Prediction of Expansive Soils Behaviour

Hussein Elarabi
Affiliation 1 Associate Professor at Building and Road Research Institute
Geotechnical Department, BRRI
University of Khartoum

ABSTRACT:

The goal of the information presented in this paper is to provide the reader with qualitative concepts that help identifying soil expansion problems for different structures erected in or on expansive soils. A diagram is described to explain the water distribution during the seasonal variations of water content which influences the behaviour of expansive soils. The damages of light structures due to expansive soil behaviour are described to assist engineers in using suitable design criteria. Another important goal of this paper involves safe construction on expansive soils. Guidelines are outlined to assist engineers in dealing with expansive soils at early stages before construction and designing maintenance in later stages.

Keywords: damages, expansive soils, swelling, maintenance, soil treatments, cracks.

1 INTRODUCTION

Expansive soils are materials that increase and decrease significantly in volume as moisture content changes. The expansive soils swell if their moisture content increases and they shrink if their moisture content decreases. The phenomenon depends on the mineralogical combination of the clay soils. When water is added to expansive clays, the water molecules are pulled into gaps between the clay plates. As more water is absorbed, the plates are forced further apart, leading to an increase in soil pressure or an expansion of the soil's volume. If the liquid limit of a soil sample exceeds 50% and the plasticity index exceeds 30, the soil shall be considered as having an expansive clay mineralogy.

The clay mineral responsible for most expansive damage is smectite, although bentonite and illite also have some expansive potential. Another category of expansive soil known as swelling bedrock contains a special type of mineral called claystone.

The montmorillonite clay minerals, one of the smectite group, are considered as a highly expansive and the most effective ones for swelling behaviour. This type of soil is found in many places all over the world especially in the arid and semi-arid regions. More than 2.4 million square km (240 million ha) of Vertisols, clayey soils high in smectite, are distributed throughout the world (Buol et al., 1997). Extensive areas are found in Australia (80 million ha), India (73 million ha), Sudan (50 million ha), southern and western states of United States (12.8 million ha), Egypt, Ethiopia, Chad, Ghana, Cuba, Puerto Rico, and Taiwan.

2 SOIL EXPANSION PROBLEMS

Expansive soil problems result from changes in volume upon wetting and drying. The moisture change can be due to natural effects such as normal seasonal variations or the root activity, or man made effects such as garden watering, leaking underground water services, or a deficient storm water drainage system. The swelling of clay soil is a very troublesome subject in various fields of civil engineering. Many problems for different types of structures created by expansive soils are well documented in the litrature (Lackner, K., 1991, Placzek, D., 1983).

Expansive soils, or shrink-swell soils, cause billions of dollars of damage to structures in the United States each year, second only to insect damage (Krohn and Slosson, 1980). Once thought to be a problem only in arid and semi-arid vertic soils, shrink-swell damage has become a significant concern in clayey Alfisols and Ultisols in the humid southeastern United States. Concrete basement walls will move and floors will crack because of this phenomenon. Heaving by swelling soils can also cause slope failures, roads to buckle, driveways to shift, and structural walls can collapse.

No one method of soil analysis estimates shrink-swell potential accurately for all soils. Soil scientists recognize that shrink-swell behavior can be predicted by examining a combination of physical, chemical, and mineralogical properties. Determining these properties and establishing a shrink-swell model that can be extrapolated across the same or similar parent materials is needed.

Structural damages due to expansive soils are quite extensive in many developing countries, especially when located in populated centres and development projects. Many significant damages to buildings, irrigation systems, water lines, sewers, roads and other structures are caused by expansive soils (Osman, Elsharif and Elarabi, ; 1989, Osman and Charlie; 1983). Observed damages include foundations, floors, walls, sewage disposal system and roofs.

In the following sections, a general discussion and a presentation of the problems of expansive soils on structural buildings, channels, and tunnels are outlined, then followed by the suitable methods of treating and maintaining this type of soils.

3 MOISTURE DISTRIBUTION IN EXPANSIVE CLAY LAYERS

The critical climate type for expansive clays is one in which there is a distinct wet period followed by a hot dry period. During the wet period the soil imbibes water and swelling occurs, while during the subsequent dry period, the soil loses moisture via evaporation, and volume reduction occurs. The severity of the weather varies, however, from year to year. Moisture content in clay sub-grades under pavements or foundations is of utmost importance as they determine the shear strength of the clay and its bearing capacity. If the clay is of the swelling type, these moisture changes also act to deform the pavement or foundations and thus may affect its usefulness. The moisture content in a soil mass varies not only due to artificial wetting, but also evaporation, change in thermal conditions, transpiration by vegetation, precipitation etc. In addition to these factors the annual fluctuations in moisture content in the upper layer of the soil depend upon evaporation and wetting due to atmospheric precipitation, which is related to the precipitation balance, Fig (1).

