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Soil Conditions and Foundation Problems in the Desert Region of the Middle East

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SYNOPSIS Soil condition in desert regions of the Middle East is discussed according to some geological features. Conditions in four different zones are presented. Common geotechnical and foundation problems in each of these zones are presented. Some remedies are suggested. Some properties of salt bearing soil (Sabkha) are studied. The influence of Nacl concentration on some engineering properties of the subsoil in desert regions is singled out.

General relations between the unique harsh desert weather and engineering practice are analysed.

INTRODUCTION

The development of subsoil is associated with the localized physical environment and climatic condition.

High temperature climate in desert regions increases evaporation and reduces moisture in soil resulting in salt precipitation to an invariably high degree.

Soil conditions in a desert climate such as Saudi Arabia would be a good representative example for the evaluation of the geotechnical properties of soil and foundation problems in desert regions. (Higginbottom and Fookes 1982; Oweis and Bowmann 1981).

Soil in desert regions is a product of the prevailing seasonal temperature changes, wind and rainfall.

Salt concentrations in the subsoil of high temperature climates of the Middle East are invariably high. Ground water in some places is found to have a salt content as high as that found in Sea water.

Various salts occur in either the dissolved form in soil moisture or as salt crusts on the surface. Chemical analyses have shown that salt precipitation in Middle East desert regions is dominated by sulphates, chlorides and carbonates of calcium, sodium and magnesium (Al Sayari and Zotl 1978, Akili and Torrance 1981, Stipho 1981, 1983).

The harsh environment in desert regions, the unique soil formation process, and the high salt contents have made soil in such region extremely variable.

The geotechnical properties need therefore to be evaluated individually before attempting any construction program. Recommendations given in codes of practice and experiences in other climatic conditions are not acceptable for direct adaption in the analyses and design of structures in such a region. These commendations would be very helpful when used in connection with a thorough understanding of soil conditions, variation and limitations experienced in desert regions. Due to these considerations and the growing international interest in participating in development projects in desert regions of the Middle East; it is important for practicing engineers to understand soil conditions and the nature of the geotechnical problems before-hand. They should be able to anticipate unforeseen features not only for design and economy but also for construction techniques.

Fookes 1978, Tomlinson 1978, Oweis and Bowmann 1981, have studied the geological nature and outlined some of the common features of soil in high temperature climates, and in particular the Middle East region. Herein the attempt is to point out the general soil conditions with associated foundation problems which arise in each geological unit.

The influence of salt precipitation on some of the apparent laboratory observed parametric behaviour is discussed.

GEOLOGICAL CONSIDERATION OF MIDDLE EAST

The Arabian peninsula is bisected by the Tropic of Cancer. It is well divided into various topographic units depending on geological features. These are the mountainous units, dominated by rock formations; the associated foothill alluvial fans, the dunes and the coastal plains. Figure 1 shows the generalized geological features of the Arabian Peninsula.

The geotechnical problems associated with desert conditions are of different nature in each of the units and in general can be summarized by one or more of the following:-

i) The presence of cavities in the limestone formations.

