

Monitoring of Vertical Moisture Barriers Using Troxler Sentry 200-AP Device

SANET JOOSTE AND TOM SCULLION

Vertical moisture barriers have been used in numerous locations in Texas to minimize damage associated with expansive clays. Most of the applications use an impermeable fabric 2.4 m (8 ft) deep installed in narrow trenches at the edge of the highway. If the barrier is working correctly it should stabilize the subgrade moisture content inside the barrier. Attempts to measure barrier effectiveness have frequently caused problems because of the unreliability of moisture-measuring sensors. An attempt to monitor a barrier is made with the Troxler Sentry 200-AP device. This capacitance-measuring system requires the installation of a polyvinyl chloride pipe 51 mm (2 in.) in diameter both inside and outside the barrier. The capacitance readings made inside the tubes are converted to moisture-content readings by a laboratory calibration procedure. The system is demonstrated on a major moisture barrier project on I-45 in which 90 km (56 mi) of barrier are being installed. To date the Troxler system is working well. The 2.4-m barrier appears to be effective in stabilizing the moisture content of the top 1.5 m (5 ft) of subgrade. Below that depth the moisture contents inside and outside the barrier are similar.

Expansive clays are known to cause millions of dollars' worth of damage to structures in the United States and elsewhere. Their effect on the riding quality of highways is well known. In Texas the treatment often recommended for minimizing the damage is to replace approximately 1.5 m (4.8 ft) of swelling material with a nonswelling low-plasticity-index fill material. On most projects this strategy is cost prohibitive. Therefore for the past 20 years the Texas Department of Transportation has been experimenting with various methods of minimizing damage by encapsulating clays with impermeable fabrics. Both horizontal and vertical moisture barriers have been used. References to their performance can be found in work by Steinberg (1) and in Picornell et al. (2).

To evaluate the effectiveness of these barriers, both long-term pavement performance and short-term instrumentation experiments have been conducted. The long-term studies have generally shown that these barriers have been successful in limiting the roughness induced in the highways by expansive subgrades (1). The short-term instrumentation studies have been less successful primarily because of the poor durability of the available moisture and suction-measuring equipment.

For a vertical moisture barrier to be working correctly it must stabilize the moisture content beneath the highway. It is the fluctuations in moisture content that are responsible for the large volume changes of swelling clays. Expansive clay damage could be minimized by limiting the infiltration of water from the edge of the highway. Therefore a quick and inexpensive method of judging the barrier effectiveness is to monitor the moisture content relative to depth both inside and outside the barrier. Once the system has reached an

equilibrium condition the moisture content inside the barrier should show significantly less variation than that outside.

In the past 20 years numerous efforts have been made to monitor moisture contents with various types of devices, including psychrometers and moisture blocks. A major concern has been the durability of these systems. Several researchers have noted instrumentation problems occurring in the first couple of months after gauge installation.

Efforts have been made to use a relatively new moisture-measuring device, the Troxler Sentry 200-AP, to evaluate the effectiveness of a vertical moisture barrier being installed on a major Interstate widening project on I-45 near Dallas, Texas. This device is described in the next section of this paper, together with a description of the field installation and laboratory calibration work. This is followed by a discussion of the data collected in the first year after barrier installation.

MOISTURE MEASUREMENT WITH TROXLER SENTRY 200-AP DEVICE

Description of Device

The Sentry 200 family of products is designed for a variety of industrial and agricultural moisture-measurement applications. The Sentry 200-AP, which is the device used in this investigation, responds to changes in the dielectric constant of a material whose moisture content is to be determined. Most dry solid materials such as sand, clay, and other organic materials have a dielectric constant between 2 and 4, whereas water has a dielectric constant of 78 (3). The moisture content of a material is determined by measurement of changes in dielectric constant of the material.

The probe operates inside an access tube that enables it to measure moisture at any depth to which an access tube can be installed. The time and calendar record the exact time and date of the moisture measurements. The device is capable of storing up to 1000 field measurements, and the data can be stored and downloaded to a computer.

The gauge consists of a calibrated moisture probe that measures volumetric moisture content, a control unit, an access tube mount, and cable stops (Figure 1).

Installation Procedure of Access Tube

The moisture probe is lowered into an access tube from which it makes the moisture measurement. The access tube consists of a polyvinyl chloride (PVC) pipe 50 mm (2 in.) in diameter, which is installed at the depth at which a moisture measurement is to be taken. A summary of the installation procedure of the access tube follows:



FIGURE 1 Sentry 200-AP moisture measurement device.

1. Locate the area where moisture is to be measured.
2. Determine the maximum depth of measurement.
3. Obtain a section of PVC access tube.
4. Ensure that the access tube is the correct length. The bottom of the tube must be sealed and should extend at least 150 mm (6 in.) below the lowest point at which a measurement will be made.
5. Auger a hole with the same diameter as the PVC tube into the soil to the desired depth of installation. A Shelby tube sample should also be taken to the desired depth, and the excavated soil can be saved for subsequent calibration.
6. Drive the PVC tube into the augered hole. The PVC pipe must fit tightly against the earth walls of the augered hole to prevent the formation of air voids between the access tube and the surrounding soil. The presence of air voids could lead to unreliable moisture readings.

