Shallow Footing Bearing Capacity on Compacted Mixtures of Excavated Collapse Soil with Granule Soil laying on Egyptian Collapsible Soil

Hisham H. Abdelmohsen
Professor, Department of Civil Engineering
Alexandria University
Alexandria, Egypt

Naema.A. Ali
Lecturer, Department of Civil Engineering
Higher Institute of Engineering & Technology
King-Marriot, Alexandria, Egypt

Abstract—**In general, collapsible soils are located in aired and semi-arid regions around the world. At or near saturation, collapsible soils undergo reduction in strength, excessive and sudden settlement due to a rearrangement of their grains and removal of bonding (or cementing) material by water. In Borg El Arab, near Alexandria Egypt, soils exhibit high susceptibility for collapse when saturated. In this paper, partial replacement compacted mixtures of excavated collapse soil with medium sand or fine crushed stone are used to limit the risk against sudden settlement and improve the bearing capacity when exposed to inundation. Experimental program including dry and wet tests was developed to explore the effect of compacted partial replacement mixtures on reduction of footing settlement and improve of the wet strength of collapsible soil when inundation occurs. The results show that the behavior of a shallow footing rests on compacted mixtures of excavated collapse soil with fine crushed stone as partial replacement on treated collapsible soil by pre-wetting and compaction reduces the foundation settlement by about 50% and increases bearing capacity by about (75-80)%, and offered high stiffness of replacement near the footing load. Using mixtures of excavated collapse soil with medium sand was found practical, economical to reduces the foundation settlement by 40%, and increases bearing capacity by about (60-65)%. Also, the study clear that selection of the best mitigation of collapsible soils depends on estimation of extend and degree of wetting, corresponding collapse strain and collapse settlement.**

Keywords— Collapse; Bearing capacity; Settlement; Improved collapsability; Replacement

I. INTRODUCTION

The detrimental volume change for problematic collapsible soils is almost always triggered by increased soil water content, and increased soil water is expected in developed and urban regions. Due to change of natural moisture state that results in most of the negative impacts of urbanization on arid soil performance, collapsible or metastable soil structure developed. Collapsible soils are not confined to arid regions and have been encountered in most parts of the world. In addition to naturally deposited collapsible soils, engineered compacted fills may exhibit volume moisture sensitivity if compaction specifications and quality control are not appropriate. Compacted fills may also develop a collapsible or metastable structure at low density, especially if the confining pressure is sufficiently high. In general wetting induces volume changes, and leads to changes in strength and stiffness. The greatest problems with problematic collapsible soils arise when the existence and extent of the collapse potential are not recognized prior to foundation construction. Collapsible soils volume usually decreases with the increase of moisture content especially when much water reaches the soil and sometimes under practically unchanged total vertical stress.

Many studies reported that collapsible soils are those in which collapse occurs on saturation since the soil fabric cannot support the weight of the overburden and it show little or no stratification. The consequences resemble inundation induced collapse problem that is commonly observed in arid and semi-arid climatic zones in different countries. During inundation, as the percentage of water in the pore spaces increases, matric suction decreases and the bond of matrix suction diminishes. However, in previous studies, it is reported also, that the structural stability of these soils are related to the lateral and vertical removal of the fine soil particles by subsurface flow which often leading to settling, formation of potholes or piping chemical and hydrodynamic which referring to direct carrying away of fine particles by flowing water. In other words, their metastable texture collapses as the bonds between the grains break down when soil is wetted, in some cases in the order of meter. These have led to foundation failures. In order to stabilize collapsible soils, there are some methods as; moistening and compaction using some additives such as cement or lime, ponding and infiltration wells, (Kakoli, et al 2011 and Sun, et al 2013). Numerous case histories pertaining to the problems caused by collapsible soils have been reported in the literature, (Soliman, et al. 2010 and Zorlu, et al. 2009). It could be difficult, costly or sometimes even impossible to modify the design of railway tracks, highways or power supply lines in order to avoid the area where such a soil is found. On the other hand, construction on collapsible soil in its natural state without special precautions may cause dramatic and undesired results, (Ayadat,T. and Hanna, A. 2013).The main geotechnical problem associated with collapsible soils is the significant loss of shear strength and volume reduction occurring when they are subjected to additional water from rainfall, irrigation, broken water or sewer lines, moisture also, increase due to capillarity or ‘‘pumping’’ as a result of traffic loading, ground water rise, etc. Generally, collapsible soils are under partially saturated or dry conditions have negative pore pressure resulting in higher effective stress and greater shear strength.

