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Model Plate-Load Tests on Collapsible Soil

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Abstract. Several factors influencing the wetting-induced collapse (hydrocompression) of alluvium soils are investigated by oedometer and plate load tests. Factors include wetting period, staged loading duration, plate size, overburden pressure, and soil thickness. Circular plates of 5 cm and 7 cm diameters were employed. Soil samples collected from Al Helwah region in Central Province of Saudi Arabia were statically compacted in 45 cm diameter and 35 cm height steel container. Surcharge pressures of 5, 7, and 9 kPa were considered. The load-settlement were modeled under dry and soaked conditions of soil at natural water content of 2% and dry density of 1.4 g/cc. Oedometer and plate load test results are presented and their capability in collapse characterization and evaluation are compared.

Results of this research program indicate that Al Helwah soil is highly collapsible and has a collapse potential of 12% under 200 kPa pressure. The plate settlement continues for 3-5 min under dry load increment and 120 min under soaked load increment. Soil stiffness and bearing capacity degraded due to wetting. The reductions are a function of the overburden pressure and plate size. A collapsive strain extending 4 times the plate diameter is observed upon wetting. Also the load step duration and the extent of effective wetting front have significant effects on the test results and interpretation; therefore, they should be considered in the planning, design, and analysis of plate load and full scale footing tests.

Introduction

Wetting induced collapse settlement (hydrocompression) is one of the major geotechnical problems in arid and semi arid regions. Collapsible soils exist in abundance in Riyadh, Hutat Bani Tamim, Al Helwah, and Al Delam among other parts in the Central Province of Saudi Arabia. Fast development and massive boundaries expansion of urban area have led to the construction of many structures and infrastructures with an increase in water consumption. Distress to structures founded on either natural or compacted collapsible soils are caused by wetting-induced collapse upon the increase of moisture content by such means as excessive irrigation of green lands and leakage of sewage and drinking water pipe systems.

Natural collapsible soil have relatively low density and low moisture content with loose structure. These soils posses relatively high apparent stiffness and strength at dry condition but these properties undergo substantial decrease upon wetting, leading to high volume changes and hence large deformations. The deterioration in the characteristics of collapsible soil is mainly due to the loss of binding agents which can be meniscus, calcite, or clays. Many researchers have investigated the collapse behavior of natural and compacted collapsible soils using oedometer tests world wide for examples in the U.S.A [1], former USSR [2], China [3], Germany [4], Czechoslovak [5], Thailand [6], South Africa [7], Saudi Arabia [8] among others.

It has been demonstrated that laboratory collapse tests can be used to obtain reasonable estimates of footing collapse settlements [9]. However, the major difficulties in oedometer tests are sample disturbance and degree of saturation. Sampling of cemented collapsible soil may be possible, but very lightly cemented sand or gravely soils are difficult to sample and may exhibit substantial disturbance [10]. Therefore, it may be more direct, in some cases, to circumvent shortcoming of laboratory testing and its difficulties by using an in-situ tests.

Full-scale field tests on collapsible soils (e.g. [11] [12]), with practical foundation size and load intensity, could provide a reliable information on load-settlement response and collapse potential. This alternative is expensive and time consuming. However, it is the most appropriate approach for calibration, verification, and modification of laboratory and numerical models.

Plate load test has been commonly used in the foundation highway design on collapsible soils by many investigators including Clevenger [13]; Clemence and Finbarr [14]; Chen *et al.* [15]; Houston *et al.* [16]; Yakov [17]; Yakov [18]; Ferreiran [19]; and Rainobvich [20]. A major shortcoming of plate load test for foundation design is the extrapolation of plate test results to prototype. Empirical extrapolation formulas are not fully justified. Therefore, researchers from Russia have suggested that a series of large plates are used on collapsible soils [17][18]. Recently, Houston *et al.* [12] developed an in-situ collapse test and a method of interpretation that empirically lead to define stress-strain relationship for soil. A circular plate with 7 cm diameter was loaded down-hole and collapse was measured. The extent of the wetting front was also determined. Then, plate load test results were used with stress distribution curves generated by simple linear finite element program to estimate the settlement of prototype footing.

This paper investigates the collapse potential of Al Helwah soils and evaluates the effects of plate size, overburden pressure, and thickness of wetted soil on the load-settlement and collapse responses. Tests performed include consistency limits, modified Proctor compaction, in-situ density, moisture content, single and double oedometer, and model plate load tests under dry and soaked conditions.

Experimental Work

Materials

The alluvial soils used in this experimental program were obtained form Al Helwah located 190 km south of Riyadh, Saudi Arabia. Soil samples of 800 kg were collected from a trial test pit in a newly developing district where the presence of collapsible soil layers was detected by previous investigations. The range of grain size distribution curves for Al Helwah collapsible soil (HCS) is shown in Fig. 1. The modified Proctor compaction curves are shown in Fig. 2. The in-situ moisture content and dry density after a dry summer session are shown in Figs. 3 and 4; respectively. The engineering properties are listed in Table 1. It seems that the material is slightly inhomogeneous with depth. According to the criteria given by Clemence and Finbarr [14], the soil has a collapse potential as reflected by low density and low moisture content.

A sand bed was placed below the soil to allow an easy up ward seeping of water during soaking and to induce a uniform wetting front throughout the plate load tests. The sand used was a crushed sand commercially available in Riyadh. Engineering properties of the sand are also listed in Table 1.