Calibration Procedure

The calibration procedure as described by the users' manual for the Sentry 200-AP is discussed briefly in the next section. However, it was necessary to make a laboratory calibration of soil from the site where moisture measurements were to be taken because of the narrow range of moisture that the field-obtained samples had. This second calibration procedure was developed by the Texas Transportation Institute and is not included in the users' manual for the Sentry 200-AP.

Field Calibration Procedure

1. It is recommended that core samples be removed from the access tube locations. These samples will be analyzed for moisture content and the data used for performing a calibration of the Sentry 200-AP.

2. If possible obtain samples with varying moisture levels. This can be accomplished by taking samples during dry periods and also by taking samples after a heavy rain.

3. In most cases the samples can be obtained during the installation of the access tube.

4. Obtain a core sample for each measurement depth. Note: Core samples may be taken from other locations as long as the soil and moisture content are the same as those of the soil around the access tube.

5. After all the core samples have been taken it is necessary to obtain a gauge reading with the moisture probe at the exact position of each core sample. This gauge reading will correspond to the laboratory-derived moisture content of the soil samples collected from the same location.

Laboratory Calibration Procedure

It is essential that the soil from which the core samples are taken have a wide range of moisture content. If it does not, the range of moisture content over which the calibration is made will not be sufficient, and the data will not fit a regression line. This problem can lead to scattered data and inconsistent moisture measurements. If the core samples do not have at least a 15-percent variation in moisture content, it is necessary to mix samples of soils with a variety of moisture content values from the location where moisture measurements are to be taken. The procedure follows:

1. Excavate enough soil of the same type as that for which the moisture measurement is to be taken to fill at least three 20-L containers.
2. Thoroughly dry and crush the soil so it will pass through a No. 40 sieve.
3. Cut a PVC pipe long enough that the bucket can be sealed airtight, and seal off the bottom of the pipe by gluing a piece of plastic material to it or by applying an end cap. Place the PVC pipe in the center of the container.
4. Mix three or more batches of soil with different quantities of water to obtain moisture contents that vary from very dry to very wet. (The difference in moisture content between wet and dry mixes should be more than 15 percent.)
5. Carefully place the soil around the PVC pipe in the container until the bucket is half full. Compact the soil carefully so as not to disturb the PVC pipe but thoroughly enough to remove all possible large voids in the soil. There should be no gap between the PVC pipe and the soil, but if the soil is compacted too tightly against the pipe the moisture readings may be artificially high.
6. Fill the bucket and compact the soil again.
7. Save a sample of each batch with a different moisture content in a plastic bag and calculate the moisture content in the laboratory.
8. Seal all the buckets airtight and save them for subsequent calibration.
9. Gauge-derived moisture readings can be taken at this stage or later when the actual moisture content is known.

Determination of Moisture Content

Refer to the following ASTM standards for more information on determining actual moisture content: ASTM D-2216, *Laboratory Determination of Water Content of Soil, Rock, and Soil Aggregate*

Mixtures; ASTM D-4643, *Method for Determination of Water Content by Microwave Oven*.

Use the core samples obtained from the field or use the self-mixed samples from the laboratory to analyze the actual gravimetric moisture content of the soil. Then calculate the percent moisture by volume (P_v), using the following formula (4):

$$P_v = P_d \times D_b$$

where P_d = percent moisture by dry weight and D_b = bulk density (g/cm^3).

Calibration of Sentry 200-AP

1. At this stage the gauge-derived moisture readings have already been entered and saved under a suitable name.
2. Recall this calibration and enter the laboratory-obtained moisture content that corresponds to each gauge-derived reading.
3. The calibration is now completed. The Sentry 200-AP will give a fit coefficient that is an indication of how well the moisture data obtained from the laboratory fit the gauge-derived readings. A plot of the gauge readings versus the actual moisture content should result in a linear curve.

Note: In general a fit coefficient of less than 0.6 indicates a less acceptable correlation of data.

Moisture-Content Readings After Calibration

Moisture-content values can now be taken at any time simply by recalling the corresponding calibration and performing a moisture measurement. The Sentry 200-AP will display the gauge reading as well as the corresponding moisture content on the screen. It is not necessary to perform a calibration for each test hole from which moisture data are to be taken. One calibration for each soil type is sufficient if the soil used for the calibration is representative of the soil type in general and if the range of moisture over which the calibration was done is wide enough.

Repeatability of Sentry 200-AP Moisture-Measuring Device

The Sentry 200-AP is equipped with a calibration factor for sandy soils only. Therefore it was necessary to obtain a standard calibration for gravel and clay soils to be able to make moisture measurements without calibrating the probe for every test location.

Repeatability tests were performed with the Sentry 200-AP on a black clay and on gravel. These tests aided in determining the reliability and accuracy of measurements made with the moisture probe and provided calibration curves for clay and gravel in general. The test procedure was as follows:

1. The soil that was used for the tests was thoroughly dried.
2. A PVC pipe 50 mm (2 in.) in diameter was sealed off with an end cap and placed in the middle of a 20-L container. The pipe was short enough that the container could be sealed airtight.
3. Three batches of soil were mixed with different amounts of moisture (from very wet to very dry) and placed in three different buckets.
4. The soil was thoroughly compacted, and the buckets were sealed.
5. A sample of each of the soil batches was taken for laboratory measurement of actual moisture-content values.
6. After these actual moisture-content values were obtained the Sentry 200-AP was calibrated with the three different soil samples as three different data points.
7. A linear curve was fitted through these points and the calibration constant entered into the Sentry control unit.
8. The repeatability of the Sentry device was tested one day after calibration by repetition of the moisture measurements on the samples, using the corresponding calibration.