In this study soil improvement by removed and replacement to increase soil strength and stiffness, permeability and/or reduce settlement. Replacement is the most simple in concept and reliable technique. Excavated collapse soil can be treated with percentage of coars granual soil coarser than 0.425 mm and finer than 4.75 mm and then be replaced in a controlled manner to be with more suitable properties for the proposed application to increase its strength and reduce its settlement.

In Egypt, recent extensions of urban communities towards the desert, where collapsible soils may exist thus in this study a series of laboratory experimental work was conducted to present the engineering techniques of Borg El Arab collapsible soils improvement by partial excavate and partial replacement by mixtures of excavated collapse soil with medium sand or fine crushed stone at different percentages using thickness equal to foundation width, (Abdel-Mohsen, H.H., and Ali, A.N., 2014, 2015) used to investigate their effect on the bearing capacity and its settlement. A series of dry ad wet tests were conducted to study the performance of mixtures of excavated collapse soil with medium sand or fine crushed stone at different percentages and their effect on the reduction of settlement at inundation. These tests also, were carried out to search, the best percentage of sand or fine crushed stone in mixtures to reduced unfavorable collapse settlement and increase bearing capacity.

II. Soil Characteristics

Samples have been collected from different locations located in Borg EL-Arab area near Alexandria city, north of Egypt to determine their geotechnical and physical properties. Basic laboratory tests were carried out on undisturbed soil samples representing the collapsible soil. Table 1 shows geotechnical properties based on results of a laboratory testing program on undisturbed soil samples recovered from sites. Void ratio, density, collapsibility potential and particle size distribution on the soil study using Egyptian code and (ASTM) standard procedures collapse soil samples.

TABLE I. INDEX PROPERTIES AND COLLAPSIBILITY POTENTIAL OF UNDISTURBED SOIL SAMPLES FROM BORG EL-ARAB REGION

Soil properties	**Sample 1**	**Sample 2**	**Sample 3**
Initial Water Content (%)	5.6	6.3	7.1
Natural Unit Weight (kN/m^3)	12.7	13.8	14.2
Percentage of Sand	30.2	35.1	40.3
Percentage of Silt	66.1	60.2	55.3
Percentage of Clay	3.7	4.7	4.4
Collapsibility Potential C_p (%)	11.2	10.7	9.2

III. Laboratory Model Work

Test equipment is shown in Figure 1. A soil bin used to contain the soil is a square tank 600mm × 600mm internal dimensions and 700 mm high. The four sides of the tank are transparent plastic (Perspex) plates with 12 mm thickness braced with steel angles to prevent lateral movements of tank sides during placing and compacting the soil and loading. The base of the bin is a square steel plate with 40 mm thickness.

The loading system consists of rigid steel frame supporting a steel lever with 1020 mm length connected to steel columns by a pivot, Figure 1. The vertical settlement of the loaded footing was measured by mechanical dial gauges of 0.01 mm accuracy which were fixed rigidly to dial gauge holders, (Abdel-Mohsen, H.H., and Ali, A.N., 2015).

An elevated water tank connected to a distribution device through a plastic tube was used to inundate the tested soil. Water was then placed in the tank and controlled to allow to seepage to the soil surface via flexible plastic pipes. It was noticed that there was no water head retained above the soil surface, figure 1(Ali, A.N., 2016).