Table 1. Engineering properties of soils

Alluvial soil (HCS)	
Specific gravity	2.75-2.77
Liquid limit (%)	20-27
Plasticity index	1-6
Soil classification (USCS)	ML
Permeability coefficient	
At natural dry density and water content (cm/s)	1.31×10^{-4}
At 95% maximum dry density on dry side of compaction curve (cm/s)	1.83×10^{-6}
Sand bed	
% passing No. 4 US sieve	97.66
% passing No. 200 US sieve	0
Gravel (%) 2.34 D10 (mm)	0.33
Maximum dry density (gm/cm^3)	1.960
Minimum dry density (gm/cm^3)	1.627
Uniformity coefficient (Cu)	5.45
Curvature coefficient (Cc)	0.95
Dry density (gm/cm^3)	1.786
Permeability coefficient (cm/s)	9.5×10^{-2}

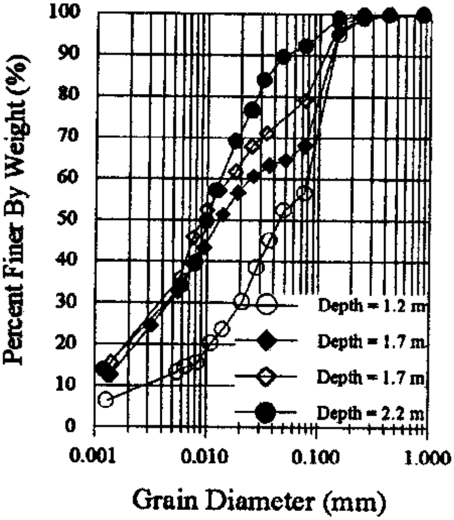

Fig. 1. Range of grain size distribution curves.

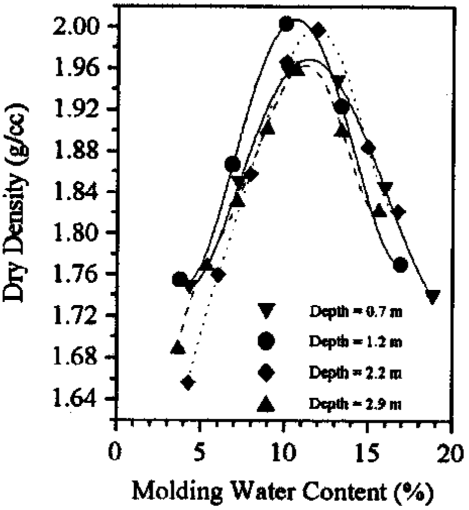

Fig. 2. Variation of dry density with molding water content.

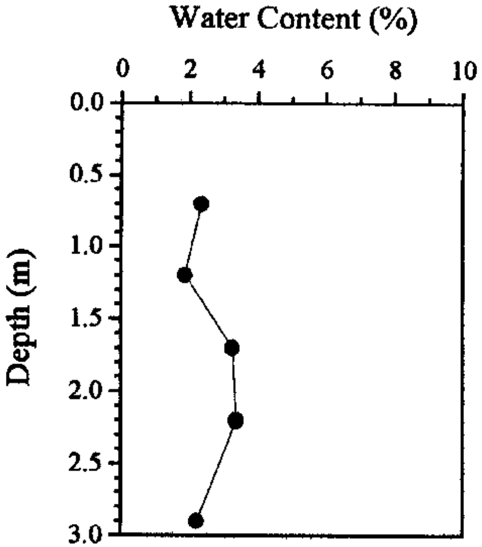

Fig. 3. Variation of water content with depth.

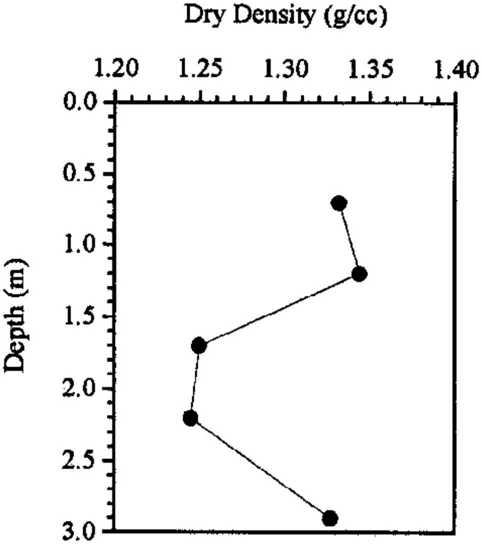

Fig. 4. Variation of dry density with depth.

Test equipment

Static plate-load tests were conducted in a rigid cylindrical steel container of 45 cm outside diameter, 1 cm wall thickness and 35 cm height with two drainage valves at the base of the container. Laboratory models used in this experimental program were rigid aluminum circular plates with 50 mm and 70 mm diameters and 50 mm thickness. The loading and geometric axisymetry will simplify further modeling and analysis using the non-linear numerical tools. Settlement was measured by means of two dial gauges with a range of 50 mm and an accuracy of 0.01 mm. A schematic representation of the plate-load test model is presented in Fig. 5.

Tests program

The soil collapse characteristics are evaluated by oedometer and plate load tests. Table 2 shows the oedometer test program. The plate load test program is shown in Table 3. One of the features of this testing program was the employment of small diameter plates which is identical to the plate diameter used in the in-situ collapse test developed recently by Houston *et al.* [12]. Soaking period and loading/unloading duration were experimentally determined. In addition, the water content was measured at the end of each soaked test to assess the extent of wetting front.

