PAVEMENT SENSORS USED AT ACCELERATED PAVEMENT TEST FACILITIES

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ABSTRACT

Pavement instrumentation has recently become an important tool to monitor in-situ pavement material performance and quantitatively measure pavement system response to loading. Parameters that need to be measured in the field include, but are not limited to strains, stresses, deflections, moisture, and temperature. With different accelerated pavement testing projects being constructed, different sensors have become available to monitor the health of the pavement and its performance. However, the reliability, accuracy, and cost of these instruments/sensors vary significantly. This paper will provide insight to recent development of pavement sensors used on various transportation projects including accelerated pavement test facilities.

TOTAL WORD COUNT: 5,450

INTRODUCTION

Accelerated Pavement Testing (APT) is the controlled application of wheel loading to a pavement structure for the purposes of simulating long-term, in-service loading conditions. This simulation of in-service pavement conditions, loading configurations and method of loading must be representative of that encountered by in-service pavements. In-situ measurements during these tests allow for the development of accurate performance models and the calibration of mechanistic pavement design approaches.

Pavement instrumentation has recently become an important tool to monitor in-situ pavement material performance and quantitatively measure pavement system response to loading. Parameters that need to be measured in the field include, but are not limited to strains, stresses, deflections, moisture, and temperature. With different accelerated pavement testing projects being constructed, different sensors have become available to monitor the health of the pavement and its performance. However, the reliability, accuracy, and cost of these instruments/sensors vary significantly. This paper will provide insight to recent development of pavement sensors used on various transportation projects including accelerated pavement test facilities.

APT SYSTEMS

A sample pavement is built with the same materials and in the same manner as that proposed for a real installation. A special machine then applies heavy truck-type loading very frequently and for almost 24 hours a day, seven days a week. A test plan can be scripted for automatic testing allowing the system to operate unmanned. APT systems can also be viewed and verified real-time by the operator and researchers to apply adjustments as needed to the dynamic loading or to change loading sequences. The benefit of APT is that it provides pavement engineers with valuable information concerning the behavior, performance, and life expectancy of pavement structures within a shorter time frame. In this way many years of real traffic can be applied in a few weeks. It also provides a controlled testing environment in which innovative pavement designs and new materials can be tested and validated in a short period without the financial risks associated with failures of in-service experimental pavements. This ultimately results in enhanced understanding of pavement structures and improved, cost effective design and rehabilitation construction methods.

Data obtained from APT is invaluable as decision support for the selection of alternative road design and rehabilitation options. The development and refinement of the international APT programs throughout the world have had a major technological and economic impact on the design, construction and maintenance of providing a significant return on research investment. APT has helped researchers and road authorities to bring theory and practice together to the benefit of both fields.

APT can be traced back to the AASHO road test of the early 1950’s, still regarded as one of the most comprehensive investigations of the performance of pavement systems. The costs involved with such full-scale APT testing on test roads using actual traffic initiated research into alternative methods. Accelerated testing varies a lot in detail. Some researchers have transportable machines that incorporate environmental chambers in which temperature can be controlled and even cycled and take this test apparatus to a real site. Others build pavements in a special laboratory at full-scale and test under controlled conditions. Some have high speed rotating machines or linear tracks. Currently APT is differentiated into three main categories namely: full scale test roads, mobile APT units, and fixed APT units.

Full-Scale Test Roads

Full-scale test roads are APT facilities at which actual vehicle traffic is utilized for the application of loading. Typical examples are the National Center for Asphalt Technology (NCAT) Test Track at Auburn University which is a 1.7-mile oval with 200 ft test sections and the MnRoad Project with a three-mile test section on Interstate 94 and the 2.5 mile closed loop section. These two facilities are shown in Figures 1 and 2.