The results of the calculation of the actual moisture contents of the black clay and the gravel are presented in Table 1. The gauge-derived repeatability results are presented in Table 2. The results in Table 2 are graphically presented in Figures 2 and 3.

It is evident from the data in Table 2 that the repeatability of the moisture probe is very good. The difference between readings at the same moisture content was insignificantly small. A regression was performed on the moisture data obtained from the repeatability tests. For both the clay and the gravel the data can be represented by a straight-line equation. The equation constants are as follows:

	Clay	Sand/Gravel
Slope	22.884447	46.566363
Intercept	3403	3238

The equation is

$$y = mx + c$$

where

- y = gauge reading,
 x = moisture content (percent by volume),
 m = slope of the curve, and
 c = intercept on y axis.

TABLE 1 Laboratory-Determined Water Content

Volumetric water content of a black clay		Volumetric water content of a gravel	
Sample no.	% moisture	Sample no.	% moisture
1	44	1	8.9
2	53	2	18.9
3	67	3	19.7

TABLE 2 Gauge-Derived Moisture Content

Volumetric water content of a black clay			Volumetric water content of a gravel		
Sample no.	Gauge reading	% moisture	Sample no.	Gauge reading	% moisture
1	4424	44.6	1	3652	8.9
	4417	44.3		3655	9
	4424	44.6		3646	8.8
	4419	44.5		3651	8.8
2	4575	51.2	2	4073	17.9
	4575	51.2		4071	17.9
	4574	51.2		4070	17.9
	4570	51		4072	17.9
3	4958	69.7	3	4196	20.6
	4959	68		4196	20.6
	4955	67.8		4197	20.6
	4952	67.8		4194	20.5

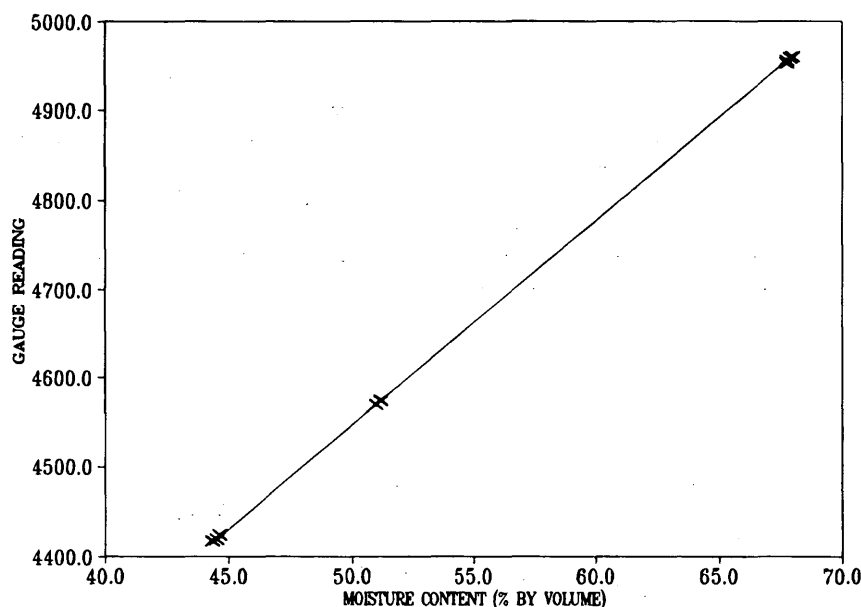


FIGURE 2 Repeatability data used for calibration of black clay soil.

CASE STUDY: FIELD DATA FROM I-45, DALLAS

Objective of Study

The objective of this study is to evaluate the moisture barrier installed on I-45. The evaluation involves stabilizing the moisture content of the soils inside the barrier and thereby minimizing the damage caused by shrinkage and swelling. To perform the evaluation the Texas Transportation Institute has placed instruments at four test locations along the highway to make moisture measurements on both sides of the barrier to a depth of 3 m (10 ft). The instrument chosen to perform the monitoring is the Troxler Sentry AP-200 device. The following section of this paper discusses mois-

ture measurements obtained from inside and outside the moisture barrier over a period of 1 year after installation. Specific objectives for this study are to (a) provide moisture data from the four locations that have been instrumented in the northbound outer lanes of I-45 near Palmer, Texas, and (b) continue monitoring these sites for 2 years to gain the full benefit of the test program.

Description of Site

The material underlying the pavement is a grayish-brown and tan mixed clay with calcarious and limestone deposits. No seepage was encountered during drilling. This indicates that the groundwater table is below the maximum depth of drilling, which was approximately 6 m.

