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Geotechnical Aspects of Loess in Kingdom of Saudi Arabia

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ABSTRACT. Loess is a geologically recent deposit, which consists of unconsolidated silt of eolian origin; it is buff in color and characterized by lack of stratification, porous and has low bulk density. This paper aimed to review the distribution and geotechnical properties of loess in Saudi Arabia as the publications about loess in Saudi Arabia are very limited. The available literatures reported that the loess soils are observed in many parts of the Kingdom where various construction projects were planned. Loess materials are generally uniform in texture, consisting of 50% to 90% silt-size particles exhibiting plasticity. Porosity is relatively high; ranging from 50 to 60%. These loess deposits subside and form earth fissures by the process of hydro-compaction upon wetting in some remote areas. The process of wetting can be either natural through storms or man-made through agricultural or civil activities.

KEY WORDS: Loess soils, Kingdom of Saudi Arabia, Al-Ghatt, Mubaraz, Al-Yutamah, Hutat Bani Tamim, Geotechnical Problems, Hydrocompaction, Earth Fissures, and Collapse.

Introduction

Loess (pronounced "luss"), is German for loose or crumbly. Loess is unconsolidated silt of eolian origin, buff in color and characterized by lack of stratification. It is porous, has low bulk density and is generally calcareous. The carbonate content depends either on the composition of the parent material or on post-depositional solutions carrying weathering and alteration products. Other original references discuss the origin of carbonates in loess as Shehata and Amin (1997). The main loess mineral constituents are quartz, clay minerals, feldspars, micas, hornblende and pyroxene (Smalley and Vita-Finzi, 1968).

Loess is a geologically post-glacial material, which is brought by wind to the places where they now lie in the periglacial areas (Fig. 1). Loess was formed during Ice Age, when glaciers covered a great portion of the earth. When the climate warmed up, the warm temperatures melted the glaciers creating tremendous flows of water down into a valley or river, and exposing vast plains of mud. When these plains dried, strong winds blew the exposed sediments and swept the finer materials from the flood plains into huge clouds of dust, which were deposited into the bluffs, that is, bold steep banks. As silt accumulated, higher bluffs were formed. Often several loess deposits are stacked on top of each other, because each individual glacier produced new loess deposits.

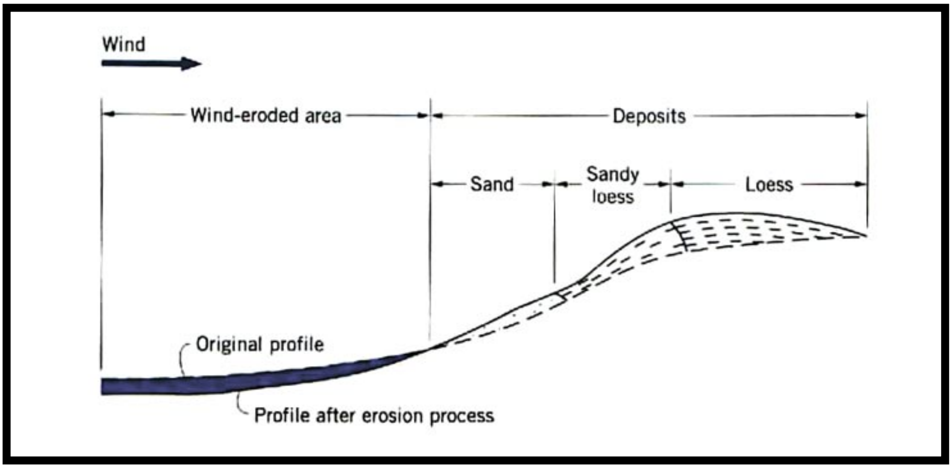


FIG. 1. Process of wind erosion, transportation, and deposits (after Cernica, 1995).

The modern loess deposits originate in desert environment or are associated with glacial rivers (Hunt, 1984). Loess deposits are homogeneous, unstratified silt up to 100 m thick, and the deposits may form vertical cliffs up to 600 m high with no cross beds or other visible internal structures (Fig. 2). Grain sizes are typically between 0.05 and 0.07 mm in diameter. The loess materials are less visible than sand dunes but are found over large areas of the earth. It is important for humans as it presents very fertile soils.

Geographical Distribution of Loess Soils in the Kingdom of Saudi Arabia

Literature findings about loess in Saudi Arabia are very limited, the available ones reported that the loess soils were observed in many parts of Kingdom where various construction projects were planned. The loess deposits were re-

Fig. 2. Photograph showing vertical cliffs of loess deposits at old terraces in Al Sayl Al Kabir area, western region.

ported mainly in selected areas, in the central part such as east Riyadh and Al-Ghatt in Al-Qassim (Dhowian, 1981; Ruwaih, 1981; Al-Solai, 1983; Al-Refeai and Al-Ghamdi,1994), in the eastern part such as Mubaraz town (Sayed, 1981), in the western part such as south Al-Madinah Al-Munawwarah (Al-Harthi and Bankher, 1999) (see Figs. 3,4 and 5), and in the southern part such as south Al-Lith (Shehata and Amin, 1997). Fookes (1978) stated that the loess materials in Saudi Arabia are found in the depression areas in the volcanic terrains, old wadi alluvium, and downwind in the Tihama.