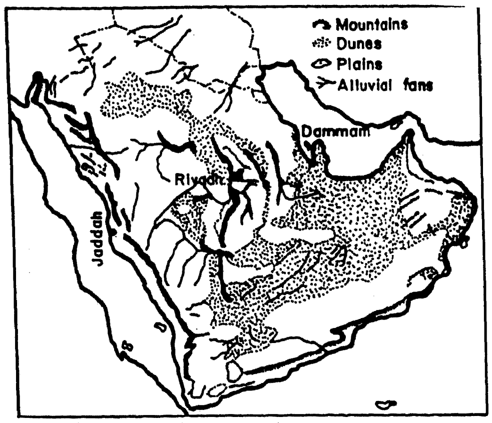

Figure 1. Main Geological units of the Arabian Peninsula

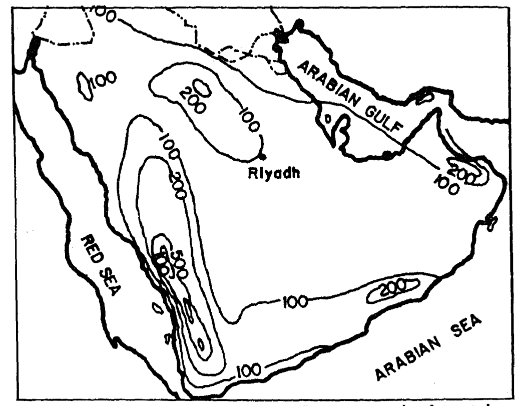

Figure 2. Isohyetes of yearly precipitation in mm (Al Sayari & Zotl)

ii) The presence of highly weathered layers and variability of foundation material.

iii) The presence of hydrated gypsum in poorly drained areas.

iv) The presence of inland and coastal salt bearing soil (Sabkha soil).

v) The presence of a weak cementation bond due to crystallized salt in the upper part of the profile.

iv) Presence of some minerals with expansive potential.

CLIMATE CONDITION

The climate in the desert region of the Middle East is characterized by constant hot prevailing winds with low precipitation. Summer air temperatures in coastal and central parts of the peninsula frequently reach 45-50^{o} C. A daily variation of 15^{o} C in temperature is not uncommon. Temperatures in winter average 20^{o} C and could well drop to below 0^{o} C in many of its regions. Such climatic conditions enhance evaporation, bringing the evaporation precipitation ratio to 1:30 in many places (Dakhil and Al Gahtani 1982).

Rainfall in desert regions is very low but it occurs with high intensity in very short periods creating flash floods with significant damage to property. (Rainfall distribution in the Arabian Peninsula is shown in Figure 2). Such floods act to wash and transport top soil from a considerable depth of the profile and deposit it in other places causing high salt concentration at the end of the horizontal flow and significant erosion of soil.

SOIL CONDITION IN MOUNTAINOUS UNIT

The terrains in Saudi Arabia are dominated by rock beds. Sound rocks as foundation material pose no stability problem. They have a bearing strength much in excess of many construction materials. However, the stability of decomposed rocks need some consideration. But decomposed rocks are not easily definable. Rocks can be decomposed by various causes, including physical and/or chemical actions. The physical action in Saudi Arabia is due to the vast temperature variation, tectonic forces and root growth. Chemical causes include the dissolution of the rocks by rain water, oxidation of hydration. These physical and chemical effects cause fracturing or caverns in the rock.

Rocks are well known for their hetrogenity in behaviour; but the extent of decomposition and weathering poses major problems. These types of foundation materials of various consistency are found within a few meters in both horizontal and vertical direction. The problem of differential settlement of structures on such soil should not be overlooked. Most rocks in the peninsula are of the carbonate (dolomite, limestone) or gypsum types. The carbonate rocks are soluble in fresh and acidic water. Thus cavities in these rocks are abundant and take various forms, shapes and dimensions. This normally depends on the composition and type of rock beds.

Theoretically cavities found in the Arabian peninsula could be due to the following different reasons.

i) Cavities resulting from solution of anyhydrite or gypsum layers.

ii) Cavities resulting from washing of salt.

iii) Cavities resulting from the arranging of collapsed original structure or fabric.

iv) Cavities resulting from dissolution of carbonates, limestone by water.

These cavities may be or may not be filled with sand, silt, calcite crystals or sediments of gypsum. A schematic description of common types of cavities found in Saudi Arabia is shown in Figure 3.

The presence of cavities has great impact on foundation design. Mostly good site preparation and geotechnical treatments are required. Touma and Bellerjeau 1981 discussed generally useful methods to treat cavities similar to those encountered in Saudi Arabia for construction purposes.

SOIL CONDITION IN ALLUVIAL FANS

This zone is characterized by wadi deposits. Wadi deposits consist of sand and gravel cemented with carbonates. Some fragmented limestones are frequently encountered in this unit.