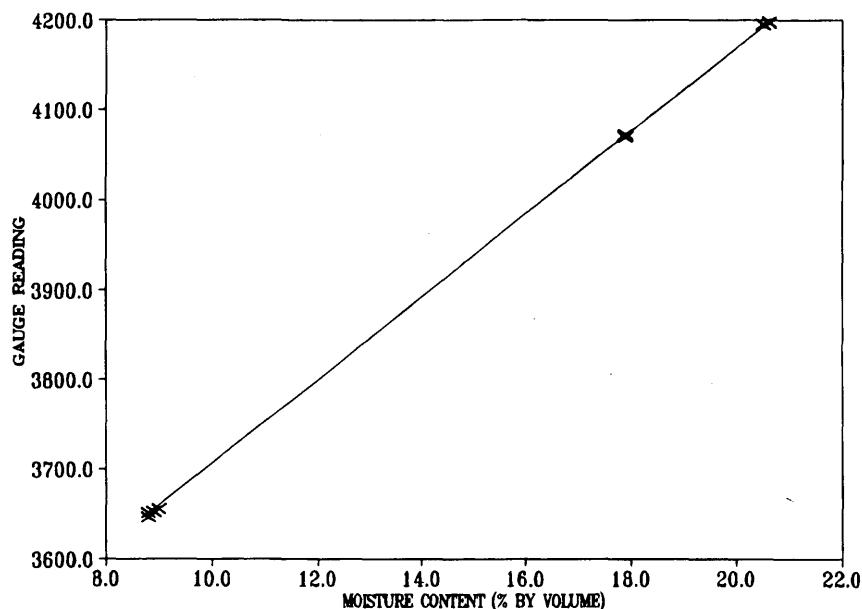


FIGURE 3 Repeatability data used for calibration on gravel.

The pavement initially consisted of 250-mm-thick concrete main lanes with an asphalt shoulder. The initial jointed concrete pavement had exhibited the roughness wavelengths typically associated with expansive clay. The pavement was scheduled for widening construction and a concrete overlay. An initial geotechnical investigation recommended replacing 1.5 m of the subgrade soil under the widened section. In lieu of this recommendation the district opted for a vertical moisture barrier, which had been reported to perform well in other dis-

tricts in Texas, notably San Antonio. A moisture barrier was installed next to the new asphalt shoulder along the highway. To evaluate the effectiveness of the moisture barrier, access tubes were installed at four locations inside and outside the moisture barrier. During August 1993 a new 330-mm-thick concrete overlay was added on top of the existing concrete lanes and asphalt shoulder. Access tubes were reinstalled at the same locations along the highway. A cross section of the pavement after the new overlay was added is shown in Figure 4.

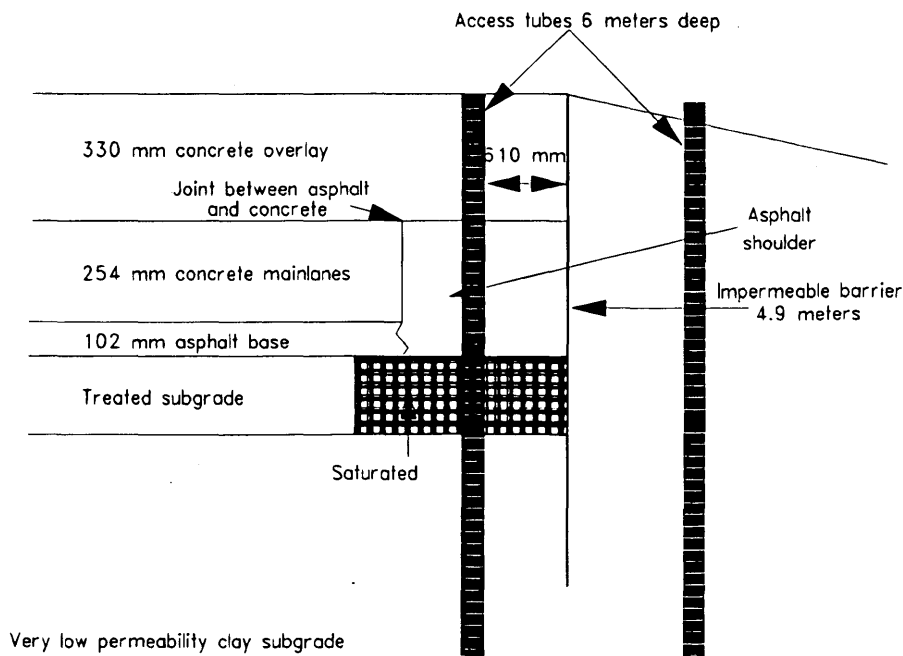


FIGURE 4 Cross section of I-45 near Palmer after concrete overlay.