Characteristics of Loess

Loess is typically buff to yellow-colored, very fine grained, permeable particularly in the vertical direction, devoid of stratification, and slightly cemented by calcareous or clay cements.

Origin

The windborne silt are dropped down from the air and retained by the protective grip of the grasses of the steppe. The successive generations of roots, represented by narrow tubes partly occupied by calcium carbonate, make it sufficiently coherent to stand in vertical walls (Holmes, 1964).

Structure

The arrangement of the silt particles with numerous voids and rootlike channels can easily be seen in photomicrograph of the undisturbed loess specimens

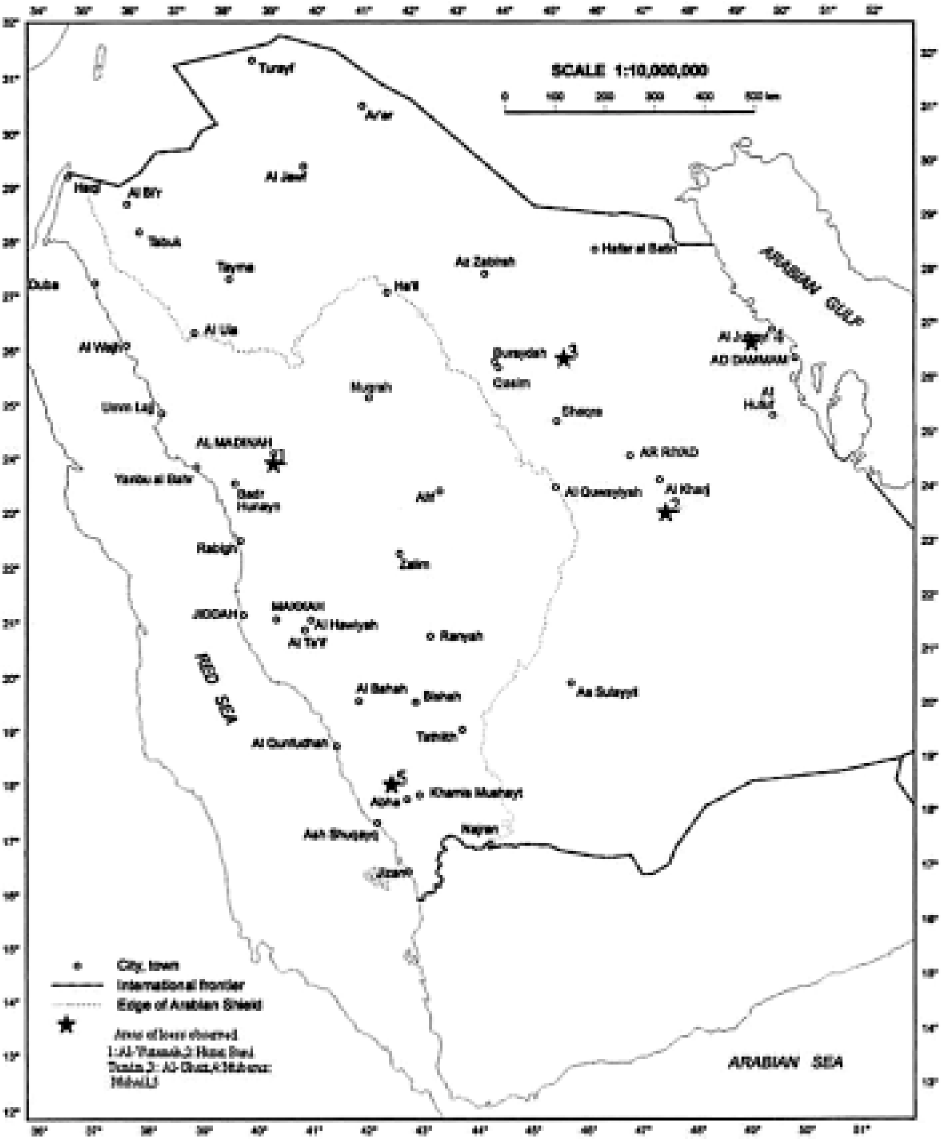


FIG. 3. Location map showing the areas where loess soils were observed.