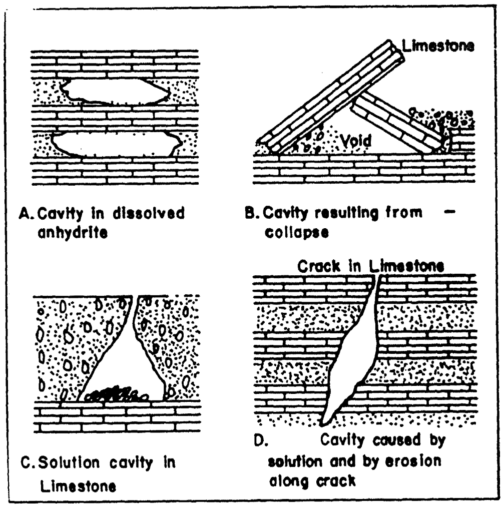

Figure 3. Schemetic description of common cavities in Arabian Peninsula.

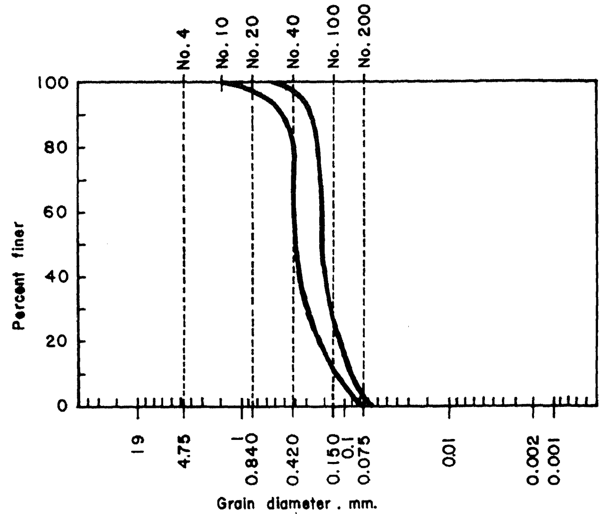

Figure 4. Gradiation curve for Dune sand

Wadi deposits are normally found underlain by beds of rock to various depths. The depth of wadi alluvium upto 9 M is not uncommon. Deeper alluvium beds are found in places near Riyadh and Taif districts (Oweis and Bowmann 1981). These beds are found in many locations in dense to very dense states depending on geological features of the site. This type of soil presents many problems during construction due to its high permeability and particularly arises where sound rock bed underlies the soil. Rain and other water accumulates and forms an underground water basin, calling for complicated dewatering techniques and design alterations during construction as in the case of the P.T.T building in Riyadh (Lord and Marcetteau 1981). Soil in this zone is found with cementing potential due to soluble salts. Collapse of soil structure often takes place under prolonged exposure to moisture.

The most efficient means of evaluating the soil bearing and settlement relations in this unit is by conducting plate load tests under both dry and wet conditions.

SOIL CONDITION IN DUNES UNIT

In this unit vast accumulations of sand move inexorably in regular formation over the surface of the earth. In the Middle East sand dunes cover over one third of the land. These dunes move, grow and retain their shapes, even breed in regular succession for hundreds of miles without change of direction. The formation of these dunes seems unalterable by local geographical features. The process of sand dune formation is governed by wind action, particle size and is controlled by the theories of aerodynamics. Dune types and dune movements are thoroughly discussed by Bagnold 1960. The dunes are dominated by fine to medium rounded loose sand. Typical grain size distribution for dune sands is shown in Figure 4. The dune zone is difficult to develop economically. It poses many geotechnical problems and requires special considerations for design.

Highways, railroads where planned to pass by or cut through such a zone would require knowledge and complete understanding of wind direction, route alignment, protection and dune stabilization techniques. Maintenance problems for such structures are aggravated due to the mobility of the sand. Sand on the roads subject the wearing surface of the road to continuous abrasion. Kazi and Al Mansoor 1980, Iqbal Khan 1982 discussed the main high way problems associated with sand movements in dune zones.

