SUBSURFACE SENSING LAB
THE UNIVERSITY OF HOUSTON

Subsurface Sensing Lab
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Project Summary Report 0-4415-S
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Project 0-4415: Remote Monitoring Moisture Content in Test Pavement in Waco and Bryan Districts

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PROJECT SUMMARY REPORT

Development of Soil Moisture Sensor for Measuring Moisture Content in Pavement Subgrade

Moisture content in the subgrade of pavements has a considerable effect on the strength and deformation properties of the road structure. Continuously monitoring the moisture content under pavements can provide significant information for pavement condition evaluation and maintenance. Such application requires the moisture sensors to be reliable, accurate, water-resistant, and long-lasting.

Fig. 1a. Moisture sensor

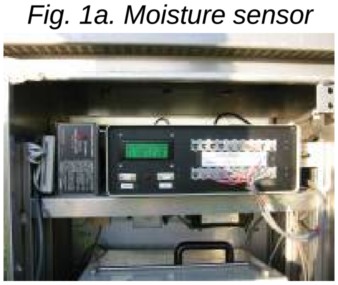

Fig. 1b. Data acquisition

In this project, the researchers developed several novel moisture sensors and data acquisition systems. These sensors were installed in the Bryan and Waco Districts at the SPS-8 sites, and at the Texas APT sites, to monitor moisture contents in the pavement. These sensors are low in cost, small in size, and remotely accessible. Twelve sensors were installed at the Bryan SPS-8 Site in April 2002 and 8 sensors were installed at the Waco site in August 2002. Figure 1 shows sensor system installed in the Bryan District. These sensors monitor moisture every 15 minutes and store the data. Data is then remotely downloaded either via modem or directly from site. The system can store data for 6 months between the two downloads.

What We Did …

In this project, the researchers developed and manufactured three types of different moisture sensors: parallel transmission line (PTL) sensor, integrated PCB sensor, and ring resonator sensor, as shown in Figure 2. These sensors operate at 1GHz to 2GHz microwave frequencies for accurate moisture measurement. The researchers also developed and prototyped corresponding data acquisition systems including wired and wireless data transmission devices. With wireless capability, these sensors are able to transmit measured data to the data collection system cordlessly thereby making sensor installation quite easy.

Fig. 2a. PTL sensor with wireless data transmitter

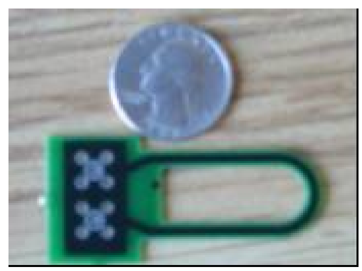

Fig. 2b. Integrated PCB

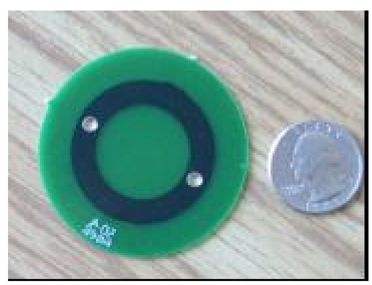

Fig. 2c. Ring resonator sensor

The **PTL sensor** employs a segment of parallel-wire transmission line as the sensor head and measures the phase

