condition of the pavement are the two typical environmental loading conditions evaluated for pavements. The influence of these parameters has already been acknowledged for many years (i.e. Croney and Bulman, 1972; Freeme et al, 1987). While temperature is a primary parameter for asphaltic and concrete pavements, moisture condition is the primary parameter affecting the performance of granular and stabilized layers as well as the subgrade. In some cases the moisture of asphalt pavements can also be varied when effects such as stripping are investigated. The application of heat or cold conditions to the pavement as well as the monitoring of these parameters is relatively straight-forward and done on a routine basis on many APT tests and facilities.

However, the application and monitoring of moisture to a pavement are typically more difficult to perform and require more planning and specific instrumentation than the monitoring of temperature alone. In this paper the protocols for moisture related accelerated testing using the Heavy Vehicle Simulator (HVS) are discussed. The paper starts with the objectives of inducing moisture to the pavement, followed by a discussion on the potential effects of water on the test pavement. Next, the available systems for applying the water to the test pavement are discussed, followed by a discussion on the various available monitoring systems and a generic protocol for the addition of water to HVS sections.

OBJECTIVES OF INDUCING MOISTURE TO THE PAVEMENT

The moisture content of the pavement can be varied to serve different purposes. The overall objective of this procedure is to determine the effect of changes in moisture condition on the performance of the pavement structure, and specific layers in the structure. The development of Moisture Accelerated Distress (MAD) was defined by De Beer and Horak (1987) as a specific failure mode where the addition of moisture to the pavement structure causes severe and relatively rapid structural damage to the pavement. The response indicated in Figure 1 indicates schematically the development of MAD for a granular pavement structure, while Figure 2 indicates data from a pavement that was initially tested in the dry condition and for the final portion of the test, surface water was added during loading. The main objectives of moisture variations include:

- Evaluation of behavior of pavement layers under different moisture states with and without the influence of loading;
- Evaluation / simulation of the effects of rainfall on the pavement;
- Evaluation of the seasonal effects of wet and dry periods;
- Evaluation of the effects of increased pore water pressures in various layers, and
- Evaluation of moisture induced failure mechanisms in pavement layers.

FIGURE 1 Schematic indication of the development of Moisture Accelerated Distress (MAD) in a granular pavement structure.

FIGURE 2 Surface rut development for a stabilized pavement with a thin asphalt surfacing where surface water was added towards the final stages of the test.

The simulation of these effects is specifically important when models of the behavior of moisture sensitive materials are being developed. These materials not only include the typical granular materials, but may also include asphaltic materials where the potential for actions such as stripping of the binder from the aggregate under high pore pressure conditions are to be evaluated. When performing HVS testing to develop a full performance model for a specific material type, it is important to vary the applied moisture conditions from a relatively dry state to a relatively wet state for a considerable period of the test, to ensure that the combined effects of the moisture condition and applied load can become visible in the parameters being monitored during the test. Often, the time required for moisture to migrate through a layer, especially if the layer is well compacted, may be considerable and in such cases a longer period of pre-treatment with water and also testing would be required.

In cases where a specific condition is simulated (i.e. rainfall) the objective of the test should guide the specific conditions simulated. In the case of the potential effect of rainfall on the pavement, for instance, the fact that some pavements will be relatively impermeable to the water when applied form the surface actually plays in the favor of the pavement structure, and water should not be forced into the pavement layers artificially, as this will negate the benefits of the impermeable surfacing.

Hugo (1999) highlighted the importance of accounting for the effects of changing moisture contents during APT as one of the major lessons learned from APT studies, specifically when evaluating failure modes of pavement structures.

POTENTIAL EFFECTS OF ADDITION OF WATER TO THE TEST PAVEMENT

When varying the moisture content of the pavement structure the potential effects of the action on the performance of the pavement should be defined and anticipated to ensure that the correct pavement response parameters are monitored during the test. The objective should also be to remain within realistic moisture conditions to ensure that the results would be applicable to pavement analysis and design procedures. Typically the behavior of the pavement under the increased moisture conditions would be termed the Moisture Accelerated Distress (MAD) phase of the test. The objective of the addition of the water is to evaluate whether (or to what extent) the presence of the water in the pavement structure affects the deterioration of the pavement structure.