Table 2. Oedometer test program

Test type	Depth (m)	P_o (kPa) at soaking	In-situ conditions		95% MDD	
			γ_d (g/cc)	w (%)	γ_d (g/cc)	w (%)
Single Oed.	1.2	200	1.344	1.86	-	-
~~	1.7	25, 50, 100, 200	1.25	3.25	-	-
~~	2.2	200	1.245	3.36	-	-
Double Oed.	0.7	-	1.332	2.34	1.872	7.7
~~	1.2	-	1.344	1.86	1.91	7.7
~~	2.2	-	1.245	3.36	1.9	8.6
~~	2.9	-	1.327	2.21	1.862	8

Table 3. Plate load test program

Test type	P_0 (kPa)	D (mm)	Soil thickness (cm)
Double (Dry & Soaked)	5	70	15
~~	7	70	15
~~	9	70	15
Single (Soaked at 100 kPa)	7	50	5, 10, 15, 20
~~	7	70	5, 10, 15, 20

Specimen preparation

For model plate load test, sand bed was first compacted at the bottom of the test container. A predetermined weight of sand needed to produce a dry density of 1.786 g/cm^3 was compacted in one 20 cm thick layer. The sand bed is considered highly permeable relative to the soil to assume uniform and continuous wetting during soaking; it is also

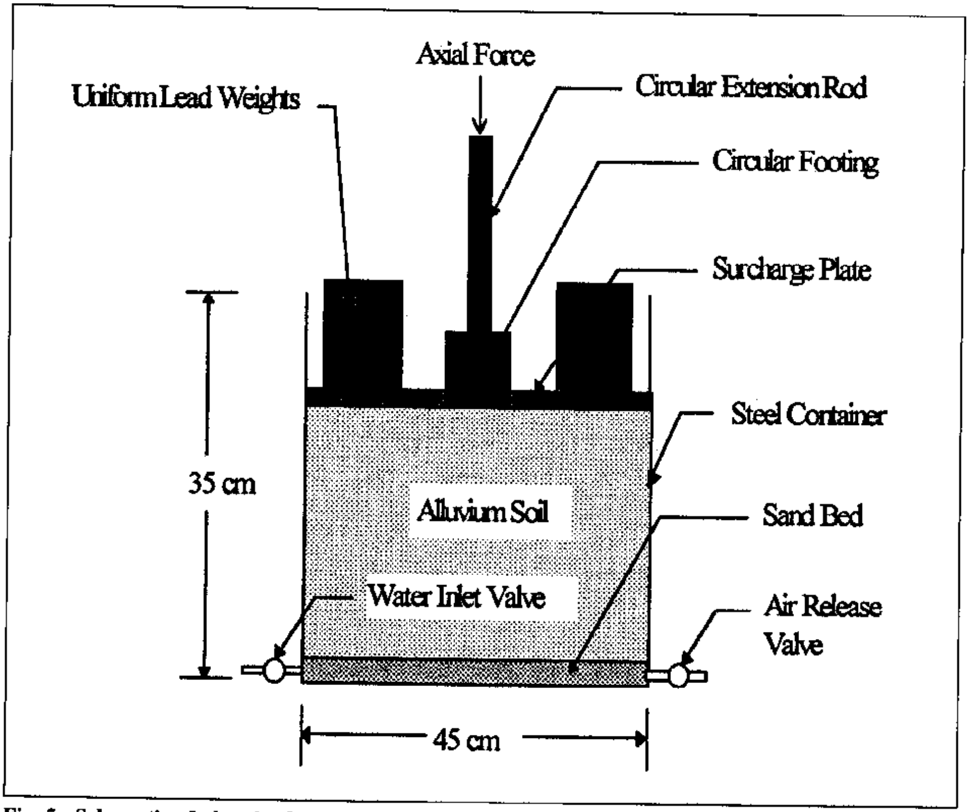

Fig. 5. Schematic of plate-load test model.

thin and dense to ensure it does not contribute to plate settlement and can be assumed a rigid layer during strain calculations.

Al Helwah soil taken from 1.7 m depth was used in its natural water content, and any lumped soil was broken into its original grain sizes such that the soil passes sieve No. 10 (2 mm opening). The soil was compacted to 1.4 g/cm^3 dry density in layers of 50 mm thickness. The final depth of the soil in the container varies from one to four times the plate diameter, D. The depth variation was considered small enough to assume a finite soil medium for collapse strain calculation, and the final total depth was considered large enough relative to the plate diameter to assume a semi-infinite soil medium.

Tests procedures

The double oedometer test consists of two oedometer conducted simultaneously on two identical samples; one test is being at dry (as compacted) condition, and the second test is under soaked condition. The test follows in general the procedure given by Alawaji and Alwail [21]. Loads were applied in cumulative increments prescribed as following: 7, 25, 50, 100, 200, 400, 800 kPa. During each load stage, the cumulative load was maintained for at least 24 hours and until the rate of deformation reaches less than 0.001 mm/min.

The single oedometer test procedure employ one oedometer test loaded initially dry up to a prescribed pressure, soaked under a constant pressure until the deformation ceased, then loaded under soaked condition in a similar manner to the previous double oedometer test.

The plate load test follows in general the procedure given by Alawaji [22]. Load was applied in cumulative increments such that the net pressure follows, in general, the following path: 0.0, 13, 25, 50, 100, 50, 25, 50, 100, 200, 300 kPa, etc. After the application of each load increment, the cumulative load was maintained until all settlements and collapse had ceased when the rate of deformation reaches less than or equal to 0.001 mm/min. over the last 10 to 15 minutes. It was generally noticed that equilibrium was reached after 15 min for the dry loading increments and after 2 hr for the wet loading increments. During soaking the pressure was kept constant for at least 12 hr and until collapse settlement had ceased according to the above rate of deformation criteria. For soaked samples, water inlet was open and water was allowed to flow into the sand layer at an initial pressure head of 15-30 cm. The net pressure was maintained constant during each loading, unloading, and reloading steps, and displacement data were collected at increasing time intervals. The final loading stage was terminated at a displacement approximately 50 to 60 mm. Plate was unloaded, then test apparatus was disassembled at the completion of final unloading stage, and samples were obtained for moisture content determination.

