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MATRIC SUCTION MONITORING IN AN EXPANSIVE SOIL SUBGRADE IN KENYA

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ABSTRACT: Pavements constructed in areas with expansive soil subgrades suffer damage caused by changes in bearing capacity and movements of the subgrade soil due to seasonal variations in moisture content. In a bid to improve the understanding of the behaviour of pavements constructed on unsaturated expansive soils, a research project was initiated to establish typical variations of matric suction in pavement layers. The selection, calibration and installation of thermal conductivity sensors in a pavement test site in Kenya are presented in this paper, as are typical variations of matric suction with pavement geometry and time.

RESUME:

1. INTRODUCTION

Damage suffered by pavements constructed on expansive soil subgrades can be attributed to deformations that accompany changes in the bearing capacity of the subgrade due to seasonal moisture variations. Many existing pavement design methods attempt to limit such damage by specifying placement of pavement layers at water contents close to empirically determined equilibrium water contents (Russam, 1965; Haliburton, 1971). Recent advances in unsaturated soil theory have shown that matric suction, and not water content, is the stress state variable controlling the behaviour of unsaturated soils. The behaviour of compacted pavement layers, which are invariably unsaturated, can be better understood using theories developed for unsaturated soils.

The application of theories of unsaturated soils to pavement design requires a knowledge of the distribution and variation of matric suction in the pavement layers. The study reported herein was undertaken to obtain typical variations of matric suction in a pavement constructed on an expansive soil subgrade in Kenya. It forms part of a broader study aimed at developing a bearing capacity approach to the design of low-volume roads (Oloo, 1994).

2. SELECTION OF SENSOR

A number of devices have been developed for the measurement of suction in the laboratory and field. These include tensiometers, thermocouple psychrometers, null type pressure plates, filter papers and thermal conductivity sensors. Tensiometers measure negative water pressure in the soil directly via a high air entry ceramic disk. They can be used in the laboratory as well as in the field. However, due to cavitation of water, tensiometers are limited to measuring pore-water pressures greater than -90 kPa. They could not be used in this project since higher negative water pressures were anticipated.

Thermocouple psychrometers can measure total suction up to 8000 kPa (Edil and Motan, 1984) but require a controlled temperature environment of ± 0.001°C (Krahn and Fredlund, 1972) which cannot be attained in field conditions. Null type pressure plate apparatus based on the axis translation technique (Olson and Langfelder, 1965) can be used to measure negative water pressures in the laboratory with reasonable success and accuracy but cannot be used for field measurements.

The filter paper technique has been used to measure matric suction by a number of researchers (McKeen, 1981; Ching and Fredlund, 1984; Chandler and Guterrez, 1986; Crilly et al., 1991) with varying degrees of success. Crilly et al. (1991) developed a suction probe based on the filter paper technique which was shown to give accurate and reliable measurements of total suction in the field. Difficulties associated with ensuring adequate contact between the filter paper and the soil renders the measurement of matric suction inaccurate.

Thermal conductivity sensors utilize the relationship between matric suction and the thermal conductivity of a reference porous ceramic stone to measure matric suction. They have been used for both field and laboratory measurements of matric suction and have been shown to give reasonable results (Sattler and Fredlund, 1979; Rahardjo et al., 1989; Loi et al., 1992). Thermal conductivity sensors are also amenable to automatic data acquisition making them particularly suitable for remote sites. The AGWA-II thermal conductivity sensor manufactured by Agwatronic Inc. of Merced, California was selected for use in this project. A detailed discussion of the construction and operation of the AGWA-II sensor is given by Phene et al. (1971).

3. SENSOR CALIBRATION

AGWA-II thermal conductivity sensors are normally supplied with a 2-point calibration curve determined by the manufacturer. The 2-point calibration curve has been found to be inadequate for geotechnical engineering purposes (Wong et al., 1989). For this reason, the AGWA-II sensors acquired for the project were recalibrated in the laboratory using a pressure plate apparatus modified to accommodate sensors.