The typical effects that occur on rigid and flexible pavements during MAD differ. In both cases the ultimate effect is a reduction in the life of the pavement structure. The following is a summary of these typical effects that can be expected for each of these types of pavement structures:

- Rigid pavement structures
  - Joint faulting;
  - Cavity formation ;
  - Reduction in Load Transfer Efficiency.
  - Pumping;
  - Loss of support / increased deflections, and
  - eventually spalling, cracking and pothole formation

- Flexible pavement structures
  - Stripping of the surfacing (Figure 3);
  - Increased rut / layer deformation;
  - Potholing;
  - Uneven surface deformation;
  - Structural failure in sub layers;
  - Stripping in permeable asphalt layers, and
  - Increased deflection in lower layers that can lead to cracking of upper layers.

A clear analysis of the potential effects for the specific pavement structure under investigation should be conducted before the test is finally planned and conducted, as these potential effects will affect the parameters to be monitored, instrumentation used and location of sensors in the pavement structure during the test.

FIGURE 3 Indication of stripping of HMA due to wet HVS test.

AVAILABLE SYSTEMS FOR APPLICATION OF WATER TO THE TEST PAVEMENT

There are various available systems that can be used to apply water to the tested pavement structure (i.e. De Beer and Horak, 1987). The selection of an appropriate system depends on factors such as the specific effect required (i.e. surface water distress or soaked base or high water table distress), for the HVS test in question. There are typically two types of water application systems, based on the conditions simulated. These are based on the addition of surface water and subsurface water. The following typical effects can be simulated:

- Simulation of rain and surface run-off
  - Spraybar attached to the test carriage of the HVS;
  - Sprayers on the side of the test section (Figure 4);
  - Slots in the surfacings with water allowed to run over the section (Figure 5), and
  - Dam around the test section and water allowed to stand before commencing with the test.

- Simulation of subsurface water and high water table
  - Core holes drilled on the outside of the test section and being filled with water (variable and constant head);
  - Water introduced through pipes into the base / subbase / subgrade (variable and constant head), and
  - Building of test sections in an enclosed pit with a controllable watertable.

FIGURE 4 Indication of sprayers next to section to supply water to section surface.

FIGURE 5 Indication of slots sawn into surfacing to allow water penetration through impermeable surfacing.

AVAILABLE METHODS FOR APPLICATION OF WATER TO THE TEST PAVEMENT

Once the type of water simulation is selected a decision should be made regarding the program to be followed for the application of the water. Again, various options exist for the type of simulation. There are essentially five methods for programming the water application to the test section:

- Water added before the test commences and stopped during the test (i.e. dam) (simulation of saturated soil conditions);
- Water added before the test commences and during the test (i.e. dam) (simulation of loading during saturated soil conditions);
- Continuous addition of water during the test surface or sub-surface;
- Intermittent addition of water during the test – high frequency (i.e. simulation of seasonal rainfall effects), and
- Water added continuously to the section during specific stages (i.e. 100 000 repetitions dry, 100 000 repetitions wet etc).

Care should be taken when selecting a method for water application to ensure that the desired outcomes of the specific test can be obtained. It is also important to note that in order to monitor the specific effect of moisture, no other parameter (such as wheel load, wheel speed and tire pressure) should be altered during the test. The effects caused by the simulated moisture condition can only be isolated if all other testing parameters stays constant during the testing period.

MONITORING

Application of water to the test section is one part of the moisture acceleration of APT sections. It is also important to monitor the amount of water applied to the section and the effect that the applied water have on the in-situ moisture content of the pavement. Various methods exist for the monitoring of water content in the pavement. The simplest method is the monitoring of the additional amount of water applied to the pavement. However, this only provides an indication of the potential volume of water available for penetrating the pavement and this information can be quite misleading when analyzing the results from the test. Ultimately some type of sensor is required to measure the specific effect that the water has on the pavement layers and the condition under which the pavement layers operate during the test. For this purpose two approaches can be followed.

The first approach is merely an evaluation of the moisture content of the various pavement layers before the test commences, and a forensic evaluation of the moisture condition after the test has been completed, and assumptions regarding the changes of the moisture content in the pavement layers between these two points. This is a simple but crude system that will not provide good data for analyzing changes in the pavement structure during the test, especially if the moisture content in the pavement layers is expected to change during the course of the test. In this approach instruments such as a nuclear gauge or material sampling can be used to monitor the moisture content in trial holes next to the section before commencing with the test and inside the section after completion of the test.