Mobile APT Units

The most common approach uses mobile linear loading devices that apply loads to small sample areas on full-scale pavements. For example, the Heavy Vehicle Simulator (HVS) is a fully mobile APT unit capable of simulating 20 years of traffic within a period of 3 months. The HVS provides a mobile laboratory with the ability to accurately and cost effectively test and monitor pavements under a variety of environmental and loading scenarios. Typical HVS units shown in Figures 3 and 4 are located at the U.S. Army Corp of Engineers Waterways Experiment Station and the University of California, Berkeley Pavement Research Center, respectively. Both of these units have closed environmental chambers (closed in Figure 3) for heating or cooling test pavement sections and a center rolling wheel (shown in Figure 4) for applying linear traffic loads.

Fixed APT Units

Fixed APT also utilizes load frames for load application but have a fixed location and cannot be transported easily to various testing locations. Typical examples of these are the FAA's National Airport Pavement Test Facility and Accelerated Load Frame (ALF) at the Turner Fairbank Highway Research Center (TFHRC) shown in Figures 5 and 6, respectively.

INSTRUMENTATION

Common to all of the above APT system is the need for measurement of pavement response to loading. Parameters that need to be measured include, but are not limited to strains, deflections, moisture, pressure and temperature. In most instances pavement sensors must have the ability to measure dynamic response. For measurements of conditions in soil such as moisture and temperature dynamic response is not needed and these types of sensors are usually read with a static type data logging system or even read manually.

It should be noted that there are two distinct differences in suitability of a sensor to accelerated pavement testing applications and they are; (1) Measurement of pavement response under normal trafficking and (2) Measurement of pavement response under anticipated failure. Therefore, sensor selection and installation techniques may need to be altered based on testing application. For example, Figures 7 and 8 show excessive rutting and pavement displacement. In these instances, extra slack in sensor leadwire or additional support for MDD road boxes may be required.

Some of the measurement categories are defined below. Although many different categories of sensors are used in APT systems and each category could contain numerous sensors from different vendors, the intent of this paper is to present sensors primarily used specifically in the pavement or sensors new to the APT technology. In each category some representative sensor types are provided with discussion on benefits and shortcomings as well as lessons learned from the author's previous applications.

Strain Gages

Since most applications require dynamic response from strain gages, only those types of sensors will be discussed. Pavement strains are measured in both concrete (rigid) and asphalt (flexible) pavements.

Asphalt Strain Gages

This is one of the most difficult sensors to install with a high survival rate. This is primarily due not only to the exposure to high temperatures, but also the subsequent rolling/vibratory impact on these gages after installation. To insure a high survival rate, manufacturers through the years have developed a robust sensor combined with installation procedures that increase gage survival rate. The first concern, temperature, is addressed by using high-temperature leadwire in all areas exposed to hot-mix asphalt. This is usually managed by using Teflon sheathing on the lead wires. This also provides superior abrasion resistance over normal wire sheathing. Following the manufacturer's instructions for gage area preparation and pre-embedment followed by hand rolling or compaction normally provides the proper protection against subsequent rolling. Splices in sensor leadwire should always be avoided as not only will it allow a path for potential moisture intrusion, it could also change the calibration or gage factor of the sensor.

Two typical asphalt strain gages are the Dynatest Past II and the CTL ASG shown in Figures 9 and 10. Specifications for these gages are shown in Table 1.

Experience has shown that the Dynatest gage is approximately 50% higher in cost and requires more lead-time for ordering than the CTL gage. Lead-time is attributed to stock status of gage. The Dynatest gages are manufactured to order in Denmark. The Dynatest gage is a 120-ohm quarter-bridge strain gage. The CTL gage is a 350-ohm full bridge strain gage and is individually calibrated. The full bridge circuitry allows for inexpensive signal conditioning, higher-level signal output and lower long-term drift than a quarter-bridge circuit.

Because these gages are constructed to match the stiffness of the flexible pavement, both gages should be handled with care and both require the same installation techniques.

Concrete Strain Gages

There are many types of concrete strain gages available. These include the Geokon model 3900 and the CTL CSG shown in Figures 11 and 12. Both gages are approximately the same cost and use full bridge circuitry. They both tend to be robust gages but should be protected during vibration of concrete. Specifications for these gages are shown in Table 2.