The soil surface is subjected to diurnal, annual and perennial temperature fluctuations. The temperature varies not only at the surface, but also vertically along the depth of the soil mass where it fluctuates. In the absence of a thermal balance, a temperature gradient sets up giving rise to migration of moisture. Vegetation is another powerful source of moisture depletion from the soil. It has a significant influence on the changing nature of moisture content in the soil mass.

It is obvious that processes leading to changes in moisture content and temperature continuously occur in the soil at foundations of structures. These variations are highly non-uniform both in time and space. Thus, in a layer at the surface of the soil the moisture content is observed to be smaller compared to that in layers which are located at depth. The moisture content of the upper layer does not remain constant but varies with time. This leads to violation of the equilibrium conditions which results in the emergence of various forces which cause migration of moisture. In other words, the moisture cycle continuously changes until an equilibrium state conforming to the physico-chemical properties of the soil and external conditions is established. The only way to reach this equilibrium state is the constancy of the external factors, which is almost impossible. As a consequence of that because of the unsteady nature of the moisture cycle in the soil mass, its properties vary with time. In certain cases this affects the task of building construction since an increase in the moisture content of expansive soils leads to an increase in their volume which may cause damages to structures.

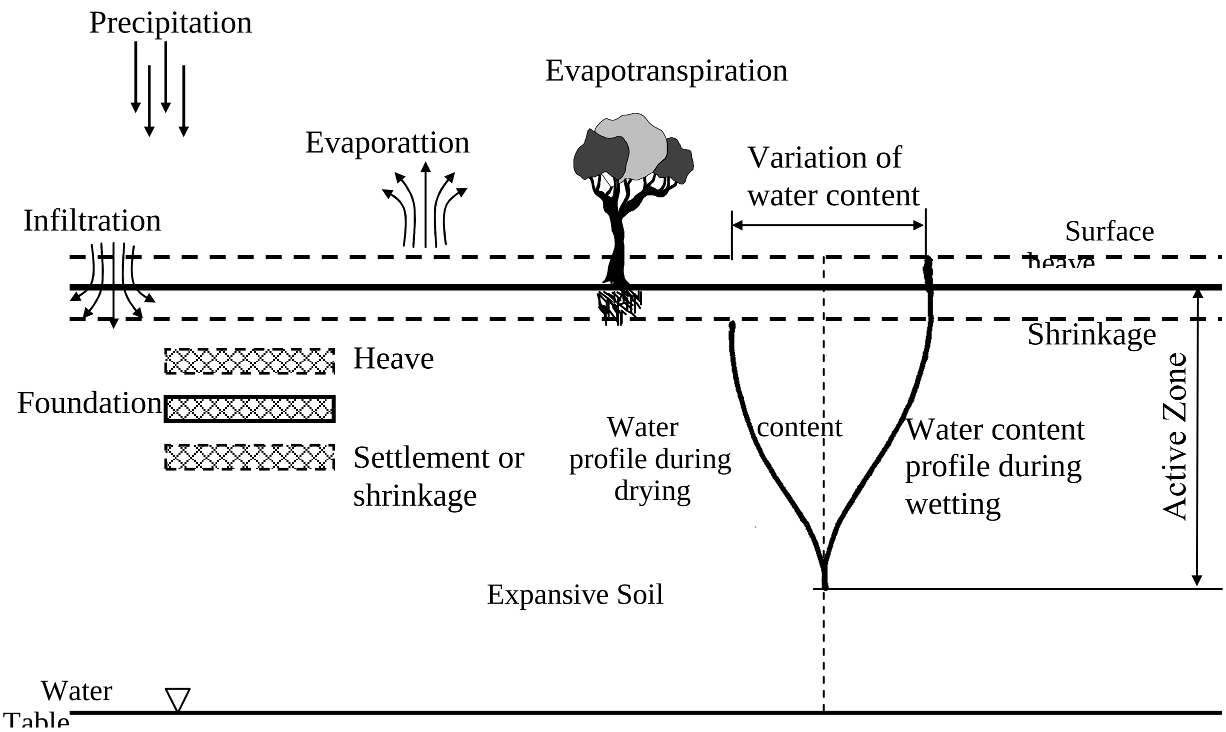


Fig (1): Effect of annual fluctuation in moisture content on expansive soil

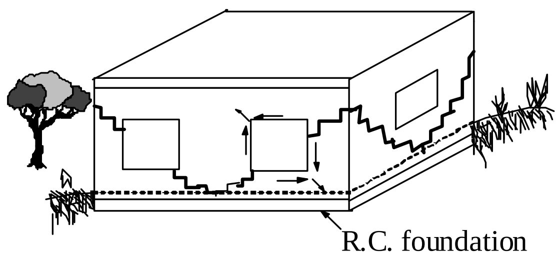
4 DAMAGES TO BUILDINGS

Expansive soils, which swell on absorption of water and shrink on removal, cause severe damage to structures if no measures are adopted beforehand. Foundations resting on expansive soils may move differentially in the vertical direction and show sign of unacceptable cracks as the position of ground water table changes with season. Observations of deformations of structural units show that both heave and settlement may occur in structures founded in swelling clays. The predominant deformation observed in buildings is that of upward heave. From data available in literature, heaving of the building generally starts some time after completion of the structure, of the order of one year. It should be noted that cracks are more likely to occur in lightly loaded structures than in heavily loaded structures; the former being easier to be moved vertically by the pressure exerted by underlying expansive soil.