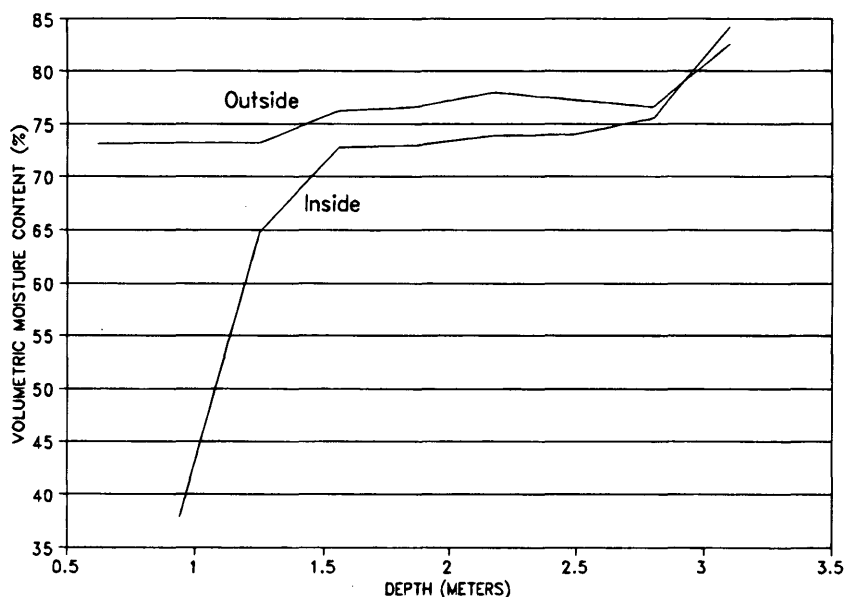


FIGURE 5 Moisture content on inside and outside of moisture barrier measured during May 1994 (Site 1).

Measurements with Sentry 200-AP Device

Moisture measurements were taken with the Sentry 200-AP device after installation of the access tubes in August 1993 and again in November 1993 and May 1994. It should be noted that all the access tubes extend to a depth of 6 m (10 ft), except at Location 2, where the depth of the hole was limited to 4.8 m (8 ft) by an impervious layer of soil. Because of distortion of some of the access tubes it was in some cases not possible to lower the moisture probe to the full depth of 6 m.

Presentation and Discussion of Results

Figures 5–8 show graphs of the measured moisture content during May 1994 inside and outside the barrier for each of the test locations. The volumetric moisture contents are reported as measured with the Sentry 200-AP with the calibration for clay soils. At each location the moisture content inside the barrier is lower than the corresponding moisture content outside the barrier for approximately the first 1.5 m (5 ft) throughout the whole period of evaluation. This is encouraging because the moisture content of the first meter below

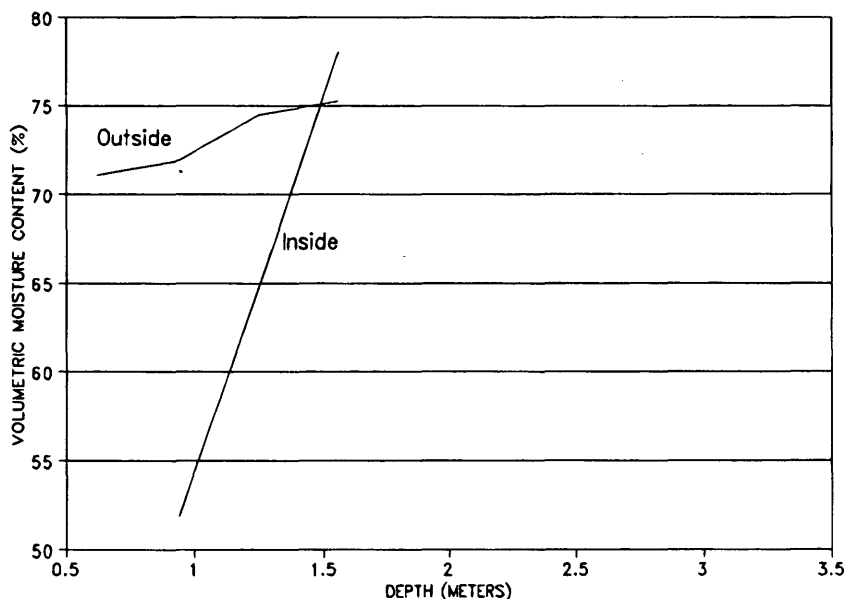


FIGURE 6 Moisture content on inside and outside of moisture barrier measured during May 1994 (Site 2).

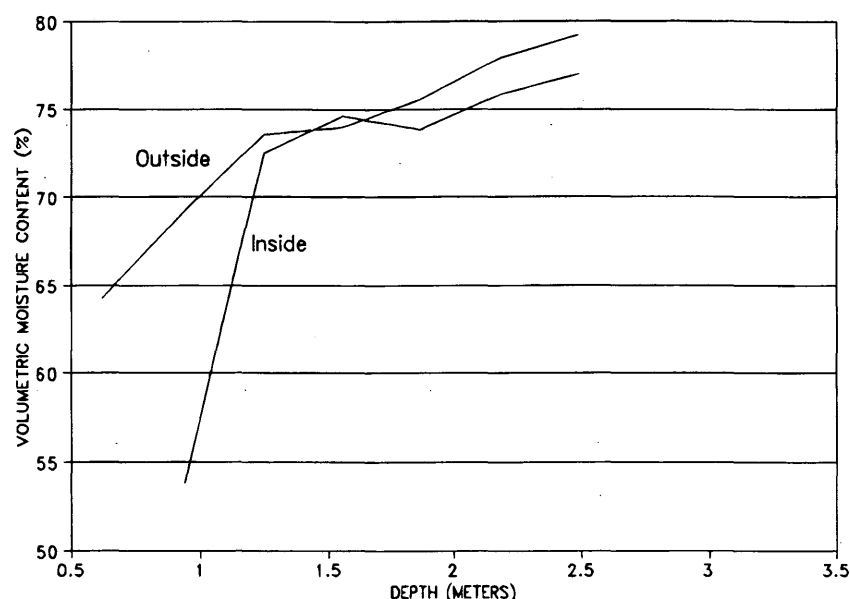


FIGURE 7 Moisture content on inside and outside of moisture barrier measured during May 1994 (Site 3).