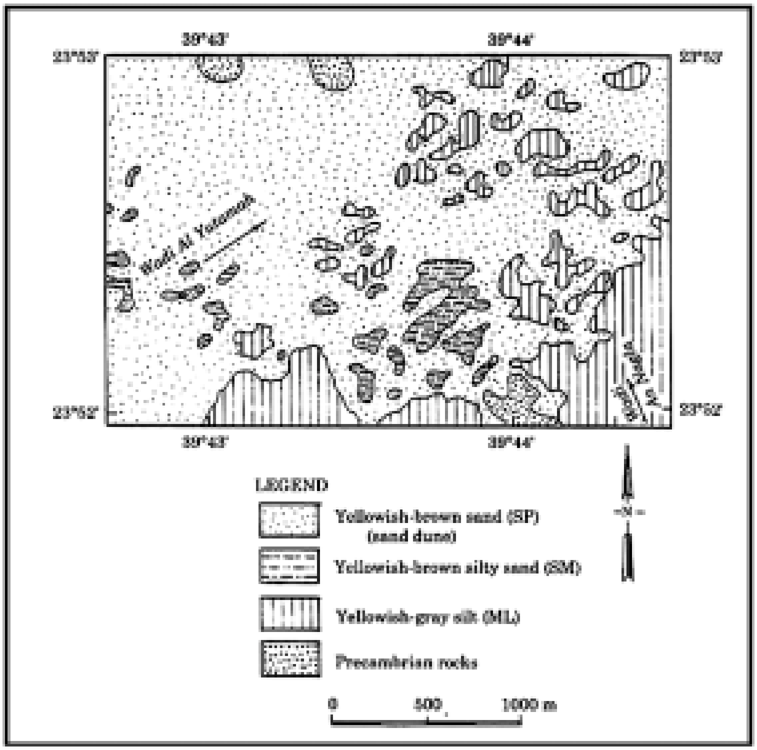


FIG. 4. Loessal soil distribution in Wadi Al-Yutamah, south Al-Madinah Al-Munawwrah (after Al-Harthi and Bankher, 1999).

FIG. 5. Photograph showing loess deposits covered the wadi floor in Muhail area, southern region.

(Hunt, 1984). The soil is coated with very fine films of clay minerals, which is responsible for binding in the structure. Upon wetting, the clay bond is readily loosened causing great loss of strength.

Collapse Phenomenon

Loess belongs to the collapsing soils, which when submerged in water their internal structure may be destroyed and the soil mass may immediately densify causing ground subsidence (Hunt, 1984).

Terrain Features

Hunt, 1984, discusses the distinguishing characteristics of loess deposits landform. Where the crests of the hills are at a uniform elevation, the drainage pattern is pinnate dendritic and the eroded slopes on both sides of the ridges are uniform.

Geology

The study area is located 60 km northwest of Abha city. The area is surrounded by moderate to high relief mountains. The geology of the study area (Fig. 6) is covered by the geologic map of the Abha Quadrangle (Greenwood, 1985), where main outcropping rock types are:

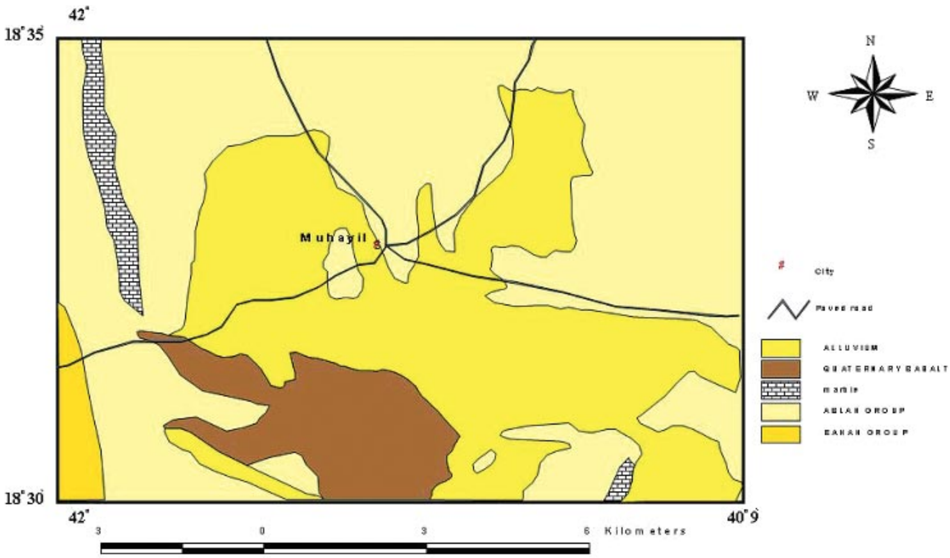


FIG. 6. Simplified geology map of the study area (after Greenwood, 1985).