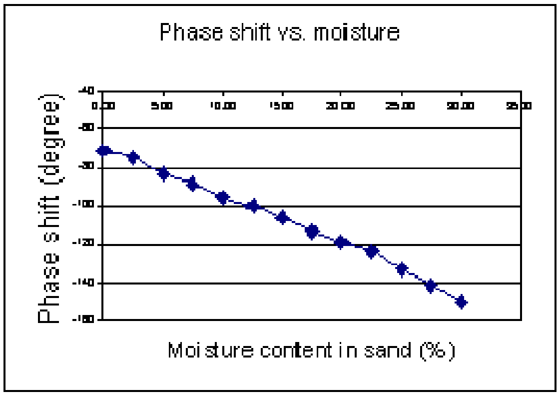

Fig. 3. PTL sensor calibration curve in sand

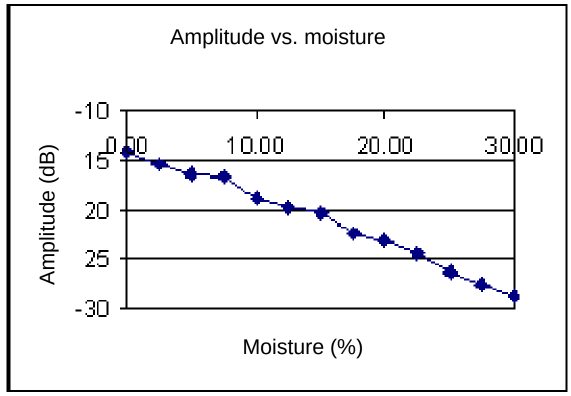

Fig. 4. MR sensor calibration curve in sand

shift on it that is caused by the surrounding moisture variation. The PTL sensors are very sensitive to moisture variation. A typical calibration curve in sand is shown in Figure 3.

An integrated PCB sensor directly prints the sensor onto the circuit board to reduce cost and to improve uniformity of the sensors during manufacturing. This sensor has the same working principle as the PTL sensor. The difference is that the integrated PCB sensor is composed of two parallel copper plates separated by a layer of low-loss dielectric material which confines part of the wave energy. This design not only guarantees stable and reliable transmitted signals, but also improves the sensors' sensitivity and measuring dynamic range.

The **microstrip resonator** (MR) sensor has different working principles than the transmission-line sensors and TDR sensors. MR sensors are based on the measurement of sensors' resonant frequencies in the presence of different moisture content. In this project, both transmission-line sensors and resonant sensors are systematically investigated. New electronic boards are designed and manufactured. The developed electronics of new sensors are all digitized and ready for wired or wireless sensor networking.

Figure 4 shows a calibration curve of the MR sensor. There are two ways in using this sensor. One way is to use amplitude versus moisture and the other is to use resonant frequency versus moisture. According to our measurement, both cases are linear with respect to the moisture content. However, amplitude measurement is easier but more dependent on the soil type.

In all sensors, the sensor electronics including microprocessors and RF circuitry are integrated with the sensor. The data sent out from the sensors is processed moisture data. An example of the sensor integration is shown in Figure 5.

Fig. 5. Sensor with electronics

In the field installation, pavement was tested using FWD. Sensors were installed using core drilling, as shown in Figure 6. In the Bryan site, the sensors were buried in different pavement layers.

Fig. 6. Field installation at Bryan District SPS-8 Site

Figure 7 shows sensor installation layout at the Waco SPS-8 site. The numbers are addresses of the sensors. Two core holes were drilled to the depth of 34 inches.

What We Found…

After the field installations, the data at these two sites have been continuously monitored. Data were obtained every 15 minutes. Measured data were downloaded from the site via a telephone line. Figure 8 shows some of the measured data during the period of 14 August 2002 to 6 February

2003. By the way of reference, the figure also plots rainfall data in the broader area surrounding Waco. It can be seen that the most of the moisture data peaks at the position of rainfall. Frequent rainfall during the period of mid-October and mid-November made average moisture in the pavement reach 13-14%. There was a relative dry period in mid-November and mid-December. From mid-December to February, the pavement moisture was fairly high due to rainfall.

From sensor point of view, the developed sensors are small in size, low in cost (estimated cost for mass production is about $30 each, and for the data acquisition box, about $500). The installation process is fairly straightforward. A list of the specifications of these sensors is as follows:

Sensor accuracy: <+/- 2%
Moisture range: 0 – 100%
Power consumption: 30 mA, 6V
Operating temperature: -30^{0}C to 70^{0}C.
Network: 32 sensors per box
Data transmission: wired or wireless (2.4GHz)
Remove access: Modem
Local access: Serial port
Data storage: 6 months for each 15-minute sampling interval.