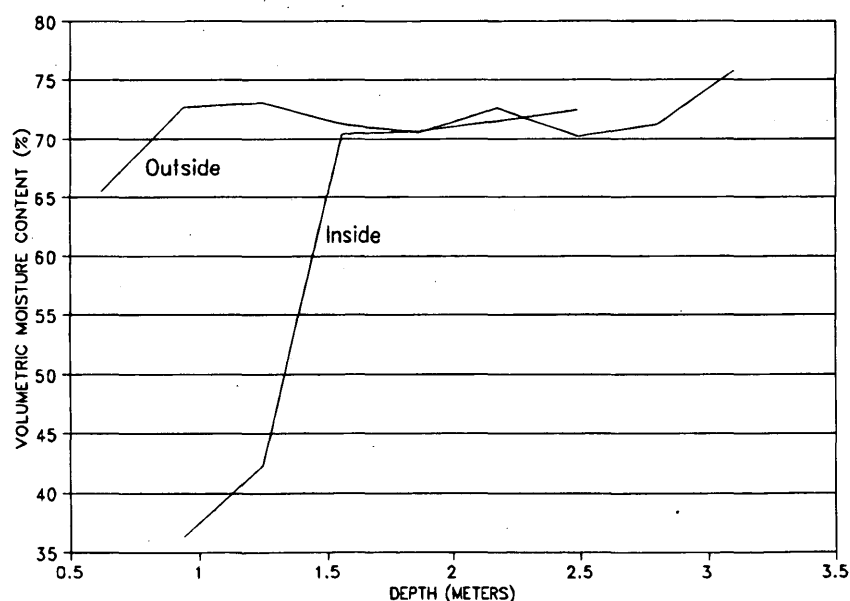


FIGURE 8 Moisture content on inside and outside of moisture barrier measured during May 1994 (Site 4).

the pavement is the most critical. Below 1.5 m the moisture content inside the moisture barrier increases gradually until it equals the moisture content on the outside at a depth of about 4.8 m (8 ft), which is at the bottom of the moisture barrier. This lends support to the conclusion that the moisture barrier operates effectively to keep water from seeping into the soil directly underlying the pavement.

However, from Figures 9–12 it is evident that the moisture content inside the barrier increases with time. It seems that the moisture outside the barrier is slowly coming into equilibrium with the mois-

ture on the inside. This phenomenon is most probably caused by poor drainage conditions on the sides of the pavement. One proposed solution is to pave the median to prevent water from accumulating between the two lanes of pavement. Whether this would be economically feasible is questionable. Sufficient drainage on the outer lanes can be ensured by sloping earth banks at the sides of the road. Another drainage problem could be caused by the difficulty in achieving proper compaction of the backfill in the trench into which the moisture barrier is installed: high permeabilities in this area cause water to accumulate.