Bahah Group

The Bahah group in the study area consists of gray to white, thin-bedded, biotite-quartz schist, carbonaceous phyllite and schist. The rocks of this unit are tightly folded and have a strong cleavage parallel to schistosity. According to Greenwood (1985), schistosity in the area has been complexly refolded and broadly domed over intrusions related to the tonalite and granodiorite suite.

Ablah Group

The Ablah group consists primarily of metamorphic sedimentary rocks: phyllite, calcareous phyllite, and slate, fine graywacke, conspicuous brown-weathering marble layers, and subordinate quartzite. The Ablah group is isoclinally folded and contains a strong cleavage or schistosity. The rocks have been metamorphosed mainly up to the greenschist fancies.

Marble

This unit consists of brown-weathering marble layers and subordinate quartzite and metabasalt. This unit is isoclinally folded and has strong cleavage or schistosity.

Quaternary Basalt

Quaternary olivine basalt forms two volcanic cones and surrounding flows in the southwestern and the west-central parts of the quadrangle. The cones and flows show minor dissection. Vegetation is sparse on the cones. Geomorphological evidences indicate Quaternary age.

Alluvium

This unit occupies the beds of all major wadis in the mapped area. It consists of silt, sand, gravel, and boulders, and is unconsolidated, poorly sorted, and more or less stratified. The loess deposits occur within this unit as old wadi terraces.

Engineering Properties of Loess in Saudi Arabia

Index properties

Loess materials are generally uniform in texture, consisting of 50% to 90% silt-size particles, with high porosity ranging from 50 to 60% and exhibiting plasticity. By using Fodor and Kleb (1994) classification, the results indicate that the loess soil ranging from Drift sand loess to Sodic loess based on their plasticity characteristics (Fig. 7). Table 1, shows some values for engineering

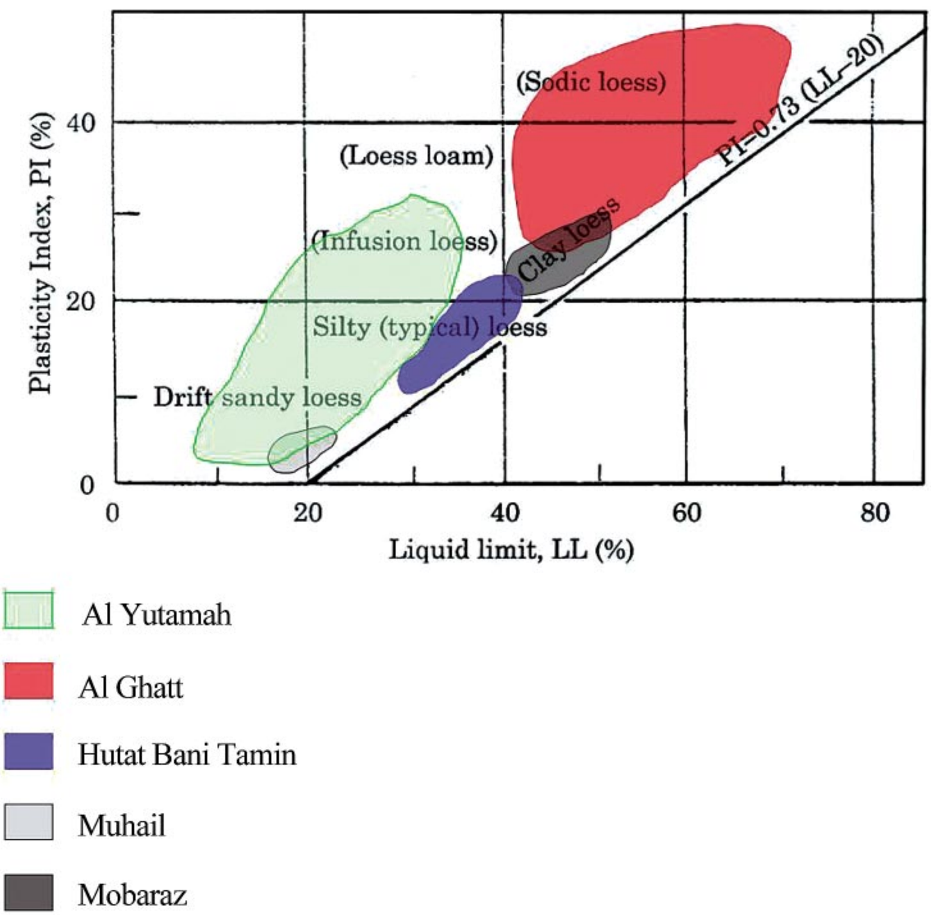


FIG. 7. Loess types based on soil plasticity of the selected areas using Fodor and Kleb classification (1994).

TABLE 1. Geotechnical properties of loess in some selected areas in Saudi Arabia.

