Unsaturated Soils/Sols Non Saturés, Alonso & Delage (eds) © 1995 ISBN 90 5410 583 6/2 85978 241 9

Matric suction and deformation monitoring at an expansive soil site in southern China

Succion matricielle et mesure de déformation dans un site de sol gonflant au sud de la Chine

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Proceedings of the First International Conference on Unsaturated Soils, Vol .2. pp. 855-862. September 6-8, Paris, France. 1995

ABSTRACT : Buildings constructed on expansive soils often suffer damage due to shrinkage and heave of the soil as a result of seasonal climate change. There is a need for a better understanding of stress state and volume change behavior of an expansive soil in response to seasonal climate change. A field test site at Nanning, China, was designed and constructed cooperatively by researchers from China and Canada. Matric suction, ground movement, weather and other variables have been monitored at this site since April, 1992. The natural environment and instrumentation at the site are presented in this paper. Data obtained to-date show that the changes in matric suction and ground movement are correlated with climatic data.

RESUME : Les bâtiments construits sur des sols expansifs souffrent souvent d'endommagement dû à la rétraction et le gonflement du sol sous les changements climatiques saisonnières. Il est nécessaire de mieux comprendre le comportement du sol expansif, notamment l'état de contraintes et les changements de volume, sous les changements climatiques saisonnières. Un champs de tests in situ à Nanning en Chine a été désigné et construit par une équipe de chercheurs chinois et canadiens en coopération. Succion matricielle, mouvement du sol , climat et autres variables ont été enregistrés sur ce site depuis avril 1992. L'environnement naturel et l'instrumentation du site sont présentés. Les données obtenues montrent que les changements dans la succion matricielle et le mouvement du sol sont corrélés avec les données climatiques.

1. INTRODUCTION

Expansive soils swell upon wetting and shrink upon drying. This causes extensive damage to buildings, embankments, tunnels and other engineered structures, causing immense loss in countries all over the world. Twenty one out of the 27 provinces in China have expansive soils, affecting approximately 300 million people. The economic losses due to expansive soil in China have been estimated around 15 billion US$ per year (Fredlund & Chen, 1988). A Sino-Canadian co-operative program was initiated to do research on expansive soil problems in China. This program was sponsored by the International Development and Research Center (IDRC), Ottawa, Canada. The objective of the program was to find practical solutions to problems caused by expansive soils in China. Field monitoring of matric suction in Nanning is one of the activities of the program.

Matric suction is one of the two independent stress state variables for unsaturated soils (Fredlund and Morgenstern, 1977). Field monitoring for matric suction is important for understanding unsaturated soil behavior in the natural environment. Previous studies have shown that reasonably reliable field matric suction measurement can be obtained (Raadt, 1987; Rahardjo, 1989). However, the technique needs to be tested in different natural environments and needs to be improved. The understanding of matric suction in response to climate change also needs to be improved.

The design of the field test site in Nanning was based on previous studies using the suction sensor. The AGWA-II thermal conductivity matric suction sensor was used in this study. This sensor has been used mainly in North America. This time it was used in a natural environment with subtropical, monsoon climate. This site was a test for the use of this sensor. Matric suction was monitored together with ground movement, meteorological information and other variables at the Nanning site. The field monitoring data will be used for detailed numerical simulations. This field test study is expected to help develop a better understanding of how a unsaturated soil responds to climatic changes from the standpoint of both stress state and strain changes.

2. NATURAL ENVIRONMENT OF THE MONITORED SITE

The monitored site is located in Nanning, a city in southern China, with a longitude of 108°23'E and a latitude of 22°54'N (Figure 1).

Nanning has a subtropical monsoon climate with sunny and warm weather. There is an abundance of rain, a short winter and a long summer. There are distinct dry and wet seasons as well as occasional droughts, typhoons and storms. The long term annual average temperature is 21.7°C. The long term average annual precipitation is 1318 mm with a maximum of 1970 mm and a minimum of 953 mm. Precipitation is not well-distributed over the year since nearly 80% of the rainfall comes in the rainy season from May to September. The long term annual evaporation from an open water surface is 1220 mm.