Multidepth Deflectometer

Multi-Depth Deflectometers (MDD) are used to measure in-situ elastic deformation and/or permanent deformations in the various pavements layers of a test section. Two types of MDDs available are the South African design and the CTL SnapMDD shown in Figures 13 and 14, respectively. Specifications are shown in Table 3.

The South African MDD system is a series of Linear Variable Differential Transformer (LVDT) modules that are mounted on a rod in a 39 mm diameter hole in the test section. Up to six (LVDT) modules can be mounted at various depths in the hole. The modules are anchored to the soil by way of small steel balls that are forced out against the walls of the hole. The reference rod is anchored into the subgrade approximately 3 m below the pavement surface.

The CTL SnapMDD system is a series of parallel rods in a 50 or 75 mm diameter hole in the test section. The parallel rods are anchored at various depths inside the MDD tube wall. Each rod, starting from the bottom hydraulic anchor passes up to the reference head where potentiometers measure rod (depth anchor) movements relative to the road surface.

The South African MDD is more expensive and requires approximately 1-2 days for installation. The CTL SnapMDD is pre-assembled (Figure 15) and can be installed at a rate of up to 3 units per day. Additional benefits of the CTL SnapMDD are that the instrumentation is at the road level for protection against high water table and that also allows for easy re-setting of the potentiometers when excessive rutting occurs in the pavement.

The Future of MDDs

CTL has developed a wireless option for the patented SnapMDD. This option allows for roadside data collection without the need for cutting into the pavement to run sensor lead wires to the shoulder area. Data can be streamed in real-time wirelessly to a laptop, or stored in the roadbox for later retrieval.

Soil Compression/Strain

When deformation of individual soil layers or base material needs to be measured, a Soil Compression Gage (SCG) developed by CTL can be used. This gage shown in Figure 16 consists of a sleeved tube with an embedded displacement transducer with large end flanges. In this application, a core of clay was removed from the subbase material, cut open and placed around the SCG as shown in Figure 17. This was then placed back into the clay core whole. This provided a measurement of soil compression in the subbase clay layer. Specifications are shown in Table 4.

Temperature

Two common sensor types for temperature measurement are thermocouples and thermistors. These are often placed in the pavement layer at pre-determined depths using non-conductive material to space the sensors to measure temperature gradients of the pavement. Typical examples are shown in Figures 18 and 19.

The thermocouple consists of a shielded soldered twisted-stranded pair of type-T thermocouple wire (constantan and copper). After the wire pair was twisted and soldered, they were dipped in epoxy to protect the ends from corrosion. The thermistor is an inexpensive element soldered onto lead wire and also dipped in epoxy to protect the delicate element and prevent corrosion attack.

Traditionally, thermocouples tend to be more rugged but slightly less sensitive to temperature change, although the difference in sensitivity is negligible. Thermocouples also tend to be slightly cheaper and have more off-the-shelf hand held devices for reading the sensor.

SUMMARY

The purpose of this paper was to present some of the sensors more commonly used in pavement instrumentation. The specific sensors presented in this paper were chosen based on first hand experience by the author(s). The intent was to share this experience with the reader and to enable the reader to choose instrumentation for pavement research based on first-hand knowledge from others.

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TABLE 1 – Asphalt Strain Gage Comparison

Specification	Dynatest Past II	CTL ASG
Physical Range	Up to 1500 με	±1500 με
Temperature Range	30 - 150°C	30 - 200°C
Resistance	120 Ω	350 Ω
Circuitry	Quarter Bridge	Full Bridge
Modulus	2.2 MPa	2.4 MPa
Sensitivity	0.11 N/με	0.06 N/με
Cost	$670	$500
Contact	1-904-964-3777 psc@dynatest.com	1-847-972-3280 tweinmann@CTLGroup.com

TABLE 2 – Concrete Strain Gage Comparison

Specification	Geokon Model 3900	CTL ASG
Physical Range	5000 με	2000 με
Temperature Range	-20°C - 80°C	-30°C - 100°C
Resistance	350 Ω	350 Ω
Circuitry	Full Bridge	Full Bridge
Sensitivity	0.125 mV/V	2.4 mV/V
Cost	$490	$500
Contact	1-603-448-1562 info@geokon.com	1-847-972-3280 tweinmann@CTLGroup.com