The second approach is to have a system for continuous monitoring of the moisture content inside the pavement layers during the test. Although this is the ideal situation, it is not necessarily always practical or attainable, and various adaptations of this approach are required. These adaptations typically include placement of permanent sensors around the test section or measurement of moisture content using nuclear probes next to the section during the test. Typically, the placement of sensors inside the test area (under the loaded wheel) disturbs the pavement layer to such a degree that the moisture sensor data may not necessarily be correct, especially if the material packing around the sensor changes to such a degree that it affects the permeability of the material. This would obviously lead to inaccurate moisture data.

Typical moisture sensors that are used for monitoring the moisture content in the pavement layers include:

- Time Domain Reflectometry (TDR) probes,
- Nuclear gauge measurements, and
- Gravimetric moisture determination

The experience from various APT programs on the use and applicability of the available sensors differs. Typically, a method such as the gravimetric moisture determination is not a first choice as it requires a destructive removal of material from the test section. Obviously this can only done at the end of a test to calibrate the data obtained during the test and also to obtain an indication of the final moisture content of the various layers. However, depending on the time between completion of the test and obtaining the moisture samples, there can be quite a difference in these values. Nuclear gauge measurements are much simpler to take and can be performed next to the section at regular intervals during the test. However, some concerns remain with the accuracy of nuclear gauge obtained moisture contents and at the very least calibration of the data is required for the specific material monitored. TDR probes have started to become a popular alternative with various smaller devices being available as sensors. Improvements in accuracy and procedures required for measurements also lead to these sensors currently being one of the better devices for obtaining moisture conditions during a test. The installation of the sensors after construction of the test section and subsequent potential changes in the density of the pavement layer material around the sensor remains a concern. These devices should be calibrated (in a laboratory) for the specific materials in which they are installed. At the very least the TDR probes can provide a good indication of the changes in moisture content during a test (Hugo, 1999).

During the monitoring and analysis of the pavement behavior during the wet test, it should be anticipated that changes in the pavement behavior can happen rapidly when the pavement material changes from a relatively dry and strong condition to a relatively wet and weak condition. Such changes can be modeled by performing California Bearing Ratio (CBR) tests in the laboratory on the selected materials at different moisture contents and densities to identify the potential implications of these variations on the behavior of the specific materials. Such tests would be valuable in determining the monitoring program of the test sections, to ensure that the required attention is given to specific properties during specific phases of the test, as well as the specific layers of the pavement structure.

Further, it should also be appreciated that in some circumstances the effect of the additional moisture on the pavement behavior may take some time to manifest itself, especially if the pavement structure is relatively insensitive towards moisture changes (i.e. a very dense and impervious layer may require more time for changes in the moisture content than a less dense layer).

The level of confidence and accuracy of the moisture determination depends on the instrument type and the number and location of sensors. It is suggested that at least two different methods should be used (i.e. TDR or Nuclear gauge in conjunction with soil sampling) on a specific test. Care should be taken that the soil samples from the test section should be taken at the same depth as the location of the non-destructive measurements. Due to potential changes in moisture content, a set of measurements and the soil sampling should be performed simultaneously. It is suggested that measurements should be taken on the upstream and downstream side of the test section to identify any gradients due to flow across the section. It is suggested that at least three measurements should be taken on each side of the section.

It is also important to measure the moisture content of the surrounding pavement outside the influence area of the added water. This would ensure that a realistic determination of the effects of the additional water on the pavement can be made. This control data would enable the natural changes in moisture content of the pavement to be evaluated together with the artificial conditions.

GENERIC PROTOCOL

Based on the experience with wet HVS tests the following generic protocol is proposed for planning and execution of wet HVS tests:

1. Decide on the objective of changes in the moisture content (i.e. why is the water required);
2. Model the potential outcome of the addition of water (i.e. what to expect from the pavement);
3. Decide on an appropriate system for adding the water;
4. Design or modify the system required to add the water;
5. Install the required devices to the HVS or onto the test section and ensure that water application can be controlled and monitored before the test commences;
6. Monitor the application of the water as well as the changes in the pavement response using standard pavement behavior parameters (be careful as rapid changes may occur);
7. Ensure that appropriate 'dry' control sections are available for comparison of behavior;
8. Ensure that any additional water (such as rain) is well recorded and accounted for;
9. Investigate the in-situ moisture content (and water table) prior to the addition of water, and
10. Perform the analysis of the data from the various parameters monitored in conjunction with the record of applied water to the section.