Location	**Al-Yutamah** (Al-Harthi and Bankher, 1999	**Al-Ghatt** (Dhowian, 1981)	**Hutat Bani Tamim** (Ruwaih, 1981)	**Muhail** (Study area, 2003)	**Mobaraz** (Sayed, 1981)
Specific gravity	2.54 - 2.66	2.63 - 2.67	2.60 - 2.64	2.57 - 2.65	2.56 - 2.68
Moisture content %	2.50 - 5.0	14 - 20	12 - 17	3 - 15	1
Dry density g / gm^3	0.89 - 1.45	1.22 - 1.55	1.28 -1.44	1.05 - 1.48	1.98
Silt content %	45 - 67	32 - 55	66 - 74	80 - 90	35 -53
Liquid limit %	33.7 - 35	46.5 - 80.6	31 - 39	17 - 20	40 - 45
Plastic limit %	16 - 28.5	24.1 - 33.5	23 - 26	14 - 17	25 - 34
Void ratio	0.89 - 1.38	0.80 - 0.92	0.91 - 1.03	0.9 - 1.0	0.86 - 1.46
Loess type	Drift sand loess to infusion loess	Clay loess to sodic loess	Typical loess	Drift sand loess	Clay loess

properties of selected areas in Saudi Arabia and loess type. An attempt has been made for mapping the potential loess type distribution in the Kingdom based on the geology and physiographical features (Fig. 8).

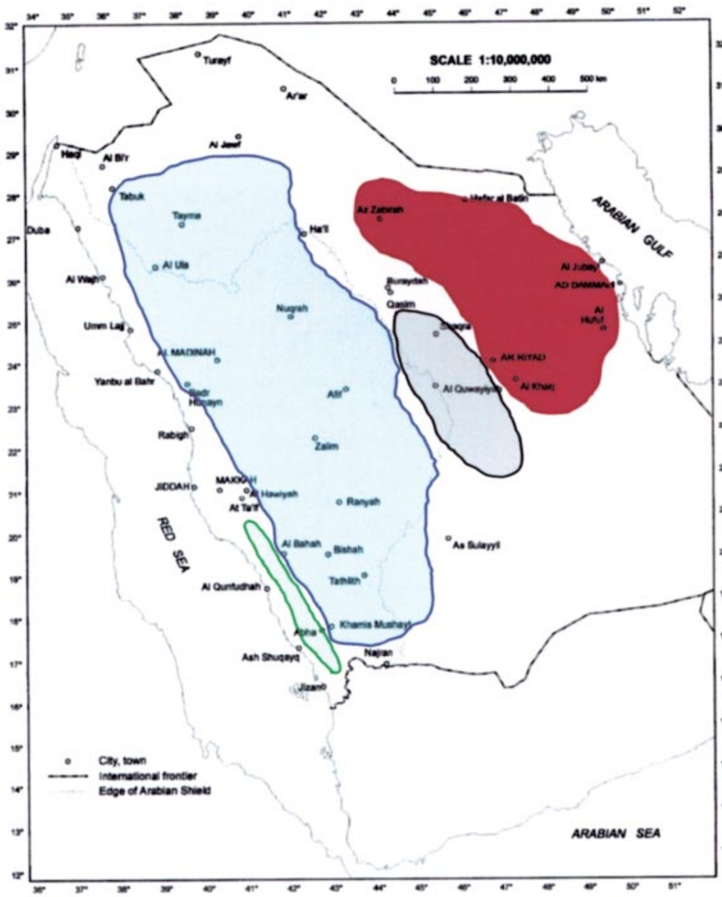
Compressibility

Compressibility is the most significant property related to collapse upon saturation; the potential of which is a function of the natural density and moisture content of the deposits as shown in (Figs. 9, 10 and 11). The potential for collapse has been related to the natural dry density and moisture content in terms of the proctor density and moisture and to the natural dry density in relation to the liquid limit as shown in (Fig. 12).

Case I: indicates that a low natural density is associated with void ratios larger than required to contain the liquid limit moisture. Thus, the soil if wetted to saturation can exist at a consistency wet enough to permit collapse.

Case II: indicates that the equilibrium situation where the voids are equal to the water volume at the liquid limit.

Case III: indicates that the natural densities are high enough that the void spaces are too small to contain the liquid limit moisture content and the soil will not collapse upon saturation, but will reach a plastic state in which there will always be particle-to-particle strength.



Explanation:

Region of potential drift sand loess to infusion loess

Region of clay loess to sodic loess

Region of drift sand loess

Region of Typical loess

FIG. 8. Proposed zonation map of loess soil types in the Kingdom of Saudi Arabia.