The pressure plate was filled with a fine silty calibration soil and groups of 8 sensors embedded in the calibration soil. The sensors were then connected to a data acquisition system to measure the variation of voltage output with time.

The calibration soil was initially saturated with water to obtain readings for zero matric suction. Air pressure increments of 50, 100, 150, 180, 300 and 370 kPa were applied to the soil. At each air pressure level, the sensors were allowed to come to equilibrium as matric suction equilibration occurred in the soil. The voltage change at equilibrium was taken to correspond to the matric suction given by the air pressure increment. The air pressure was then increased to the next level.

The voltage change reading at equilibrium was converted to a temperature change reading and plotting against the matric suction to obtain the calibration curve. A typical calibration curve is shown in Fig. 1. The sensors exhibit a bi-linear calibration curve with a breaking point at around 170 kPa. The accuracy of matric suction measurement decreases significantly at matric suctions greater than 170 kPa. The calibration curves thus obtained were used to back-calculate matric suction values from temperature readings of sensors in the field.

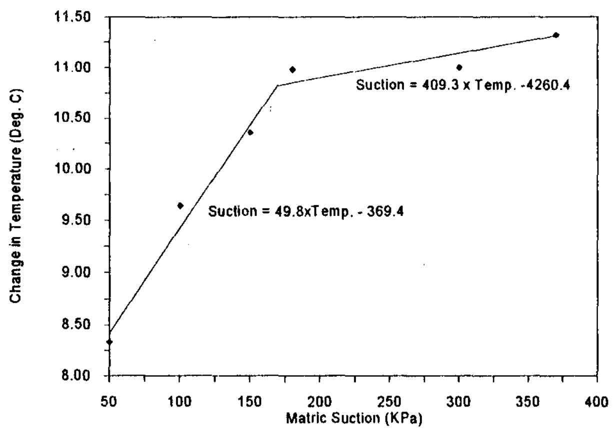

Figure 1: calibration curve for sensor 1.

4. LOCATION OF THE TEST SITE

The site selected for instrumentation was located at Km 29+900 on the Kiserian-Isinya Road, 60 km South of Nairobi. The area in which the site is located is semi-arid with an annual rainfall of 500 mm and mean annual temperature of 20^{o}C. The Kiserian-Isinya Road traverses areas with thick layers of black cotton soil. It was commissioned in 1991 and consists of a thin surface dressing overlying a stabilized gravel base (150mm) and a gravel subbase (150mm). The subgrade is mostly black cotton soil. To improve the bearing capacity of the subgrade, a fill of quarry stone of varying depth was placed directly over the black cotton soil subgrade. A subsurface exploration carried out to identify the stratigraphy and recover undisturbed samples for testing revealed the profile shown in Fig. 2.

5. INSTALLATION OF SENSORS

A trench, 1 m wide and 3 m deep was excavated through the pavement and fill into the subgrade. Fourteen sensors were installed at various depths in the fill and black cotton soil subgrade at locations corresponding to the outer and inner wheel paths, and the beginning and end of the shoulder. The last sensor was installed just below the soil surface in an uncovered area outside the side slope. This sensor was installed to measure the variation of matric suction with the micro climate without the blanketing influence of the pavement. A total of 15 AGWA-II thermal conductivity sensors were installed in the test site in August 1992. The positioning of the sensors along the walls of the trench is shown in plan in Fig. 3 and in profile in Fig. 4.