Results and Analysis

Oedometer tests

Figure 6 depicts the results of single oedometer tests carried out on remolded samples from various depths compacted to the in-situ density (Fig. 3) at natural moisture content (Fig. 4). The samples were first loaded dry up to 200 kPa vertical stress, then soaked, and the collapse magnitudes were observed. Collapse potential (CP) is defined as the collapsive strain due to wetting at applied pressure of 200 kPa (Jennings and Knight [23]). Figure 5 indicates that the CP ranges between 8 and 12%. The variation in CP are mainly due to variations in the fine content and density with depth as shown in Figs. 1 and 4.

Figure 7 shows the results of a series of single oedometer tests carried out on remolded samples taken from 1.7 m depth and compacted to the in-situ density at natural moisture content. The samples were first loaded dry incrementally up to various vertical stresses of 25, 50, 100, and 200 kPa; then saturated, and the collapse magnitudes were observed; after that, samples were loaded then unloaded under soaked condition. All specimens

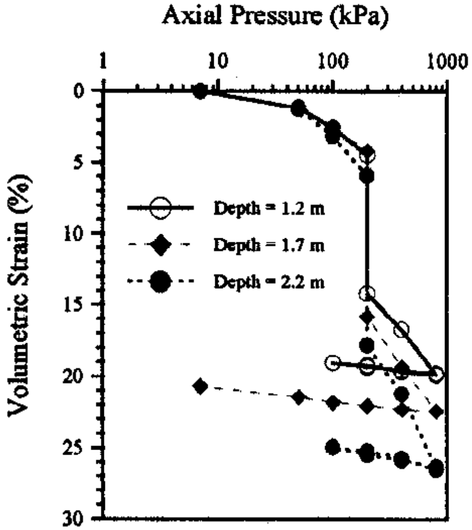

Fig. 6. Single oedometer tests on samples from various depths soaked at 200 kPa.

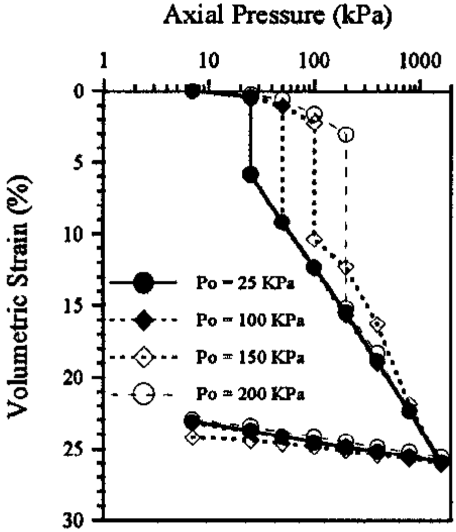

Fig. 7. Single oedometer tests on samples from 1.7 m depth soaked at various pressures.

that were subjected to wetting at different levels of stress showed a unique post-wetted relationship between stress and volumetric strain as demonstrated by Phien-Wej *et al.* [6]. The post-wetted coefficient of compressibility ($C_{\varepsilon n}$) is defined as the slope of the straight-line portion of the loading curve and is determined as $C_{\varepsilon n} = (\Delta\varepsilon_n / \log(p_2/p_1)$, where $(\Delta\varepsilon_n$ is the change in volumetric strain under stress changes from p_1 to p_2. For soil at 1.7 m depth, $C_{\varepsilon n}$ equals to 0.111.

Figure 8 shows the results of two sets of double oedometer tests carried out on remolded samples from various depths. One set was compacted to the in-situ density at natural moisture content. The other set was compacted to 95% of maximum dry density (MDD) on the dry side of the corresponding compaction curve (Fig. 2). Dense specimens swell slightly when soaked under 7 kPa. At this low pressure the swell was in the range of 1-2%. Therefore, when excavation and recompaction is possible, the collapsible soil at Al Helwah region can be improved by compaction to 95% MDD at optimum moisture content (OMC).

Plate load tests

Water content was measured at 9 points, uniformly distributed in the bottom, middle, and top of soil, at the end of each plate load test. Measured water content was around 28-30%, which is highly sufficient for the soil to collapse.

Effect of overburden pressure (p_o) on load-settlement response of the 70 mm diameter plate was investigated under dry and soaked conditions. Figure 9 shows the variation of