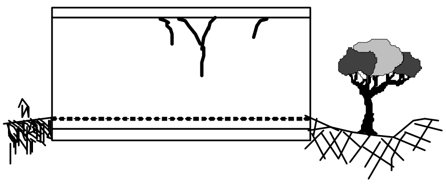
This fact appears clearly in severe cracking of single story domestic houses of rigid construction like load bearing brick walls which are constructed in many places of arid and semi-arid areas. The more heavily loaded buildings and more flexible constructions, e.g., multi-story frame buildings are less affected because of their large applied load, greater depths of foundations, and their flexibility.

Damage caused by expansive soil appears firstly as cracks on external and internal walls, joints of brick and concrete elements or stones, and interior plaster walls. The types of cracks appearing in structures are: diagonal shear cracks, horizontal and vertical shear cracks, horizontal and vertical cracks caused by bending moments and horizontal and vertical tension cracks, Fig.(2). It is expected that for buildings on expansive soils, the size of cracks increase with time until it leads to total damage of collapse.

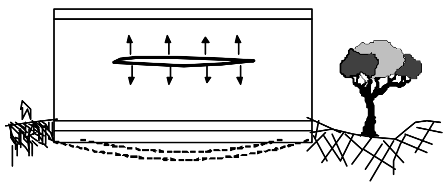
The engineering problems of expansive soil are the determination of parameters and criteria which can be used in the design of structures built on or with such soils.



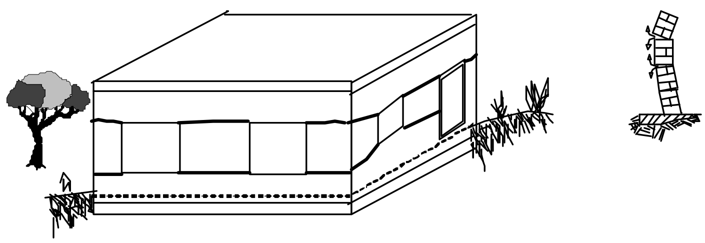
a) Diagonal shear cracks.



b) Vertical cracks caused moments.



c) Horizontal cracks caused ground deformation.



d) Horizontal cracks caused by bending moments.

Fig (2): Common type of cracks in buildings with shallow foundations.

5 DAMAGES TO TUNNELS

The phenomenon of the heave of a tunnel floor, or of the damage of an invert arch, has been well known since the beginning of railroad-tunnelling in the middle of the 19th century. In several cases swelling clay soils have caused tunnel collapse which has resulted in considerable additional costs and delays for the project (Anagnostou, 1992, 1995, Kaelin, etal. 1992, Wittke, 1976, 1978). Selmer-Olsen(1989) state that in Norway about 75% of the cost of extra reinforcement for tunnels after they have been put into operation, is associated with swelling clays.

An examples of tunnel collapses in swelling zones is illustrated in Fig.(3) In this case clay minerals had been detected during tunnel excavation, but insufficient rock support had been installed because of underestimating the large forces produced by the swelling of the soil.