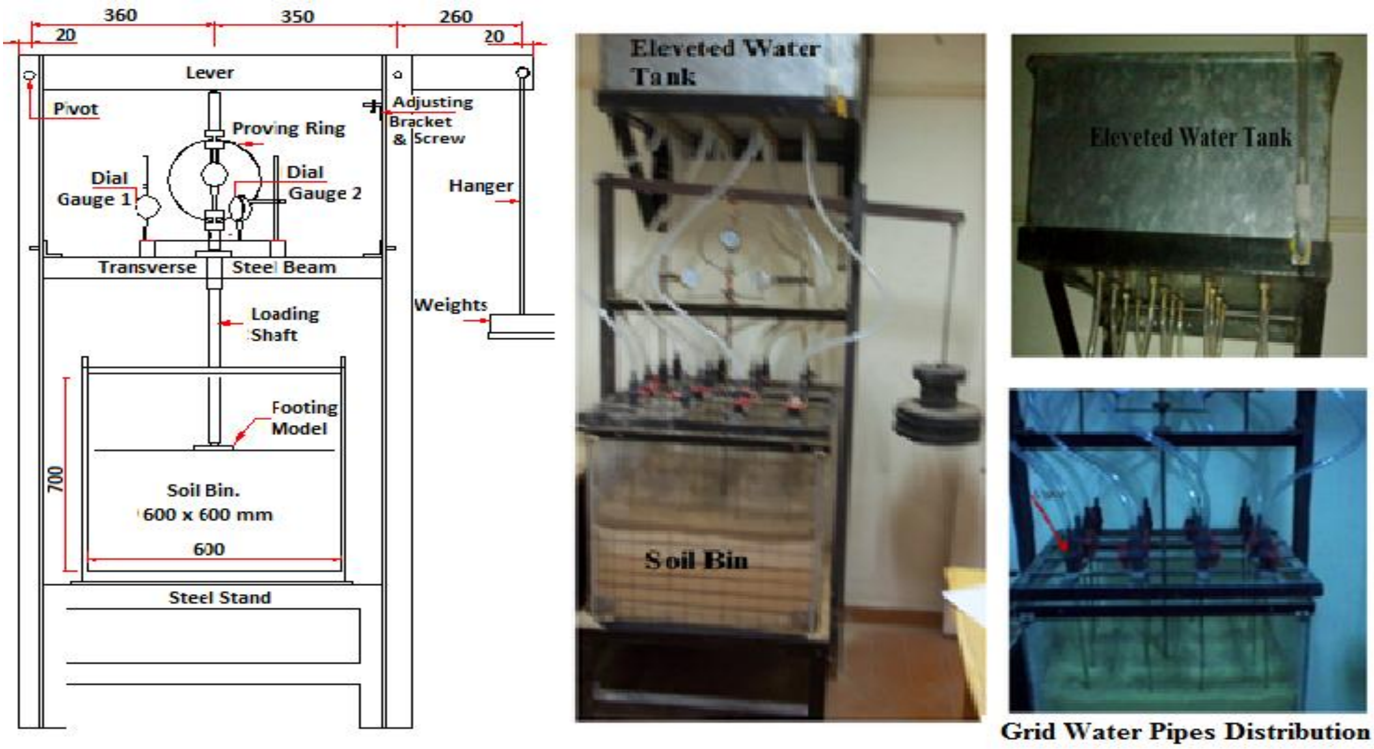

Fig. 1. Test Equipment.

The study is a part of detailed investigation program designed to investigate the performance of partially replacement of Borg EL-Arab collapsible soils and to search for a suitable method to mitigate their potential risk upon wetting and increase its bearing capacity. In the current laboratory study, a footing model was loaded up to failure on partially replacement mixtures of excavated collapsible soil with different percentage of sand or fine crushed stone laying on improved subgrade using pre-wetting and compaction to reduced collapse settlement and increase bearing capacity. Improved compacted samples were prepared from disturbed collapsible soil finer than 0.425mm, with maximum dry unit weights, varied between 16.2 kN/m3 and 16.8 kN/m3 at corresponding optimum water content varying between 15.6% and 16.2%. Compacted samples were prepared at dry unit weight of 95% of the maximum dry unit weight determined by Modified Proctor Test. In each test, the collapsible soil was placed in layers 50 mm thick, and the total thickness of improved subgrade equal to 400mm.

IV. Sample of Partially Replacement Mixtures Preparation

Partially replacement mixtures of excavated collapsible soil with medium sand or fine crushed stone with different percentages. The artificially soil samples were prepared from disturbed collapsible soil finer than 0.425mm mixed with sand coarser than 0.425mm, or fine crushed stone finer than 4.76mm. In percentages of (25, 50 and 75) % by weight. The soil is prepared outside the container and mixed thoroughly with 14.2 and 16.5% of water optimum moisture content. The mixture is poured into the container, carefully spread in two layers perpendicular directions each 40 mm and statically compacted before conducting the tests. The replacement sample was directly compacted into the bin and leveled with straight edge to reach a thickness about 80 mm (equal to footing width B). Figure 2 shows the gradation of the medium sand and fine crushed stone used in the top partially replacement mixtures used in the testing program.

Steel Square footing 80 mm length and 40 mm thickness was used and centered on top of the replacement layer. Vertical loads were applied incrementally via loading lever, for each and load, settlement was recorded with time till it ceased, after which next increment was applied. The problem of induced collapse due to wetting involves many uncertainties related not only to the soil variability, but also to the primary source of driving stress. To study the wetting / inundation effect, soil was inundated with 4000 cm3 of water which was allowed to seep on the soil surface via flexible plastic pipes, to simulate inundation in field due to rain fall or excessive irrigation and/or leakage from water and / or sewer lines. Soaking stage of sample was found to take one day wetting the soil from top to bottom.