CONCLUSIONS

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

- Changes in the moisture content of pavement layers during APT can produce significant changes in the behavior of the pavement structure;
- There are various outcomes possible when allowing changes in the moisture content of a pavement and these should be anticipated when planning the test;
- Various methods are available for adding water to an HVS test section, and
- Appropriate planned is required to ensure that a wet HVS test is well planned and that the potential outcomes are planned for and monitored during the test.

ACKNOWLEDGEMENT

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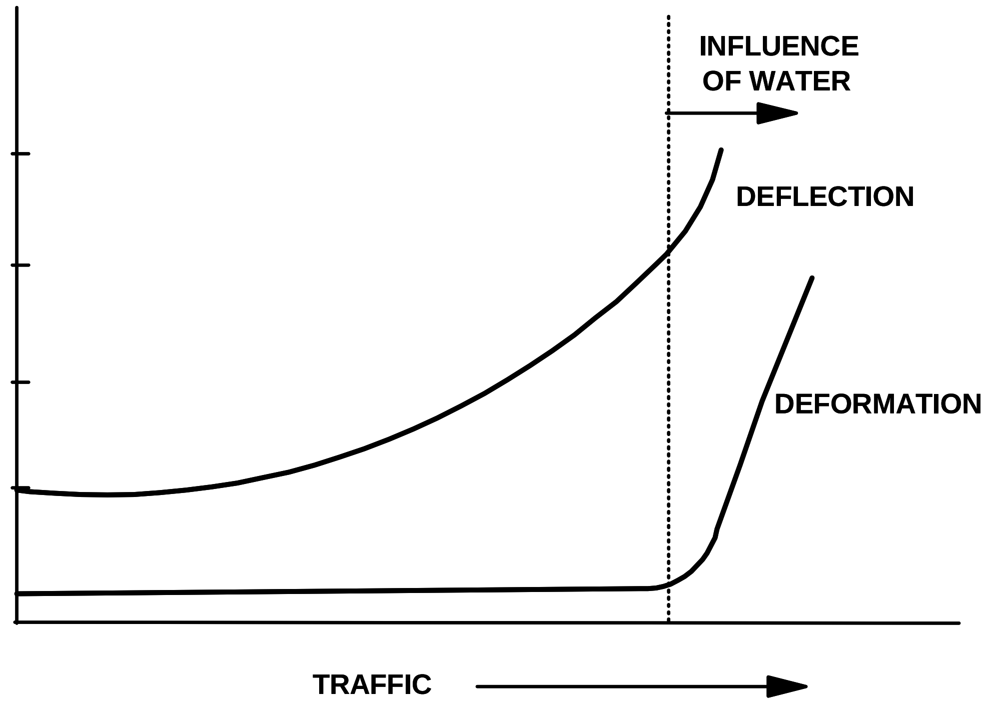


FIGURE 1 **Schematic indication of the development of Moisture Accelerated Distress (MAD) in a granular pavement structure.**