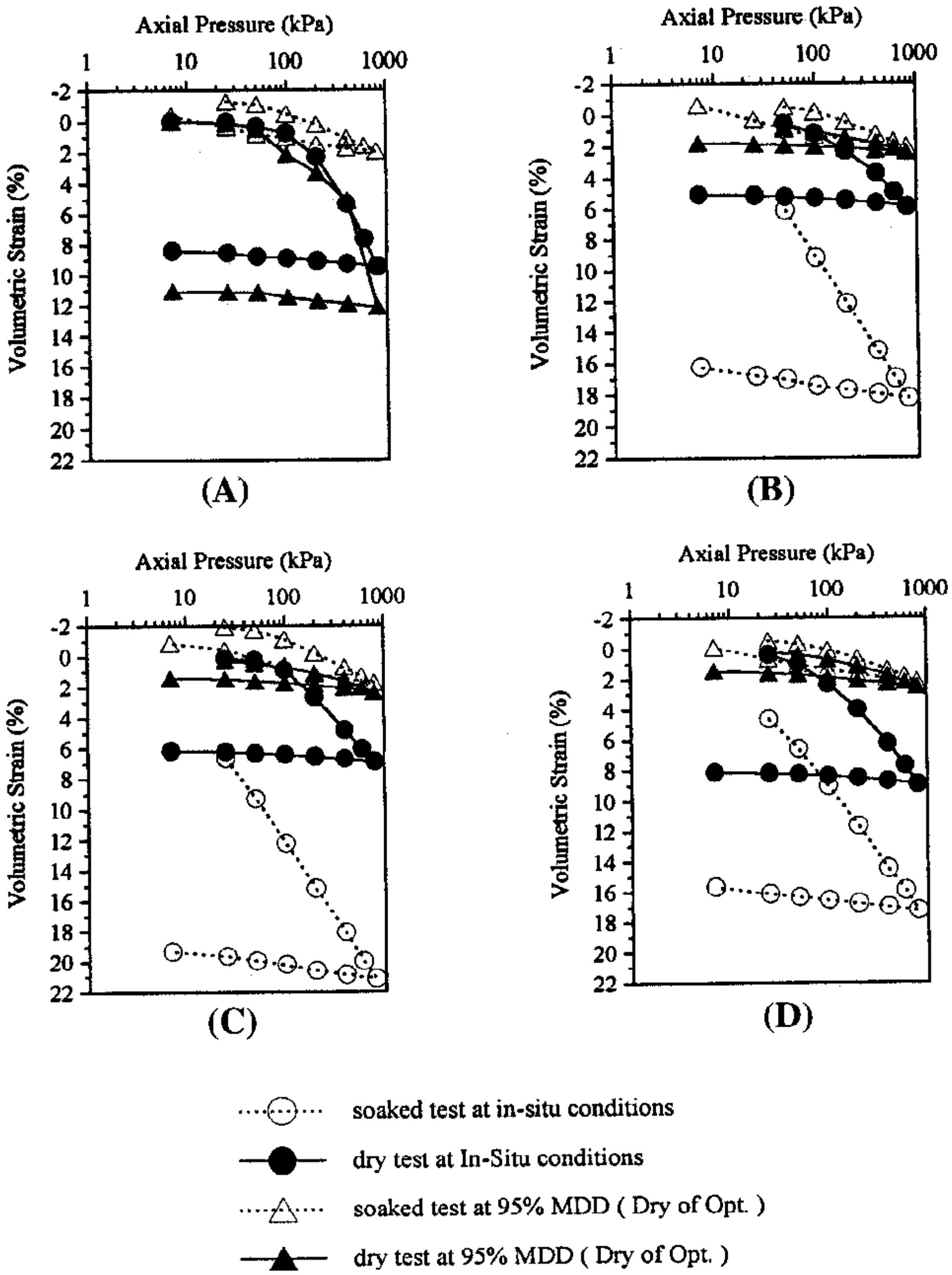

Fig. 8. Double-oedometer test results on compacted samples from various depths: (A) depth = 0.7 m; (B) depth = 1.2 m; (C) depth = 2.2 m; (D) depth = 2.9 m.

net pressure-settlement curves under 5, 7, and 9 kPa overburden pressures. It is evident that the range of overburden pressure used here cannot permit a clear determination of the effect of overburden pressure, since the maximum to minimum pressure ratio is 2 (i.e. 9/5). However, for low overburden pressure level, the effect on bearing capacity and stiffness can be evaluated. For comparison, the ultimate bearing capacity (q_{ult}) was determined by the slope tangent method (Ismael, [24]; Adams and Collin [25]. From the net pressure-settlement curves in Fig. 9, the bearing capacity is determined at the intersection of the tangents to the initial linear portion and the steeper linear portion following failure on each curve. Soil modulus (E) is calculated from the theory of elasticity (Timoshenko and Goodier [26]), for a rigid circular plate on homogeneous soil with Poisson's ratio of 0.3 as

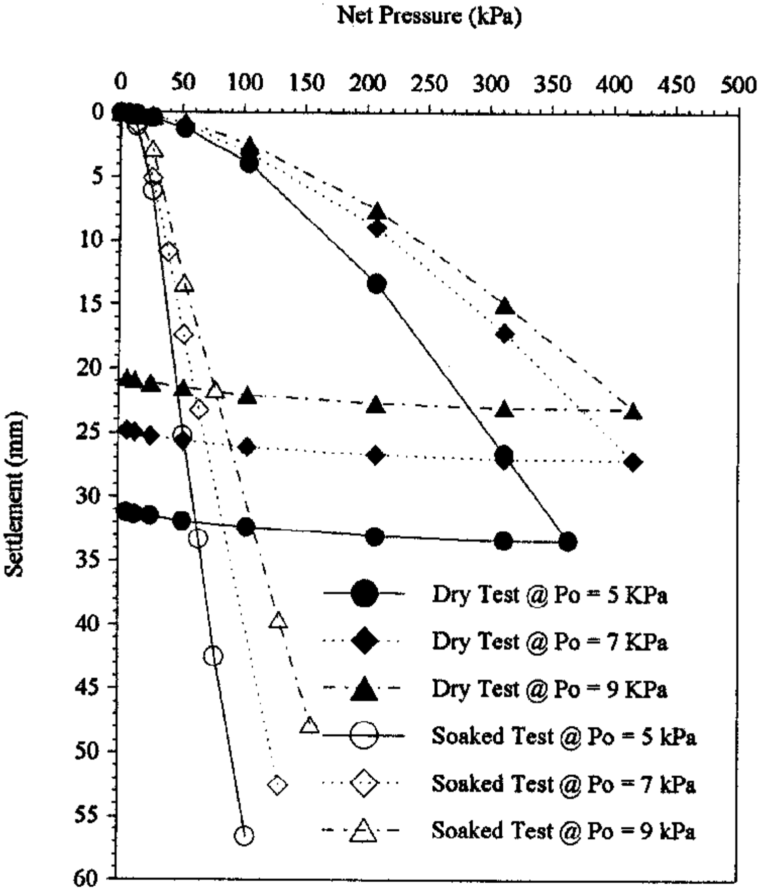

Fig. 9. Pressure-settlement curves of 7 cm plate on A1 helwah soil of 15 cm thickness, compacted at natural conditions, under various overburden pressures.