The problems that have arisen have often been caused by the lack of experience on the part of the people involved concerning the swelling mechanism, combined with an underestimating of the high pressure, existing from swelling clays. Therefore, the planning engineer always attempts to support his observations with test results. In this connection, the results must be as conclusive as possible.

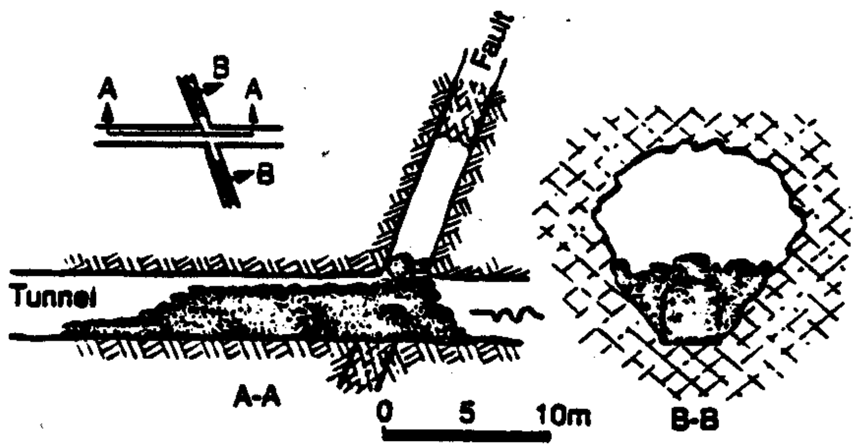


Fig. (3): Sketch of the collapse blocking the 12m² headrace tunnel at Hemsil Power Plant(1960). It was caused by a 2.5m-thick, brecciated zone with thin veins containing swelling material.

6 DAMAGES TO CHANNELS

Performance records show that continuous concrete linings used for channels or canals can be destroyed by foundations on expanding clay unless precautions are taken.

The above discussed types of damages are only example from many sort of damages for different kinds of structures including pipelines, hydraulic structures, irrigated farms, factories, mills, surroundings walls, caverns, shafts, ... etc. Jones and Holtz;(1973) estimated average annual losses due to shrink-swell phenomena in U.S.A. alone as $9 billion in 1981.

7 TREATMENT OF EXPANSIVE SOILS

It has long been recognized that expansive soils pose a severe threat to civil engineering infrastructure such as roads, housing, and transportation facilities in the world. Expansive soil formations in the United States alone are responsible for billions of dollars in damage costs each year, an amount exceeding that of all other natural hazards combined, including earthquakes, floods, fires, and tornadoes (Jones and Holtz, 1973). To date, many measures have been practised to overcome the severe problems posed by swelling soils. One of the very common methods of mitigating expansive soil problems is to lay foundations beyond the depth of moisture fluctuation. But very often it becomes difficult to determine the depth of moisture fluctuation with precision and if this depth is found to be very deep, placing of foundation may become practically impossible. In these situations insertion of belled piers is a preferable practice.

Expansive soils can be mitigated by either removing the soil and backfilling with non-expansive soil, instituting a chemical stabilization of the soil, or by constructing a foundation treatment that resists uplift of the expansive soil. A site-specific soils investigation would be conducted during facility planning and construction to confirm that mitigation measures are not required for expansive soils at the site.

Partial replacement of expansive soil with non-expansive granular soils is also an economical measure. The depth and extent of removal and replacement are often decided on the basis of experience and judgment. To date, no rational methodology has been developed to determine the optimum depth of removal of expansive soil layer and replacement of this soil with non- expansive granular soil.

The goals for soil treatment are to reduce the amount of water that enters the ground near the foundation and to reduce the swell potential of the soil. Contractors may install vertical or horizontal moisture barriers to protect the foundation. In this case, the homeowner should know where the barriers are and should not irrigate inside them. Normal gardening can occur outside the barriers.

8 LIVING WITH EXPANSIVE SOILS

If a light structure is located on expansive soil it is likely that will experience hairline cracks in the walls and slabs. This is due to the native soil in the area, and not much can be done to prevent minor soil movement. However, the light structure on this type of soil can be protect from major damage, and minor cracking can be minimized by taking a few precautions to ensure that the soil under the foundation does not become either saturated or dried out completely.