TABLE 3 – Multi-Depth Deflectometer Comparison

Specification	South African MDD	CTL Snap MDD
Transducer	LVDT	Potentiometer
Resolution	Infinite	Infinite
Measurement Points	Up to 6	Up to 7
Transducer Orientation	Serial	Parallel
Time of Installation	2 Days	3 Hrs
Time for Re-Setting Stroke	1 Day	10 Minutes
Cost	> $6,000	$4,500
Contact	1-904-964-3777 psc@dynatest.com	1-847-972-3280 tweinmann@CTLGroup.com

TABLE 4 – Soil Compression Gage Specification

Specification	Soil Compression Gage
Physical Range	25 to 75 mm
Gage Length	Customer Specifies
Transducer	Potentiometer
Resolution	Infinite
Cost	$550
Contact	1-847-972-3280 tweinmann@CTLGroup.com

FIGURE 1 NCAT Test Track.

FIGURE 2 MnRoad Project.

FIGURE 3 HVS at USCOE Waterways Experiment Station.

FIGURE 4 HVS at Berkeley Pavement Research Center.

FIGURE 5 FAA's NAPTF Load Vehicle.

FIGURE 6 TFHRC's ALF.

FIGURE 7 Excessive Rutting.

FIGURE 8 Pavement Displacement.

FIGURE 9 Dynatest Past II.

FIGURE 10 CTL ASG.

FIGURE 11 Geokon Model 3900.

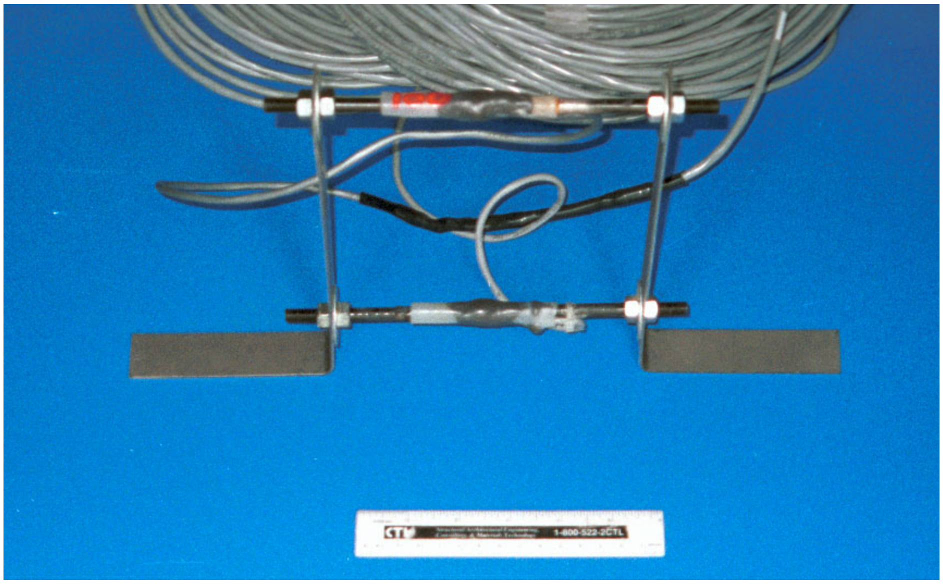

FIGURE 12 CTL CSG.

FIGURE 13 South African MDD.