$$E = 0.715 * D * (dq / ds) \tag{1}$$

where q = contact pressure intensity, s = settlement, D = plate diameter. The soil is nonlinear; therefore, for comparison and simplicity, the secant soil modulus (E_s) is calculated as the secant modulus in the stress range 0-100 kPa. Moreover; the initial soil modulus (E_0) is calculated using the initial linear portion of the net pressure-settlement response. The bearing capacity and moduli values under dry and soaked conditions are given in Table 4. Results indicate that q_{ult}, E_s, and E_0 increase non-linearly with overburden pressure. It also reflects the significant reductions in the moduli and bearing capacity upon wetting.

Table 4. Soil bearing capacity and deformation moduli under dry and wet conditions

P_o (kPa)	Dry q_{ult} (kPa)	Wet q_{ult} (kPa)	Dry/Wet q_{ult} ratio	Dry E_s (kPa)	Wet E_s (kPa)	Dry/Wet E_s ratio	Dry E_o (kPa)	Wet E_o (kPa)	Dry/Wet E_o ratio
5	118	16.4	7.2	1283	92	14	3403	606	5.6
7	123	17	7.2	1854	126	15	4895	666	7.4
9	139	16.4	8.5	2002	165	12	5405	2412	2.2

The rate of deformation under constant applied pressure is investigated under dry and soaked conditions. The dry state deformation ceases after 3-5 min. and the wet state deformation ceases after 120 min. Upward wetting under a constant pressure is also investigated. It is noticed that complete wetting under a hydraulic head of approximately 10-15 cm, takes about 2 hr and the deformation ceases after 4 hr. These time periods can be considered as a minimum criteria for load stepping and soaking duration at this region.

The effects of soil thickness and plate size on the collapse variation with depth are also investigated. Figures 10 and 11 show the variation of net pressure-settlement curves for the 50 mm and 70 mm plates; respectively. These tests were conducted under 7 kPa overburden pressure and soaked under 100 kPa net pressure which is close to the bearing capacity commonly used locally for 1-2 story buildings on collapsible soils. The dry then wet loading condition was chosen since it simulates closely the wetting conditions of a real loaded footing. The collapse increases with soil thickness in a decreasing rate. Figure 12 shows that the collapse extends to a depth of 4 times the plate diameter, which is far beyond the 1-2 plate diameter zone commonly used in practice for soaking and analysis of plate load tests. However, it is consistent with the well known theoretical stress influence zone of 4-5 plate diameter.

The range of size used here can not permit a clear evaluation of the effect of plate size on the collapse settlement, since only two plates are used and their diameter ratio is 1.5 (i.e. 7/5). Figures 10 and 11 also show that for the 5 cm and 7 cm plates on soil of 20 cm thickness, soaking induced around 4.3 cm collapse. This was mainly due to the use of limited plate size and finite soil thickness. Theoretically, larger footing experience a

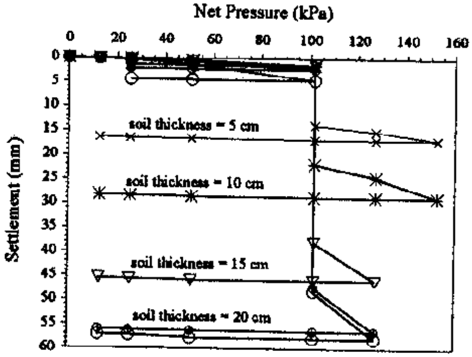

Fig. 10. Pressure settlement responses of 5 cm plate on soil of various thickness soaked under 100 kPa.

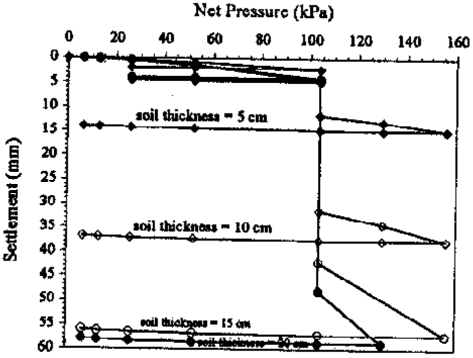

Fig. 11. Pressure settlement responses of 7 cm plate on soil of various thickness soaked under 100 kPa.

larger collapse at the same pressure. Both the dry and wet moduli increased with plate size. For example, the dry and soaked secant moduli, for plate of 7 cm on soil of 20 cm thickness, are 1754 kPa and 107 kPa; respectively. Whereas, the dry and soaked secant moduli, for plate of 5 cm on soil of 20 cm thickness, are 1289 kPa and 78 kPa; respectively. Finally, additional centrifuge and/or field tests are needed to establish the influence of plate size and overburden pressure on the deformation moduli, collapse, and bearing capacity of collapsible soils.