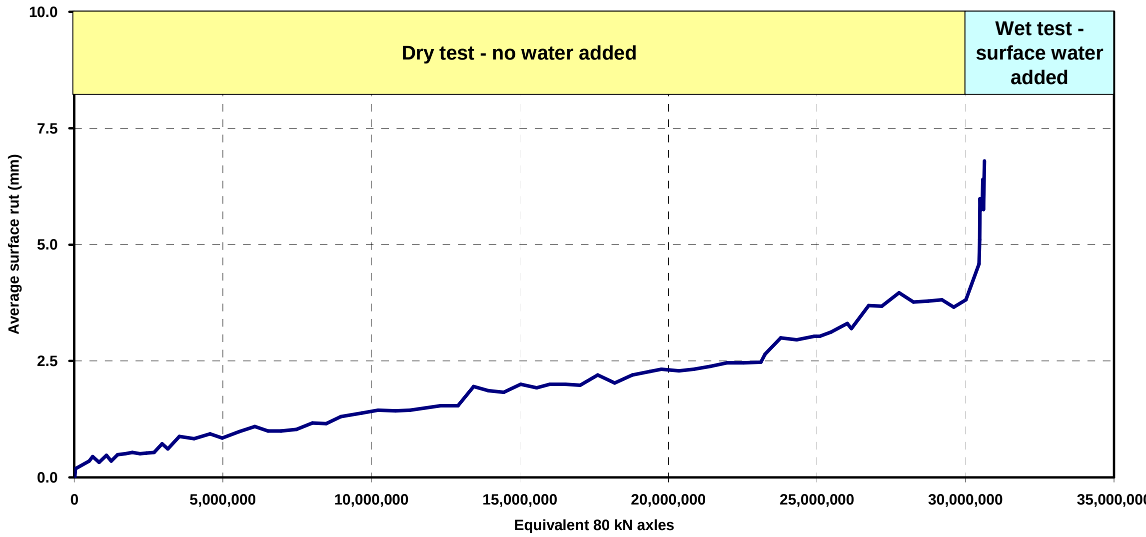
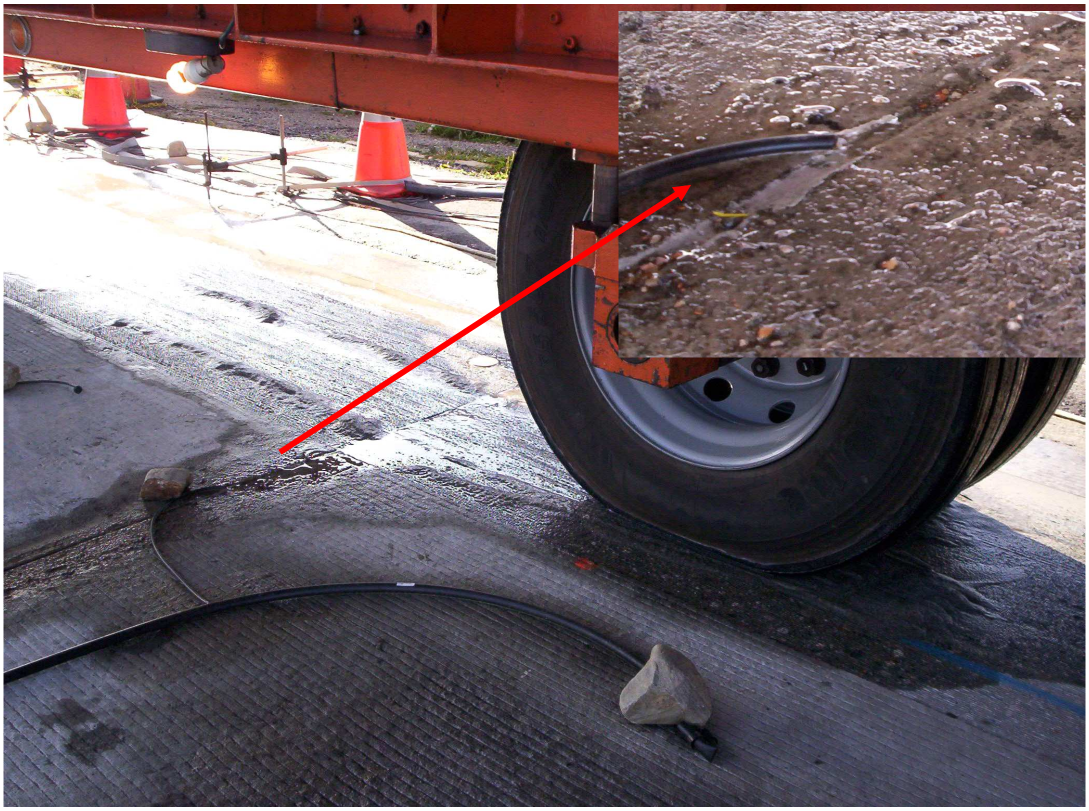


FIGURE 2 **Surface rut development for a stabilized pavement with a thin asphalt surfacing where surface water was added towards the final stages of the test.**

FIGURE 3 Indication of stripping of HMA due to wet HVS test.



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