Expansive soils do not swell and shrink if the moisture content remains constant. One of the recommended solutions is to maintain consistent moisture; this is done by applying water selectively near foundation walls. The long-term maintenance of slope, drainage and the landscape is crucial to avoid problems. The importance of maintaining drainage systems cannot be overemphasized. This includes gutters, downspouts, downspout extensions and splash blocks. Tree leaves can clog gutters and downspouts. This, in turn, can cause rainwater to overflow near foundations, a serious concern on expansive soils. Settling of minimally graded slopes near buildings can create reverse drainage next to foundations. Result soil to restore drainage away from buildings. Reinstall landscaping if necessary.

Attention should be paid to watering practices near buildings. In the summer lawn should be watered lightly two or three times a week. Heavy watering is not recommended as this could saturate the foundations. Both overwatering and underwatering can affect the integrity of a building and associated structures. However, it should be emphasized that a uniform moisture condition around foundations should be maintained throughout the year. This will prevent periodic drying (shrinkage) and wetting (expansion) which will cause damage to structures.

Periodically look should be done for leaks in all sprinkler system lines, backflow devices and other connections from the building to the landscape. An immediately maintenance should take place malfunctioning or broken sprinkler heads that throw water back towards a building.

Planting trees (even small ones) within about three meter from the house is not recommended. Trees tend to extract moisture from soil causing shrinkage. Greater separation is appropriate for larger trees. Plants that require a large amount of moisture are also not recommended near buildings.

9 CONCLUSION

Expansive soils are subject to swelling and shrinkage, varying in proportion to the amount of moisture present in the soil. As water is initially introduced into the soil (by rainfall or watering), an expansion takes place. If dried out, the soil will contract, often leaving small fissures or cracks. Excessive drying and wetting of the soil will progressively deteriorate structures over the years. This excessive wetting and drying causes damage due to differential settlement within buildings and other improvements. The engineer should first try to find out the depth of the active zone for exercising the option of removing soil down to the depth of the active zone. Alternatively, other soil stabilization procedures and/or alternative methods of constructing foundations may be necessary. There are several practices depending on the area, mineralogy of clay and climatic conditions that can one follows to avoid the potentially damaging effects of swelling soils.

REFERENCES

Anagnostou, G., 1992. Untersuchungen zur Statik des Tunnelbaus in quellfähigem Gebirge, Institute für Geotechnik, Eidgenössische Technische Hochschule Zürich, Band 201 8/92.

Anagnostou, G., 1995. Seepage Flow around Tunnels in Swelling Rock, Int. Joun. for Numerical and Analytical Methods in Geomechanics, Vol. 19, pp.705-724.

Buol, S.W., F.D. Hole, R.J. McCracken, and R.J. Southard. 1997. Soil Genesis and Classification, 4th Edition. Iowa State Univ. Press, Ames, IA.

Handy, Richard L., 1995. "The Day the House Fell," New York: ASCE Press.

Jones, D. E., and Holtz, W. G., 1973. Expansive soils-the hidden disaster. Civil Eng., ASCE 43(8), pp 49-51.

Krohn, J.P. and J.E. Slosson. 1980. Assessment of expansive soils in the United States. p. 596-608. In D. Snethern (ed.) Proc. 4 Intl. Conf. on Expansive Soils, Denver, CO. Am. Soc. Civil Eng., New York.

Lackner, K., 1991. Schwellen und Schrumpfen im organogenen Ton als Ursache von Gebäudeschäden, Geotchnik 14, pp. 118-124,.

Osman Mohammed A.; Elsharif A. M.; Elarabi, E. A., 1989. Effect of Water Seepage on Buildings constructed on Expansive Soils, Proceeding of CIB, Paris.

Osman, M. A.; Charlie, W. A., 1983. Expansive Soils in Sudan, BRRI Current Papers, No. CP.3/83, Building and Road Research Institute, University of Khartoum, Khartoum, Sudan,.

Placzek, D., 1983. Über das Schwinden bindiger Böden als Ursache für Bauwerksschäden, Die Bautechnik, Heft 5.

Selmer-Olsen, R., 1989. Tunnel collapses in swelling clay zones, Tunnels and Tunnelling Magazine, November.

Wittke, W., 1978. Grundlagen für die Bemessung und Ausführung von Tunnels in quellendem Gebirge und ihre Anwendung beim Bau der Wendeschleife der S-Bahn Stuttgart, Veröffentlichen des Instites für Grundbau, Bodenmechanik, Felsmechanik und Verkehrswasserbau der RWTH Aachen, Heft 6, Aachen.