Nanning city is built on a lake basin which is about 37.5 million years old. The lake deposits were covered by fluvial terrace sediments of the Yongjiang River which flows through this area. The monitored site is 13 kilometers from the center of Nanning. The surface topography is a gently rolling hill slope (Figure 2). The monitored site is a gentle

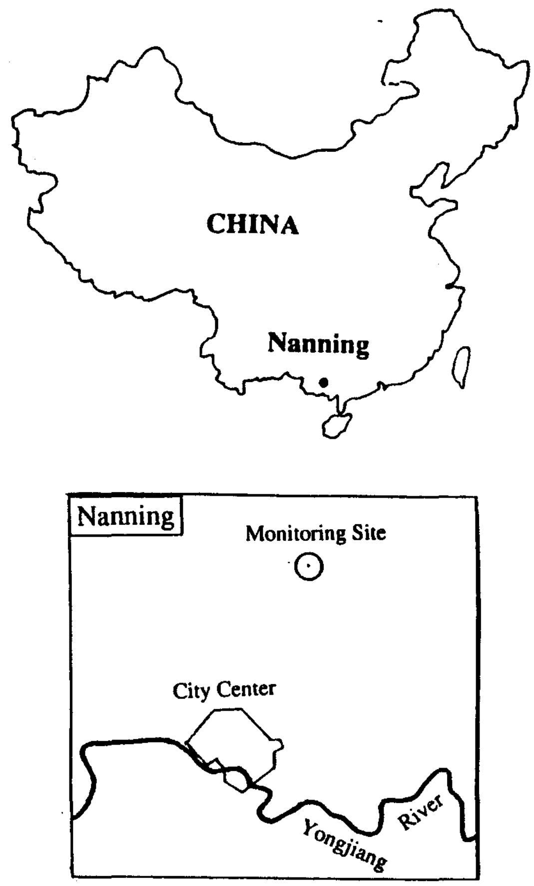

Figure 1 Location of the monitored Site

sloping area. The hill slope soils are mainly lake deposits which are weathered. There is little trace of fluvial deposits found in this area because of erosion. Rapid weathering occurs because of the subtropical monsoon climate. The uppermost soil layer, from ground surface down to 1 m below, is totally different from its parent rock in both mineralogy and soil structure. Lake deposits and their weathered materials form a typical type of expansive soil in China.

The soils at the site have a high total unit weight and a low void ratio. The soils has a moderate swelling potential. The infiltration rate for the uppermost soil layer, from ground surface down to about 1 m below, was about 10^{-6} m/s. This is considerably higher than that of the soils below the 1 meter depth which were about 10^{-8} to 10^{-9} m/s. The difference in infiltration is due to the fact that the uppermost soil layer has many open cracks,

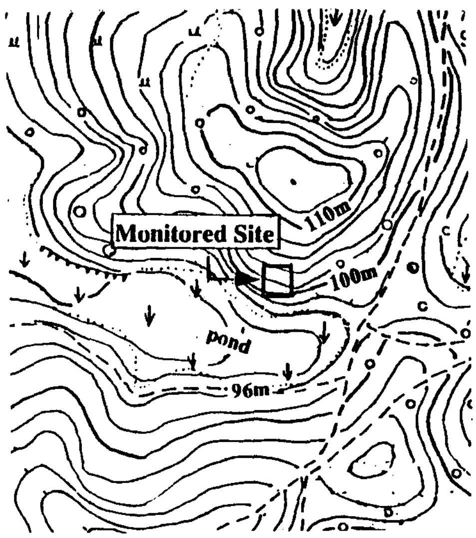

Figure 2 Topographical map of monitored site (1:5000)

particularly during dry seasons.

There is no permanent ground water table in this area according to the information provided by Provincial Hydrographical Station. There are some transient ground water and perched water, which occurs as a result of infiltrating rainfall in rainy seasons. Runoff water from rainfall flows away along a natural gully system. There are some ponds in the gullies due to small man-made dams. These ponds are full of water following the rainy season but some become dry during the dry seasons.