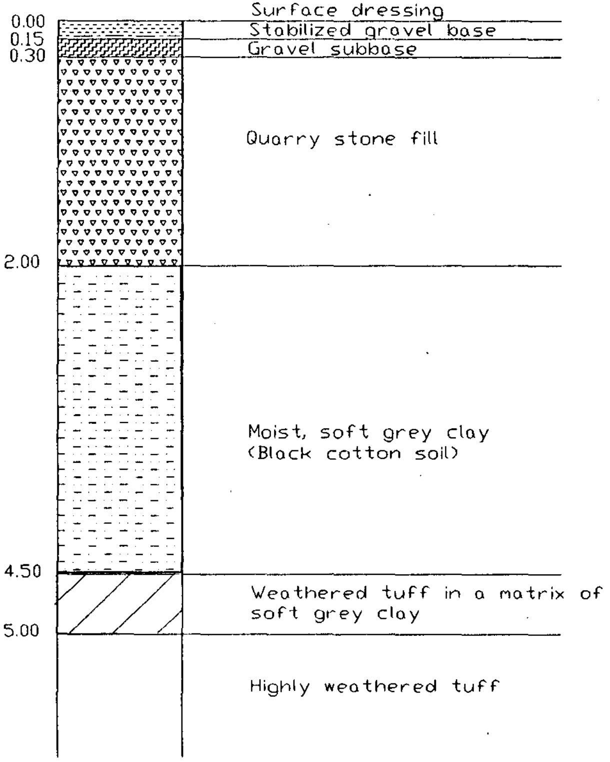

Figure 2: profile through pavement

To install each sensor, a horizontal circular hole 3 mm diameter and 10 mm

PaperN^{O} 223 ; Oloo et al., Matric Suction Monitoring in an Expansive Soil Subgrade in Kenya

long was drilled into the side of the trench using a long screw driver. The hole was filled with a moist lump of black cotton soil. The sensor was then pushed gently into the hole through the lump of black cotton soil. By so doing, good contact between the surrounding soil and the sensor was ensured.

Cables housing the sensor leads were laid along the floor of the trench to an instrument box housing the data acquisition system located on the side ditch. After installing all the sensors, the trench was backfilled and compacted to the level of the surfacing. Fresh surface dressing was applied to the area over the trench to restore it to the original state.

The data acquisition system consisted of a CR10 Data Logger, a AM416 16 channel Multiplexer and REL-12 4 channel Relay Driver supplied by Campbell Scientific Inc. Power was provided by a 12 Volt car battery.

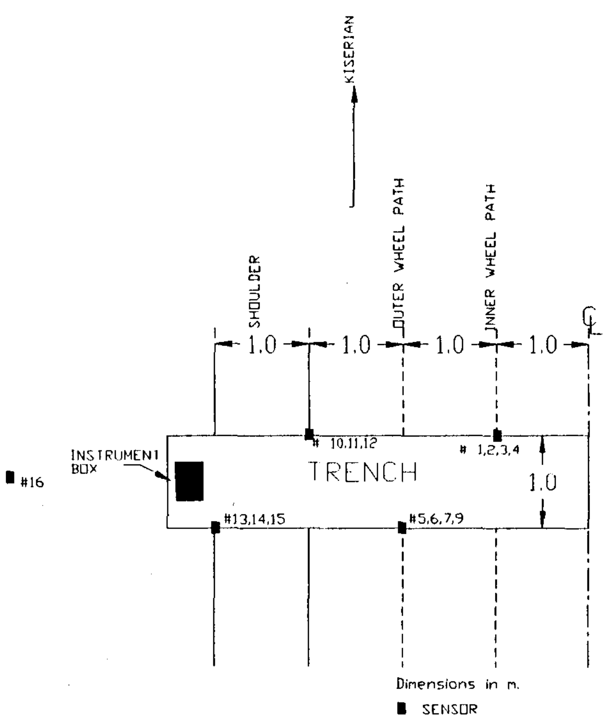

Figure 3: Location of sensors in plan.

6. MONITORING

The data acquisition system was programmed to take readings every 3 hours for the first four months. From January 1993, readings were taken every 12 hours and downloaded from the data logger once every month using a laptop computer.