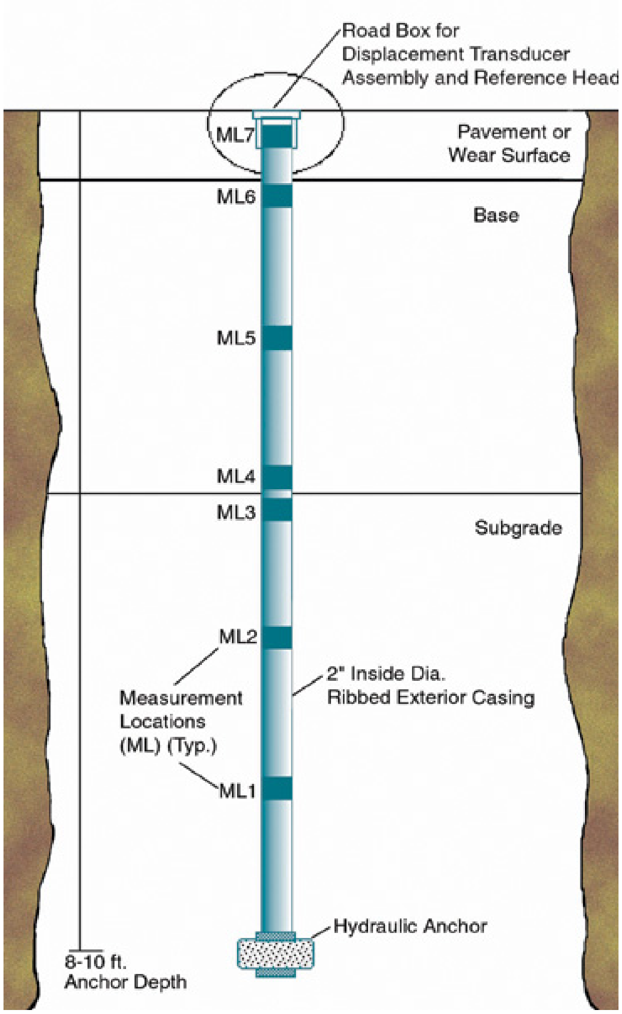

FIGURE 14 CTL Snap MDD.

FIGURE 15 Snap MDD Installation.

FIGURE 16 Soil Compression Gage (SCG).

FIGURE 17 SCG Embedded in Soil.

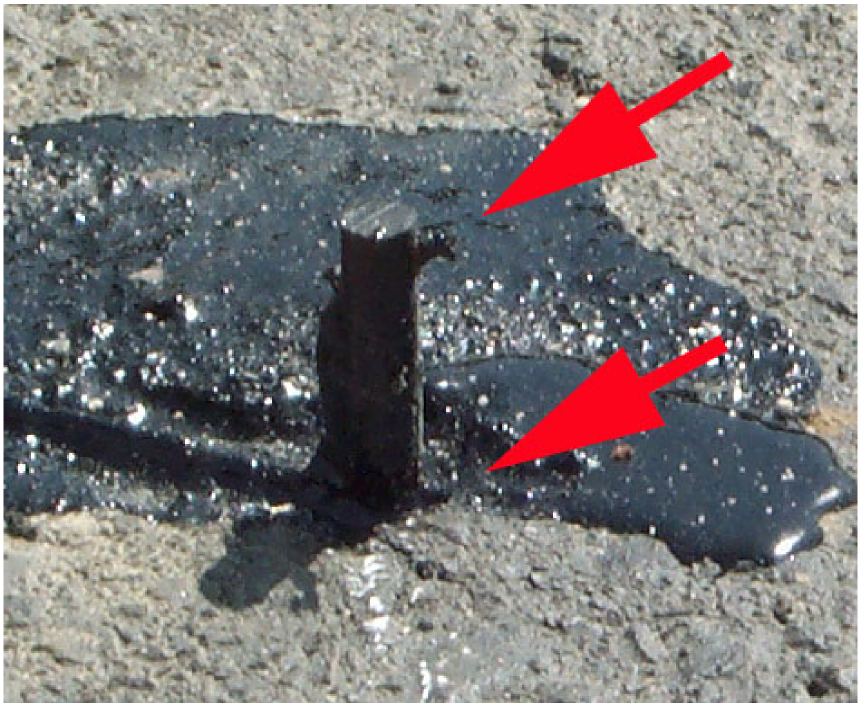

FIGURE 18 Thermocouple "Tree".

FIGURE 19 Thermistor “Tree”.