There are many types of grasses and bushes which grow well in this area because of the warm weather and sufficient rainfall. The grasses sprout in spring and grow to as high as 1 to 1.5 m in summer and wither in winter. The grass roots go down to about 100 to 200 mm below the ground surface.

3. FIELD PROGRAM

The instrumentation details at the monitoring site is presented in this section.

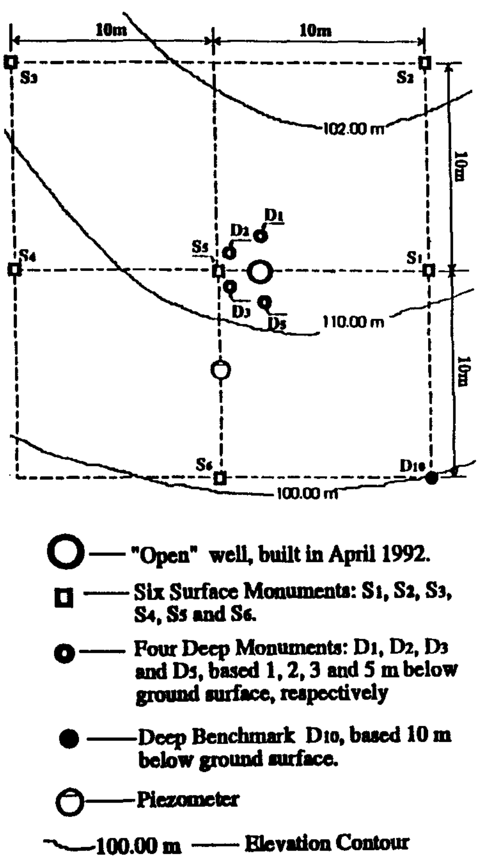

Figure 3 Layout of instrumentation at the site

3.1 Site Topography

The layout of instrumentation at the monitored site is shown in Figure 3. A monitoring well, a deep benchmark, six surface monuments, four deep monuments, and a piezometer were built in a small area of 20 m by 20 m on a gentle slope. All instrumentation was installed in March and April, 1992.

Matric suction sensors, water content sensors and ground temperature sensors were installed in the soils at various locations below ground surface from within the monitoring well. The output from the matric suction sensors was collected using a movable data acquisition system placed at the ground surface. The deep benchmark, and both surface monuments and deep monuments, were installed for the purpose of measuring ground movements. Ground movements were monitored by measuring the movement of the surface and deep monuments with reference to the deep benchmark. A rainfall gauge was installed about 100 m away from the monitoring site for precipitation monitoring. Daily weather information included: precipitation, potential evaporation, temperature, relative humidity, sunshine hours, and wind speed, which were monitored at a weather station about 1 km away from the site.

3.2 Thermal Conductivity Matric Suction Sensors

AGWA-II thermal conductivity matric suction sensors were used in this research. This sensor was produced by Agwatronics Inc. of Merced, U.S.A.. The sensors have shown relatively consistent and reasonable results in previous studies and were recommended as a preferred method for field monitoring of matric suction. Their main weakness has been related to a deterioration of the ceramic and electronics with time. The theory and the calibration apparatus for this sensor have been described previously (Fredlund and Wong, 1989).

3.3 Data Acquisition System

Figure 4 shows a sketch of the data acquisition system illustrating the relationship between the various major components. The data acquisition system, with the AM416 multipexer, is capable of measuring up to 32 sensors in succession at a given time. The measurements are controlled by a Campbell Scientific CR10 measurement and control system, which is fully programmable. The CR10 programming can be easily done on the IBM PC with the support from the PC208 software provided by Campbell Scientific Inc.