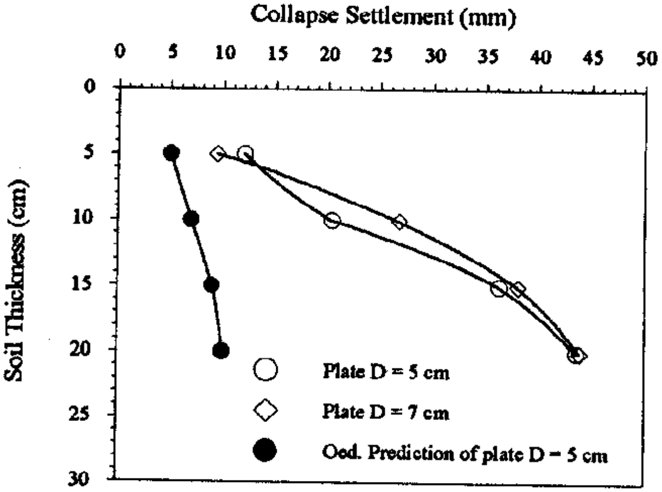

Fig. 12. Variation of collapse settlement with soil thickness for various plates soaked under 100 kPa.

Collapse Prediction

A comparison was made between the collapse found from the plate load test (D = 5 cm), soaked at 100 kPa, and that predicted based on the oedometer test. In the collapse calculation, stress increase in the subsoil due to load from a circular area were assumed to follow the linear elastic solution. It can be seen from the comparison shown in Fig. 12 that the prediction based on the oedometer test results underestimate the collapse settlement. The discrepancy was partly attributed to the deformation constraint in the oedometer test (one dimensional), the more sever loading conditions in the plate load test (shear stress and stresses concentrations), and the continuous penetration of the plate with follower load.

In practice, allowable bearing capacity of collapsible soil is considered settlement control criterion, corrections are needed for actual size of footings and overburden pressure if the load settlement result from a plate load test is to be used. Houston *et. al.* [16] suggested conducting tests using a plate size comparable to the actual footing size. However, that approach is expensive. Therefore, there is a need to develop a constitutive driver with collapse strain capability and implement it in a numerical tool (FEM), that program can be calibrated and verified using simple oedometer, triaxial, and plate load tests on collapsible soil, then employed for foundation modeling and analysis.

Conclusion

Based on the results presented in this paper, the following conclusion remarks can be derived:

1. The Al Helwah soil was found to have a relatively high collapse potential of 12% under 200 kPa overburden pressure. Therefore, severe trouble to foundations is expected upon wetting [14].
2. Samples compacted at 95% MDD on dry side of optimum have negligible collapse potential compared to samples compacted at the in-situ conditions.
3. Al Helwah soil stiffness and bearing capacity increase with plate size and overburden pressure under both dry and soaked conditions.
4. The wetting of Al Helwah soil decreases soil stiffness and bearing capacity.
5. The ratio of dry to wet secant deformation modulus at 100 kPa net pressure was found to be in the range of 10 to 20.
6. The ratio of dry to wet plate bearing capacity was found to be about 5.
7. The influence zone for collapsive strain due to wetting front propagating upward towards the loaded plate, which is practically similar to rise of ground water table, was found to be far larger than the double plate diameter which is a commonly used criteria in data reduction and analysis. The influence zone was in the range of 4 plate diameter.
8. The deformation ceased after about 5 min of load increase for the dry stage of plate loading, and after about 2 hrs for the wet stage.

9. The deformation ceased after about 4 hr of wetting initiation for the soaked plate test under a constant net pressure.
10. Collapse prediction based on oedometer test underestimate the measured plate collapse settlement.

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References

[1] Romani, B. and Hich, B.A. "Collapsible Soils in the Antelope Valley-California." *Proc. Fouds. Engr. Current Principles and Practices,* ASCE, 1 (1989), 135-142.

[2] Kratov, V.I. "Foundation Construction on Collapsible Soils." *J. Soil Mech. and Fouds. Engr.*, 24, No. 6 (1988), 219-223.

[3] Dijkstra, T.A., Rogers, C.D.F., Smalley, I.J., Debyshire, E., Yong Jin, L. and Xing Min, M. "The Loess of North-Central China: Geotechnical Properties and their Relation to Slope Stability". *J. Engineering Geology,* 36 (1994), 153-171.

[4] Rizkallah, V. and Kesse, K. "Geotechnical Properties of Collapsible Soils". *Proc. 12th Int. Conf. Soil Mech. and Founds. Engrg.*, 1 (1989), 101-104.

[5] Feda, J., Bohac, J. and Herle, I. "Compression of Collapsed Loess: Studies on Bonded and Unbonded Soils." *J. Engineering Geology*, 34 (1993), 95-103.

[6] Phien-Wej, N., Pientong, T. and Balasubramaniam, A. S. "Collapse and Strength Characteristics of Loess in Thailand". *J. Engineering Geology*, 32 (1992), 59-72.

[7] Wilkins, C.B., Van Schalkwyk, A. and Eriksson, P.G. "Origin and Some Engineering Properties of Read Soils Overlying Dolomite Bedrock in an Area South of Pretoria". *J. Civil Engrg. in South Africa,* 29, No. 3 (1987).

[8] Rahim, K.S.A. "Characteristics of Desert Deposits from the Central Region of Saudi Arabia". *The Second Symposium on Geotechnical Problems in Saudi Arabia*, King Saud University, (1984), 181-198.

[9] El-Ehwany, M. and Houstons, S. "Settlement and Moisture Movement in Collapsible Soils". *J. Geotech. Engr., ASCE,* 116, No. 10 (1990), 1521-1535.

[10] Houston, S.L. and El-Ehwany, M. "Sample Disturbance of Cemented Collapsible Soils". J. *Geotech. Engr., ASCE,* 117, No. 5 (1991), 731-752.