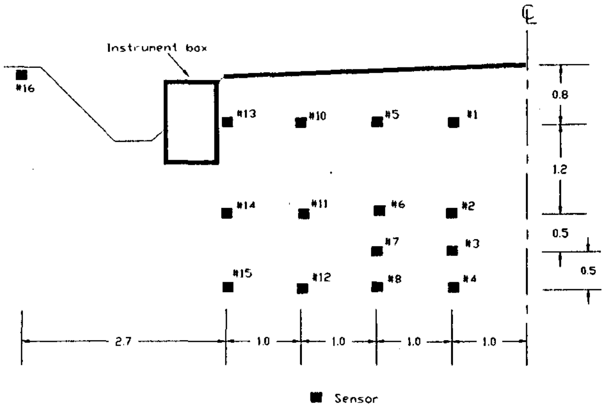

Figure 4: location of sensors in section.

7. RESULTS

The variation of matric suction in the pavement and subgrade two months after installation is summarized in Fig. 5. Matric suctions are generally lower under the road centerline but increase towards the shoulders. There is an apparent decrease of matric suction with depth from the pavement surface. However, matric suction is lower in the quarry stone fill layer than in the black cotton soil subgrade. The general trends of matric suction variation depicted in Fig. 5 are similar to observations by Aitchison and Richards (1965) for pavements in Australia.

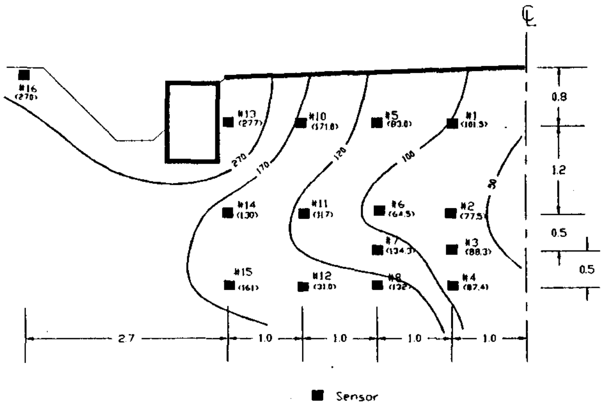

Figure 5: matric suction profile on 26-09-92.

Measurements of total suction made by Crilly et al. (1991) using the filter paper technique in a test site within the same climatic and geological zone as the present site suggest matric suctions significantly higher. Matric suction measurements were cross checked in the laboratory using the pressure plate technique on undisturbed samples of black cotton soil. Values of matric suction less than 300 kPa were obtained in all cases. The large differences between the two observations may be due to the location of the present test site in a swampy area.

The variations of matric suction with time over a period of five months are summarized in Fig. 6 for four of the sensors installed. There is a general decrease of matric suction with time towards an equilibrium value. However, a number of the sensors failed after some time and were indicating negative matric suction readings. About half of the 15 sensors had failed by the end of the first year of monitoring.

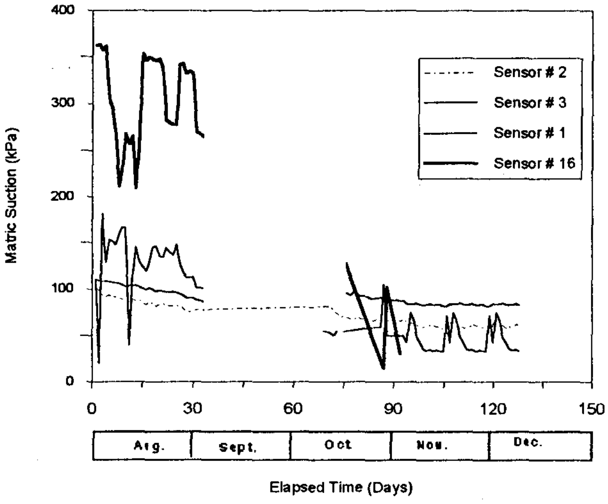

Figure 6: matric suction variation with time.

8. CONCLUSIONS

The results presented indicate that matric suctions under pavements with expansive soil subgrades tend towards equilibrium values that are dependent upon the stratigraphy as well as the depth and distance from the centerline line.

Although the AGWA-II thermal conductivity sensors appear to give reasonable estimates of matric suction, they suffered a high failure rate in this project. The failure rate may be attributed to differences in climatic conditions since previous usage of the sensors has been mainly in North America.

7. ACKNOWLEDGEMENTS

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