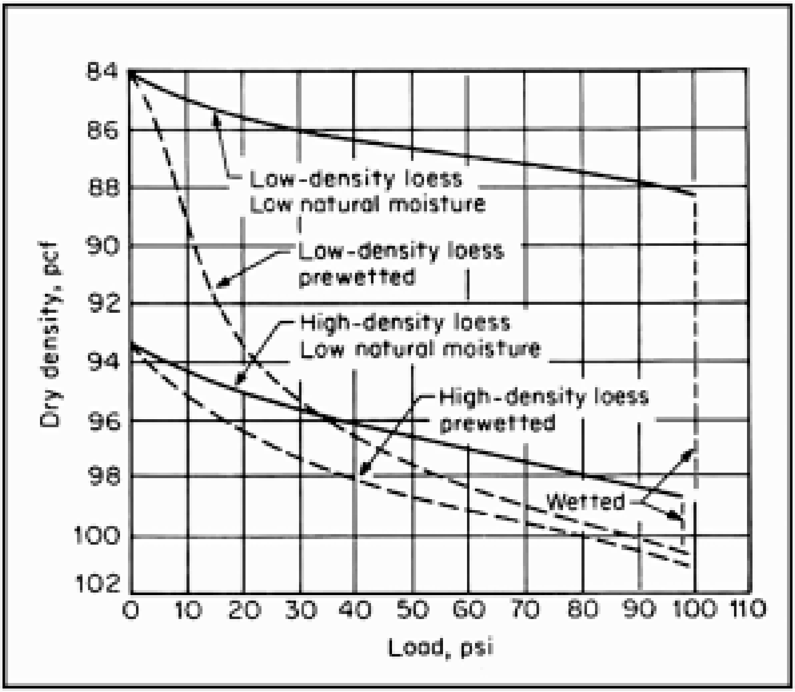


FIG. 9. Typical consolidation curve for loess (after Hunt, 1984).

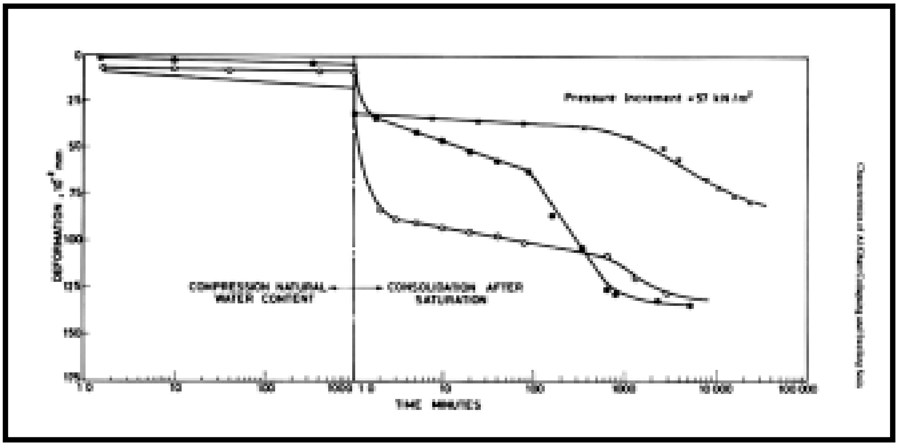


FIG. 10. Collapse behaviour of loess in Al-Ghatt (after Dhowian, 1981).

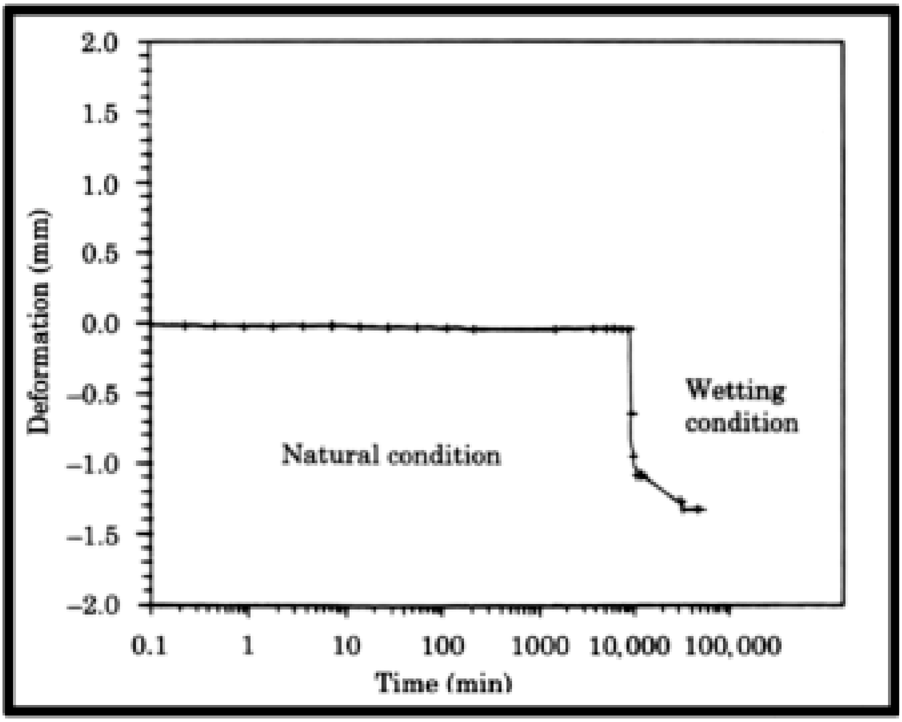


FIG. 11. Collapse behaviour of loess soil in Al-Yutamah (after Al-Harthi and Bankher, 1999).