The Researchers Recommend…

The moisture sensors developed in this project are very accurate and quite inexpensive. Compared with existing capacitive sensors, the developed sensors are far more accurate. Compared with TDR sensors, the developed sensors are much less expensive (TDR sensors cost about $600 each). The sensors are very small in size, easy to install, and durable. Implementation of these sensors will greatly benefit TxDOT.

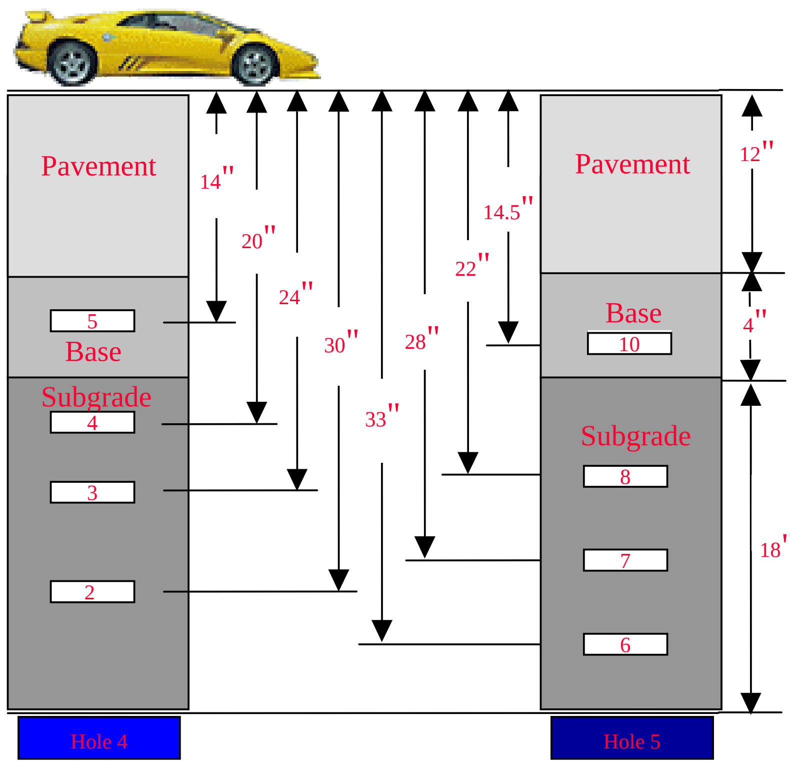

Fig. 7. Sensor layout in Waco District SPS-8 Site: Eight sensors were installed in base and subgrade in two holes. The depth of the sensors in two holes is slightly different.

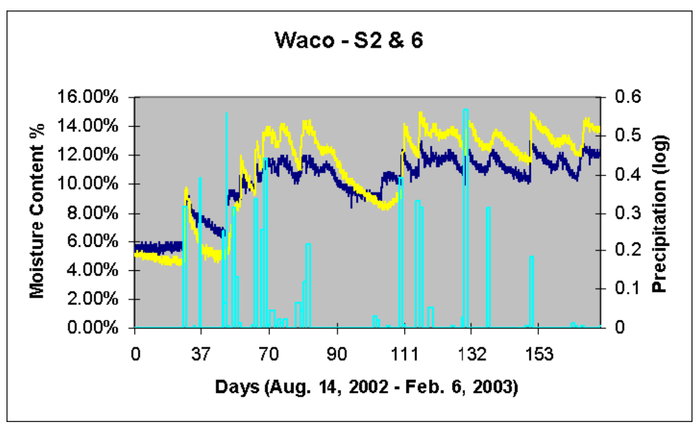

Fig. 8. Recorded data of sensor 2 and 6 in Waco District SPS-8 Site: The horizontal axis is in days with 0 representing August 14. The green lines are precipitation in the general area of Waco obtained from a public website. It can be seen that the rainfall data is closely correlated with the peaks of moisture data.

For More Details...

This research is documented in: Report 0-4415-2, Remote Monitoring Moisture Content in Test Pavements in Waco and Bryan Districts

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