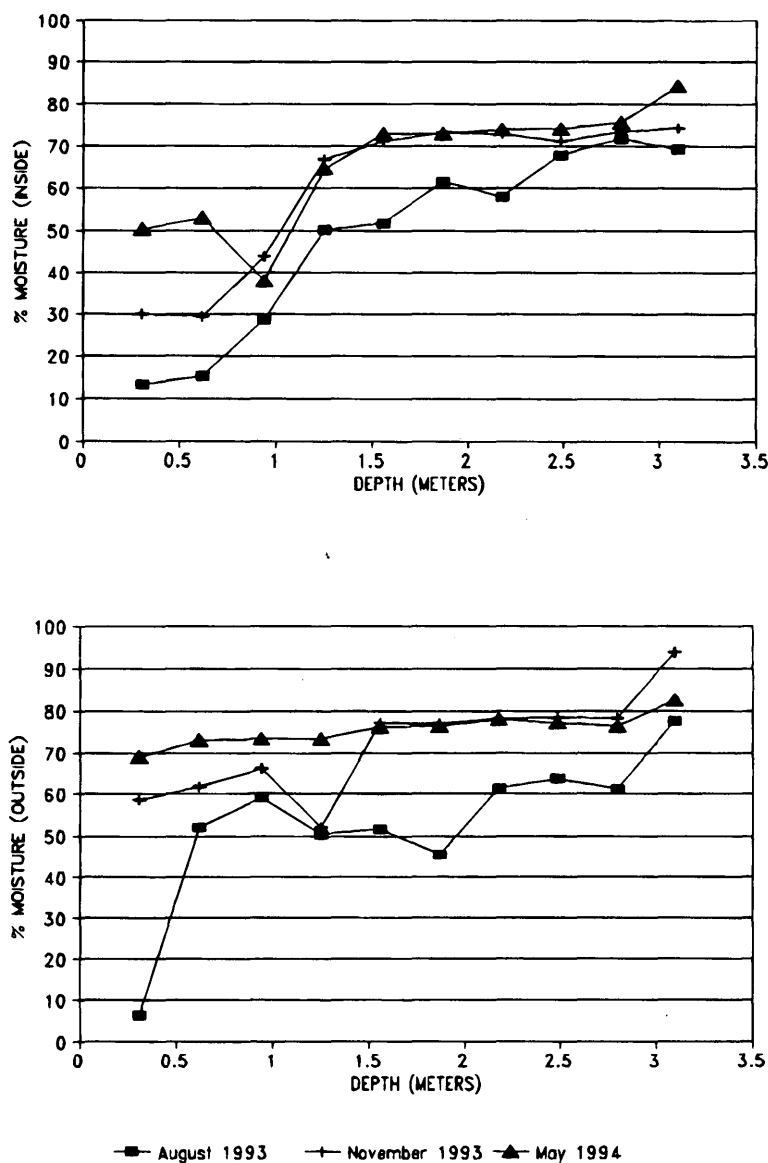


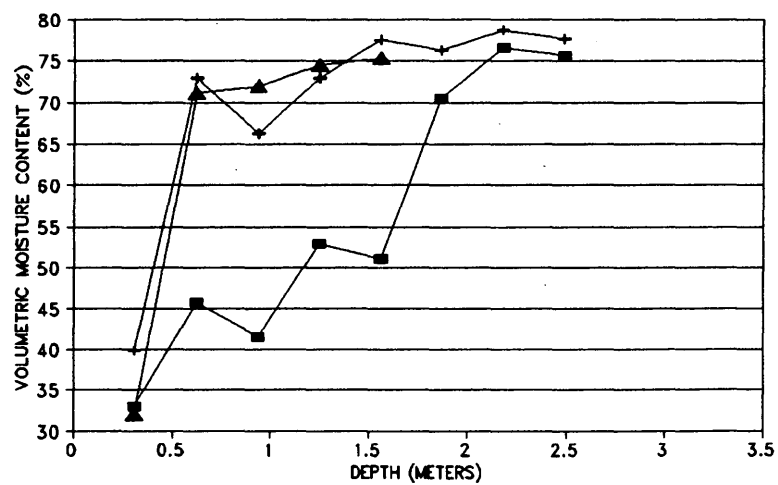
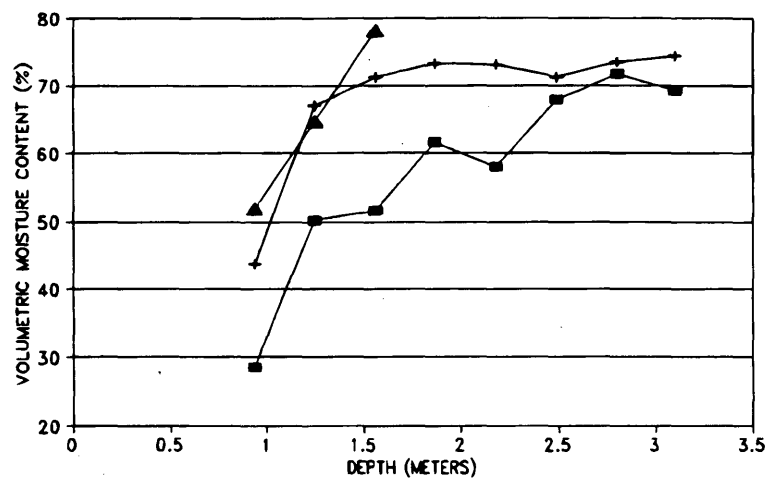
FIGURE 9 Volumetric moisture content on (top) inside and (bottom) outside of moisture barrier (Site 1).

CONCLUSIONS

From the first section of this paper it is evident that the Troxler Sentry 200-AP moisture-measuring device performs well in evaluating vertical moisture barriers. Moisture measurements taken with this device are quick and inexpensive and have been proved to be highly consistent and accurate. Laboratory calibration of the device permits moisture measurements of any soil type, and the PVC access tubes seem to be durable enough for repeated use for moisture measurements.

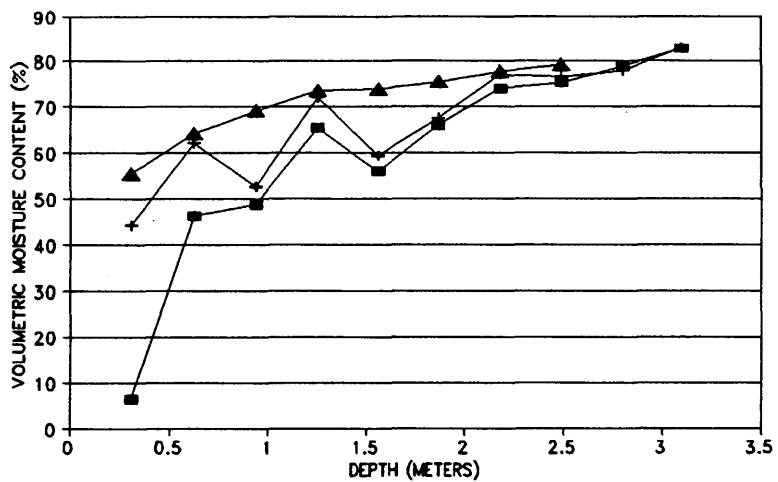
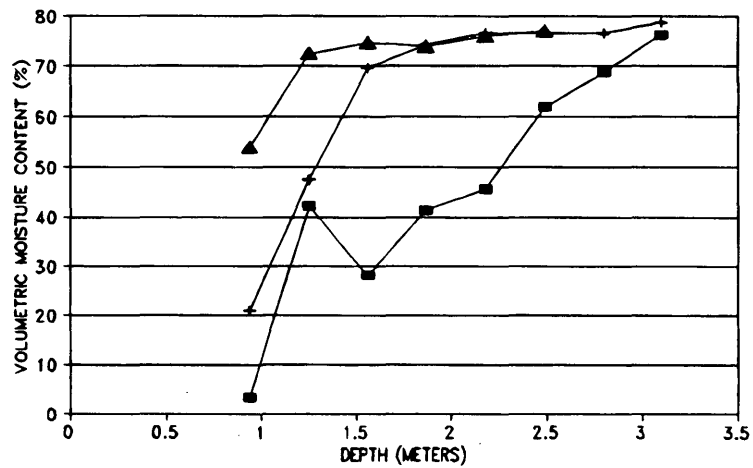
This device has been used for monitoring a vertical moisture barrier on a major Interstate highway near Dallas, Texas. Moisture contents inside and outside the moisture barrier have been recorded over a period of a year. The vertical moisture barrier seems to be