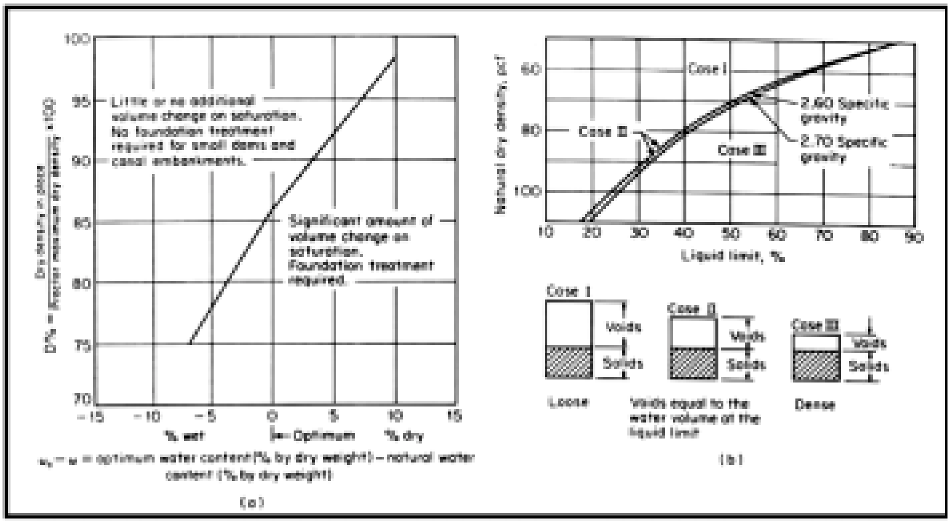


FIG. 12. Criteria for treatment of relatively dry fine-grained foundations: (a) the ratio of natural dry density of proctor maximum dry density, (b) natural dry density and liquid limit (after Hunt, 1984).