[11] Wiseman, G. and Lavie, Y. "Arid Zone Surface Exploration and Load Testing". *Proc. 7th Asian Reg. Conf. on Soil Mech. and Founds Engr.*, Dept. of Civil Engr., Israel Institute of Technology, Haifa, Vol. 1 (1983), 98-104.

[12] Houston, S.L., Mahmoud, H.H and Houston, W.N. "Down-Hole Collapse Test System". *J. Geotech. Engrg. Div., ASCE,* 121, No. 4 (1995), 341-349.

[13] Clevenger, W.A. "Experience with Loess as Foundation Material". *J. Soil Mech. Found. Engrg. Div., ASCE,* 82, No. 3 (1956), 1-26.

[14] Clemence, S.P. and Finbarr, A.O. "Design Consideration for Collapsible Soils". *J. Geotech. Eng. Div., ASCE,* 107, No. 3 (1981), 305-317.

[15] Chen, Z.Y., Qian, H.J. and Bar, C.G. "Problem of Regional Soils". *Proc. Asian Reg. Conf. Soil Mech. and Found. Engr.*, 8th (Kyoto), Vol. 2 (1987), 167-190

[16] Houston, S.L., Houston, W.N. and Spadola, D.J. "Prediction of Field Collapse of Soils Due to Wetting". *J. Geotech. Engr. Div., ASCE,* 114, No. 1 (1988), 40-58.

[17] Yakov, M.R. "Plate-Load Tests of Collapsible Soils". *J. of Geotech. Engr., ASCE,* 119, No. 3 (1993), 608-614.

[18] Yakov, M.R. "Determination of Deformation Properties of Collapsible Soils". *Geotech. Testing J., ASTM*, 15, No. 3 (1992), 248-255.

[19] Ferreiran, S.R.M. "Collapsible Soil - A Practical Case in Construction (Pernambuco, Brazil)". *Proc, 12th Int. Conf. Soil Mech. and Founds. Engr.*, Rio de Janeiro, Brazil, 1 (1989), 603-606.

[20] Rainobvich, I.G., Baghdasarov, Y.A., Konstantinovskii, D.I. and Shabalin, A.I. "Features of Deformations of the Rammed Collapsible Soils." *Proc. 10th European Conf. Soil Mech. and Founds. Engr*, Italy, (1991), 157-158.

[21] Alawaji, H. and Alwail, T. "Influence of Interlayer Cations on Collapse Potential of Sand-Clay Mixtures." *Proc. of the Seventh International Coll. on Structural and Geotech. Engr.*, 7th ICSGE, Ain Shams University, Cairo, Egypt, December 17-19, (1996), 295-305.

[22] Alawaji, H. "Model Plate Load Tests on Collapsible Soil Overlaying Sand Pads." *Proc. Int. Conf. on Found. Failure ICFF*, Singapore, (1997), 385-392.

[23] Jennings, J.E. and Knight, K. "A Guide to Construction on or with Materials Exhibiting Additional Settlement Due to Collapse of Grain Structure." *Proc. 6th Regional Conf. for Africa on Soil Mech. and Found. Engr.*, (1975), 99-105.

[24] Ismael, N. "Loading Tests on Circular and Ring Plates in Very Dense Cemented Sands." *J. of Geotech. Engrg., ASCE*, 122, No. 4 (1996), 281-287.

[25] Adams, M. and Collin, J. "Large Model Spread Footing Load Tests on Geosynthetic Reinforced Soil Foundation." *J. of Geotech. Engr., ASCE*, 123, No. 1 (1997), 66-72.

[26] Timoshenko, S.P. and Goodier, J.N. *Theory of Elasticity*. 3rd edn, New York, N.Y.: McGraw-Hill Book Co., 1970.

اختبارات على نموذج لوح التحميل فوق تربة إنهيارية

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ملخص البحث. هناك عدة عوامل تؤثر على هبوط الأساسات نتيجة لارتفاع منسوب المياه الأرضية. ومن هذه العوامل: فترة الترطيب، مدة التحميل، حجم الأساس، عمق الأساس، وسمك الطبقات الإنهيارية. وفي هذا البحث، تمت دراسة التربة الإنهيارية بمنطقة الحلوة باستخدام اختبارات الضغط المحصور ولوح التحميل. حيث تم استخدام ألواح بقطر ٧,٥سم عند عمق مكافيء لضغط ٧,٥ و٩ كيلو باسكال. تم التحميل تحت كل من الظروف الجافة والرطبة للتربة في وضعها الطبيعي بكثافة جافة عند ١,٤٥غم/سم^{٣} ونسبة رطوبة ٢٪.

ودلت النتائج أن هذه التربة لها قابلية عالية للإنهيار تساوي ١٢٪تحت ضغط ٢٠٠ كيلوباسكال. واستمر هبوط الألواح أثناء التحميل على التربة الجافة من ٣ إلى ٥ دقائق وعلى التربة الرطبة لمدة ساعتين. ولوحظ أن هناك نقص حاد في قوة تحمل التربة ومتانتها نتيجة الترطيب، ومقداار هذا النقص له علاقة مباشرة مع قطر اللوح وعمق التأسيس. وامتدت إجهادات الهبوط إلى عمق يقارب أربع أضعاف قطر اللوح على خلاف ما يعتقد بأنها تصل إلى عمق يساوي قطر اللوح إلى ضعفه. وكذلك تبين أن فترة زيادة الأحمال ومدة الترطيب لها تأثير فعال على مقدار الهبوط. ولذلك يجب أخذها في الاعتبار أثناء تحميل ألواح الاختبارات والأساسات الحقلية.