effective in keeping the moisture content underneath the pavement from fluctuating and in keeping moisture from infiltrating from the edge of the highway. To a depth of 1.5 m the moisture content inside the moisture barrier seems to be lower than corresponding moisture contents outside the barrier. However, it is also evident that the moisture content inside the barrier increases with time as it slowly comes into equilibrium with the moisture content outside the barrier. This phenomenon could be a result of poor drainage conditions at the sides of the pavement. However, even with these poor drainage conditions the moisture activity is very slow, and the barrier is effective in keeping the moisture content from fluctuating with seasonal changes. Expansion of the subgrade clay soils is thus controlled and associated damage minimized by the use of a vertical moisture barrier.



■ August 1993 + November 1993 ▲ May 1994

FIGURE 10 Volumetric moisture content on (top) inside and (bottom) outside of moisture barrier (Site 2).



■ August 1993 + November 1993 ▲ May 1994

FIGURE 11 Volumetric moisture content on (top) inside and (bottom) outside of moisture barrier (Site 3).

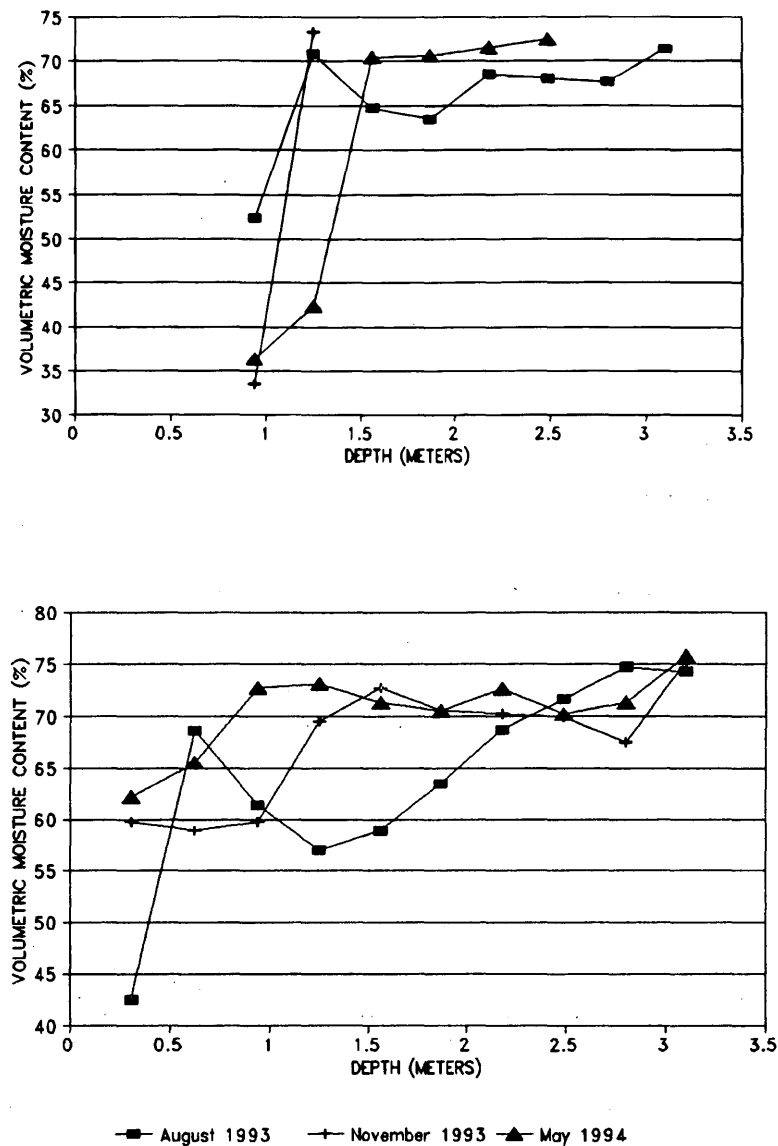


FIGURE 12 Volumetric moisture content on (top) inside and (bottom) outside of moisture barrier (Site 4).

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Publication of this paper sponsored by Committee on Environmental Factors Except Frost.