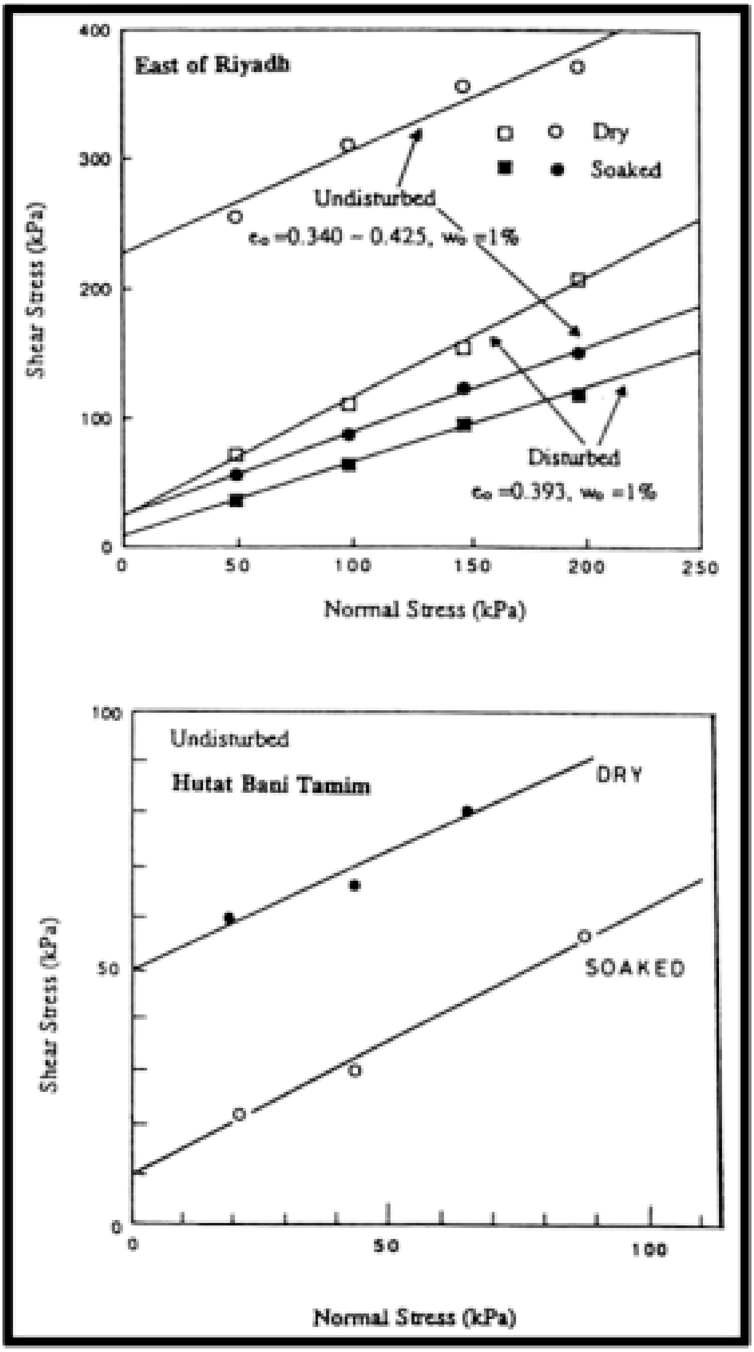


FIG. 13. Shear envelopes for loess soil in dry and soaked direct shear tests (after Al-Refeai and Al-Ghamdi, 1994).

Shear Strength

At natural moisture contents loess has relatively high strength, as well as low compressibility, because of its slight cementation. Figure 13, shows that the soaking process considerably reduces the cohesion from 225 to 25 kpa for soils of east of Riyadh and from 50 to 10 kpa for soils of Hutat Bani Tamim (Ruwaih, 1981). Unconfined compressive strength in the dry condition may be several kilograms per square centimeter, where at natural moisture contents loess has an apparent cohesion which may be as high as 15 psi (1 kg/cm^2). When wetted, cohesion is reduced to less than 1 psi (0.07 kg/cm^2) and even for initially dense loess becomes less than 4 psi (0.28 kg/cm^2). The breakdown can occur at 20 to 25% moisture content which is in the order of 50 to 60% saturation.

Environmental Problems of Loess in Saudi Arabia

The aridity of the Arabian Peninsula’s deserts ranges between arid to hyper-arid with hot dry climate, scarce precipitation and sparse vegetation. These harsh environmental conditions enhance some geomorphologic processes more than others, cause specific geotechnical problems, and increase desertification. Loess deposits are one of the typical examples of the geotechnical problems in arid regions. As mentioned before there were no extensive findings about loess soils in Saudi Arabia, the description will be based on available published data. Accoring to Shehata and Amin (1997) and Al-Harthi and Bankher (1999), these loess deposits subside and form earth fissures by the process of hydro-compaction upon wetting in some remote areas (see Fig. 14). The addition of water can be either natural through storms or man-made through human agricultural or civil activities. Also Dhowian (1981), found that damage to the buildings in Al-Ghatt, in fact, some of them have already been deserted and it is felt, based on the rate of crack extension, he reported that ultimately most of them will be uninhabitable. Finally, studies on loess distribution and its engineering properties are desirable.

Conclusion

In this paper, the available information about the geotechnical properties of loess soils in Kingdom of Saudi Arabia is presented. The harsh environmental conditions cause specific geotechnical problems, and increase desertification. Loess soils are one of the typical examples that create geotechnical problems in arid regions, as it subsides and forms earth fissures by the process of hydro-compaction upon wetting. Due to the limitations of findings about loess soils in Saudi Arabia, the distribution and engineering properties are required.

FIG. 14. Photograph showing an example of an earth fissure at Al-Yutamah area.

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المظاهر الجيوتقنية لتربة اللوس في المملكة العربية السعودية

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جـــدة - المملكة العربية السعودية

المستلخص. تعتبر تربة اللوس أحد الرسوبيات الحديثة والتي تتكون من الغرين غير المتماسك والمنقول بالرياح ، ذات لون أصفر برتقالي وتمتاز بعدم وجود ظواهر التطبق وذات مسامية عالية وكثافة متدنية. تهدف ورقة العمل المقدمة إلى مراجعة الانتشار الجغرافي والخواص الجيوتقنية لهذه التربة في المملكة نظرا" لقلة الأبحاث العلمية المنشورة حول هذه التربة في المملكة . الأبحاث السابقة أشارت إلى وجود هذه التربة في مناطق عدة من المملكة من خلال مشاهدتها أثناء القيام بمشاريع هندسية . ويمتاز نسيج هذه التربة بشكل عام بأنه منتظم ويحتوى على نسبة تتراوح ما بين ٥٠٪ إلى ٩٠٪ من حبيبات الغرين. في المناطق الصحراوية تتعرض هذه الرسوبيات للهبوط وتشكل شقوقا أرضية عند ازدياد معدل الرطوبة في التربة ، حيث قد يكون مصدر هذه المياه طبيعيا كما في سقوط الأمطار أو بفعل نشاط الإنسان من خلال عمليات الري الزراعي والنشاط الحضري.