SOIL CONDITION IN THE PLAINS ZONE

Most of these plains are low in elevation in many areas. In the inland some elevated plains are found and covered with fine sand and clay deposited from sediments transported by floods from nearby mountainous and terrainian zones. This fine material cover could range to several meters and overlie wadi alluvium or residual clays. Most of these plains particularly at coastal regions are dominated by salt bearing soils, with their sensitivity to moisture and low bearing strength. In this region soil with swelling potentials were noticed in various localities. Swelling soil is encountered more in the Western coastal plains of Saudi Arabia, such as in the Madina district. Swelling soil imposes some potential problems caused by changes in soil moisture. Other problems encountered in this unit are associated with the presence of soluble salts, which give rise to a potential for temporary cementation. This type of soil has a structure that is prone to collapse upon prolonged exposure of water. This leads to serious foundation failure as is the case in Al Ghat housing project in Central Saudi Arabia (Al Dhawian et al 1980).

A survey of the plains unit in Saudi Arabia showed that most of these plains are covered with very corrosive salt bearing soil (Sabkha). Part of the Western plains near Yanbu district is shown in Figure 5.

Sabkha soil is a source of trouble to engineer-

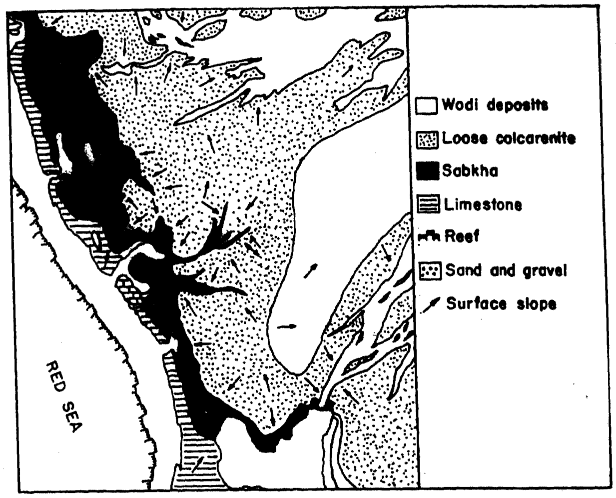

Figure 5. Engineering Geologic map of Yanbu area

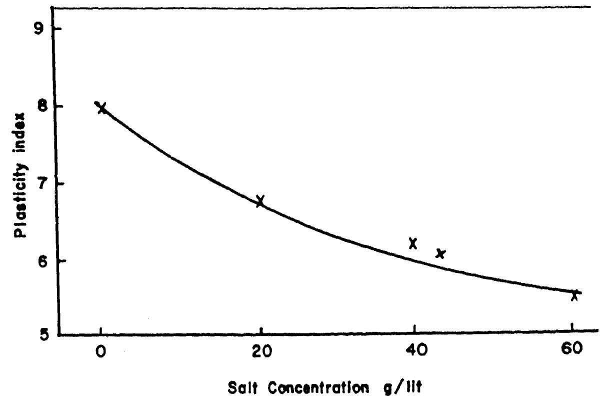

Figure 6. Influence of Nacl on the plasticity Index

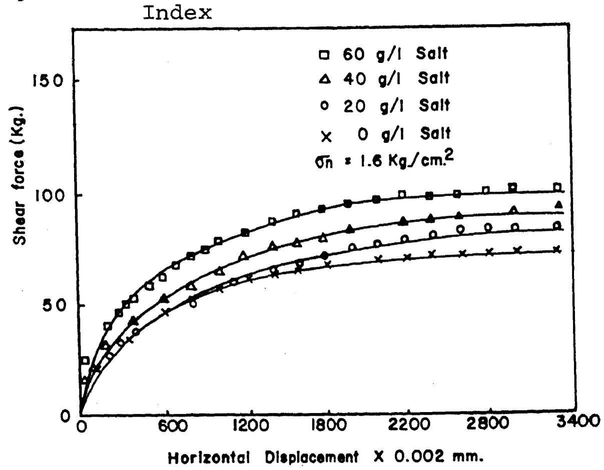

Figure 7. Influence of Nacl on the shear Resistance

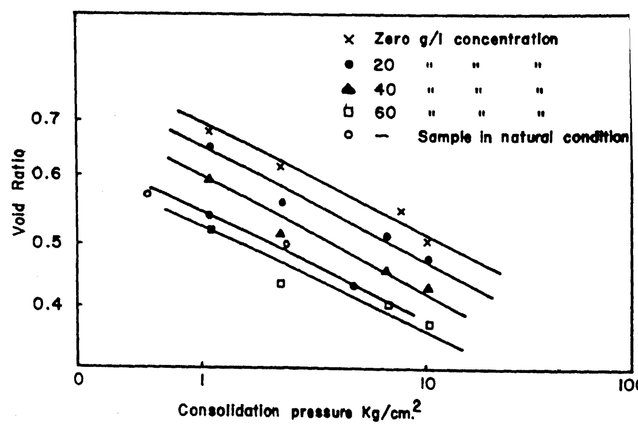

Figure 8. Influence of Nacl on the Consolidation Behaviour

ing practice. It contains a high precipitation of sulphates, chlorides or carbonates of sodium, magnesium or calcium. Salt in soil attacks substructure materials (concrete and its reinforcements). It corrodes metal elements and pipes and also affects the physical properties of soil and its behaviour under loading. Measures to protect pipes and foundation materials are discussed by Stipho 1983, b). The mechanism and the process of salt development in soil of the Middle East is well discussed by Akili and Torrance 1981, Stipho 1981. The texture of the salt bearing soil in desert regions is quite varied. Its natural moisture content varies from 8% to as high as 68%. These changes in moisture would reflect changes in density, consistency and strength. Thus the stability of the soil profile in Sabkha region is highly affected by these moisture changes. Influence of salt content in Sabkha soil on its engineering properties is complex. By singling