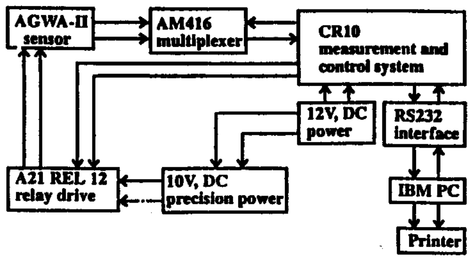

Figure 4 Data acquisition system for AGWA-II thermal conductivity sensors

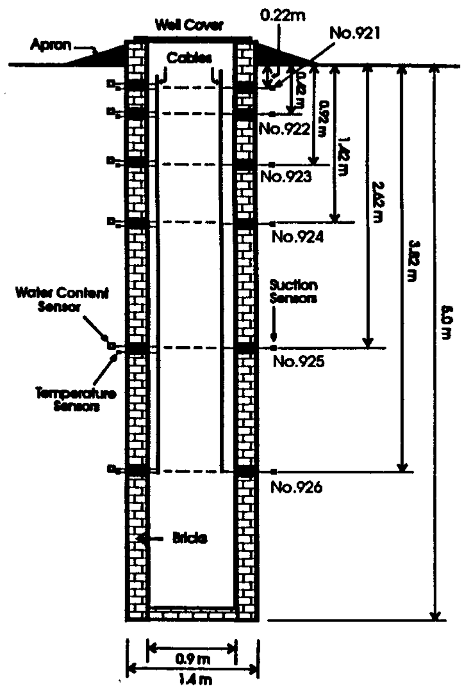

Figure 5 Cross-section of the "open" well

3.4 Installation of the Matric Suction Sensors

An "open" well was built for sensor installation in March, 1992 (Figure 5).

The "open" well is 5 m in depth and 0.9 m in diameter. Sensors were installed from within the well into soils at various locations

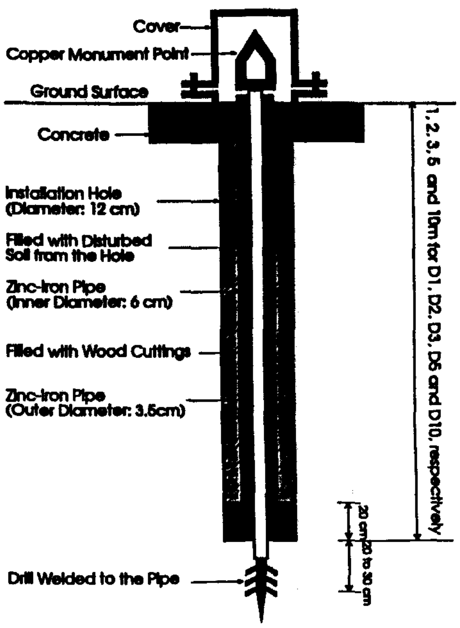

Figure 6 The construction details of benchmark D10 and the deep monuments (D1, D2, D3, and D5)

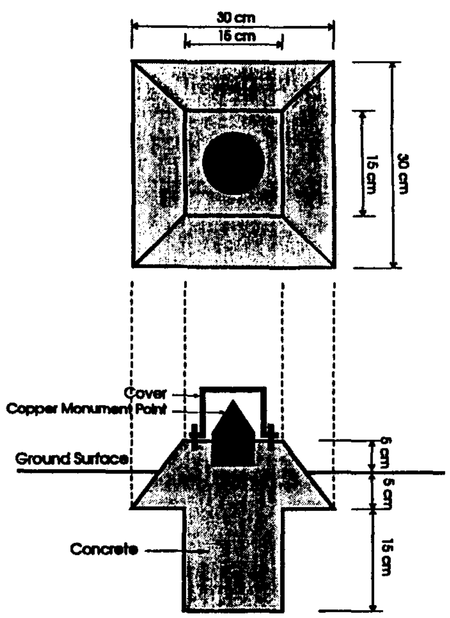

Figure 7 The construction details of surface monuments (S1, S2, S3, S4, S5 and S6)

of 0.22, 0.42, 0.92, 1.42, 2.62 and 3.82 m below ground surface. The following procedure was used for the installation of a matric suction sensor through a small window opening. First, a round hole was drilled into the soil, which was the same diameter as the ceramic sensor block. The hole was drilled 0.25 m perpendicular to the well wall. A wooden model sensor block, which was the same size as the ceramic sensor block was then pushed to the bottom of the hole and retreated. This helped to smooth the way to the bottom of the hole for the ceramic sensor block and to ensure good contact between the soil and the ceramic block. A thin mud coating made of the cutting material from the hole was applied to the sensor block to further ensure good contact. The sensor block was subsequently pushed slowly into the bottom of the hole using two small wooden sticks. The hole was backfilled with the cutting material which had been removed during the drilling operation.