out the effects of a particular salt content (Nacl for example) would help to understand this. A sample of Sabkha soil from the inland plains of central Saudi Arabia was used to study the effect of Nacl on some of its engineering properties. Sample identification and method of testing is discussed by Stipho 1983. It was found that the soil plasticity index is reduced with increasing Nacl content (Figure 6). On the other hand although the shearing strength f Sabkha soil is in general low, it was found at this strength increases with increasing ·l content (Figure 7). Consolidation proper- have shown some changes due to increased content. A parallel trend of void ratio - onsolidation pressure curves for various content is noticed (Figure 8). This trend ilar to that found for anisotropically idated kaolin clay samples under various anisotropy (Stipho 1978).

SUMMARY AND CONCLUSION

The topographical units for a typical Middle East desert region are listed. Soil and found ation conditions in each of these units is discussed and remedies for foundation problems are suggested. It could be concluded that sub surface conditions in a desert climate are qui variable. The soil profile is unstable, continuously changing due to severe climate condition, salt rising etc. cavities, weathered rocks, expansive and collapsable potential, high salt precipitation are the main features affecting geotechnical practice in the region.

Properly conducted site investigation with elaborate identification on the particular problems prior to design and foundation selection, would reduce risks related to subsurface conditions in any sized light or heavy structures. Continuous observation and flexibility of the design to allow changes during construction is essential, as small localized trouble zones could well be missed by test boring on large job sites. It is always recommended that visual examination and a site visit by the designer is a very good practice in this area.

Laboratory and field observed parameters need to be viewed from type and quantity of salts available in the soil. The possibility of applying correction factors for such parameters need not be overlooked. On the other hand special protection measures for foundation materials from salt attacks; specific construction methods and techniques would be necessary for such unique subsurface conditions. Although rainfall is scarce in the region the designer should not belittle its affects. Alternative wetting and drying increase salt content, activate swell potential and cause collapse. To overcome these problems and avoid flash flood problems in washing out foundations, foundation level should be selected with this problem in mind.

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