Water content sensors were installed in a manner similar to that for suction sensors. Ground temperature sensors was simply buried 50 mm deep into soil.

3.5 The Construction of the Benchmark and the Monuments

Benchmark and some monuments were constructed at the site for monitoring ground movements. A precise benchmark is very difficult to achieve. As the major concern is the ground movements caused by seasonal climate change, a benchmark was based in soils free from climatic influences. This was considered to be sufficiently accurate. The benchmark was based in soil 10 m below ground surface. This soil is free from any climatic influence because the active zone in this area is about 4 to 5 m. The construction details of the benchmark (D10) are shown in Figure 6.

Four deep monuments were installed in the soils at 1, 2, 3, and 5 m below ground surface in order to measure ground movements at these locations. The deep monuments were built in the same manner as the deep benchmark (Figure 6). Six surface monuments were built at ground surface and their

Figure 8 Photograph showing matric suction monitoring

construction details are shown in Figure 7.

3.6 Site Monitoring

The site has been monitored since April, 1992. It was measured about once a week in the first two months, once every two weeks in the following four months, and once a month for the remainder of the monitoring time. The frequency of once a month proved to be sufficient for observing matric suction changes, which is in response to seasonal climatic changes.

The data acquisition system, without the computer, was housed in a wooden box and was carried to the site each time for matric suction measurements (Figure 8). The ground movements were monitored using a highly precise leveling instrument and a precise surveyor's pole.

4. COMMENTS ON THE NANNING SITE

The design and monitoring of the Nanning field test site has proved to be successful. Data obtained to-date showed that the change in matric suction and ground movement can be correlated with climatic data. The data is not shown in this paper due to limitations on space. The data will be used in numerical simulations using a soil-atmospheric flux model. The results from the analysis will be helpful in better understanding the behavior of an expansive soil in its natural environment.

The AGWA-II thermal conductivity sensors were found to have worked quite well. This type of sensor has proven to be suitable for a natural environment with a subtropical monsoon climate. The main problem encountered in the site monitoring was the accumulation of ground water in the "open" monitored well. The infiltration rate from the surface soil layer down to 1 m below ground surface is quite high, whereas the soils below this layer are quite impervious. As a result, groundwater infiltrated into the well from the uppermost layer during the rainy season. This resulted in some drastic reductions in suction measurements for the sensor located 3.82 m below ground surface. A "backfilled" monitored well was built 4 m away from the "open" well in March, 1993 to correct for the difficulty associated with the accumulation of groundwater. The "backfilled" well was similar to the "open" well except that it was backfilled with original soil, leaving no room for the accumulation of groundwater. This procedure has worked well. "Backfilled" monitoring wells are recommended for field monitoring in a subtropical natural environment such as Nanning.

5. ACKNOWLEDGEMENTS

The work presented in this paper was undertaken under the Sino-Canadian Cooperative Research Program on Expansive Soils sponsored by the International Development and Research Centre, Canada, under the supervision of D. G. Fredlund (Canada) and Z.Y. Chen (China).

S. K. Huang (Guangxi University) coordinated the monitoring program in Nanning, China. The authors also want to acknowledge the contributions of the following engineers for this work: P. Rivard and J. K-M. Gan (University of Saskatchewan), Z. Y. Chen, Y. C. Diao and W. X. Li (Tsinghua University), X. M. Wu and G. N. Liu (China Academy of Railway Sciences) and W. M. Li (China Comprehensive Institute of Geotechnical Investigation).

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