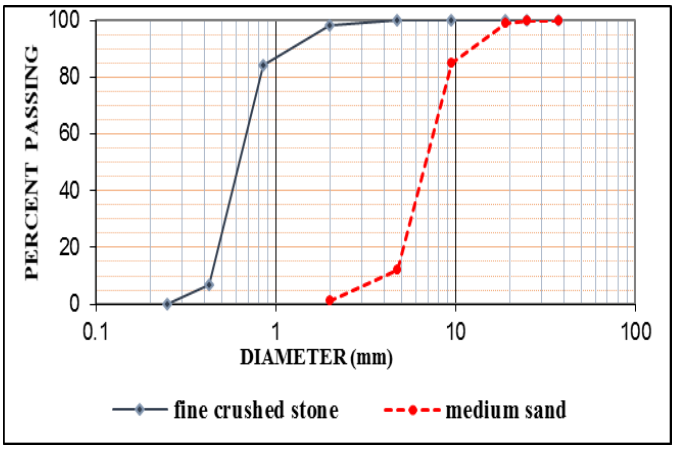

Fig. 2. The particles size gradation of the medium sand and fine crushed stone used in the top partially replacement mixtures.

Four groups of tests were designed to study the effect of different types of mixtures of replacement materials with thickness equal to footing width, B placed on top of improved compacted collapsible soil layer on settlement and bearing capacity of shallow footing in dry and wetting states. Test procedure was conducted by the load is applied concentric on soil through 80 * 80 mm footing model using non repetitive static plate load test method according to procedures of ASTM, (Ali, A.N., 2015). The designed testing program is summarized in Table 2.

TABLE II. TEST PROGRAM

Effect of mixtures types as partial replacement materials B thickness on compacted improved collapsible soil	
Group A Types of replacement layer (Dry)	The mixtures prepared from a mix of excavated collapsible soil finer than 0.425mm with sand coarser than 0.425mm in percentages of 25%, 50% and 75% by weight.
Group B Types of replacement layer (Dry)	The mixtures prepared from a mix of excavated collapsible soil finer than 0.425mm with fine crushed stone in percentages of 25%, 50% and 75% by weight.
Effect of inundation on treatment of soil	
Group C Inundated with 4000 cm^3 of water (rain fall)	Effect of inundations on replacement layer mixtures of sand coarser than 0.425mm in percentages of 25%, 50% and 75% by weight placed on compacted improved collapsible soil.
Group D Inundated with 4000 cm^3 of water (rain fall)	Effect of inundations on replacement layer mixtures of fine crushed stone in percentages of 25%, 50% and 75% by weight placed on compacted improved collapsible soil.

V. RESULTS AND DISCUSSION

Figure 3 shows the relationship between applied pressure and settlement of the collapsible soil improved by using partial replacement with mixtures prepared from a mix of excavated collapsible soil finer than 0.425mm with sand coarser than 0.425mm in percentages of 0%, 25%, 50% and 75% by weight with thicknesses equal to footing width, B under concentric footing load, group A. It can be noticed that the bearing capacity increases with partially replacing collapsible soil. The bearing capacity also increases with increasing the weight of medium sand in replacing mixtures. For the four cases under study the estimated ultimate bearing capacity values are 300, 355, 455 and 495 kN/m2 respectively for compacted collapsible soil, and mixture medium sand with collapse soil, Figure 3. The increased in estimated ultimate bearing capacity are 0.18, 0.52 and 0.65 respectively. The experimental work conducted for employed the mixture of removed collapsible soil with different percentages of fine crushed stone (25, 50, 75) %, as a partially replacement layer rest on improved collapsible soil by pre-wetting; test group B. Figure 4 shows that by adding the fine crushed stone to collapsible soil has significantly influenced the allowable applied pressure and reduced settlements that is at the same applied pressure the settlement is lower. The largest reduction in settlement was achieved with the increase of percentage of added medium sand / fine crushed stone. The settlement decreased with the increase of percentages of medium sand / fine crushed stone mixed with the collapse soil. From three cases under study, figure 4, the estimated ultimate bearing capacity values are 365, 500 and 540 kN/m2 respectively with the different percentage of fine crushed stone mixed. As shown in figure 4, an increase in the percentage of fine crushed stone mixed with collapsible soil from 0% to 75% reduced the footing settlement and increased the estimated ultimate bearing capacity, with increase of 0.22, 0.56 and 0.80 respectively. The largest increase in bearing capacity was achieved at the largest percentage of added medium sand / fine crushed stone which is 75%.

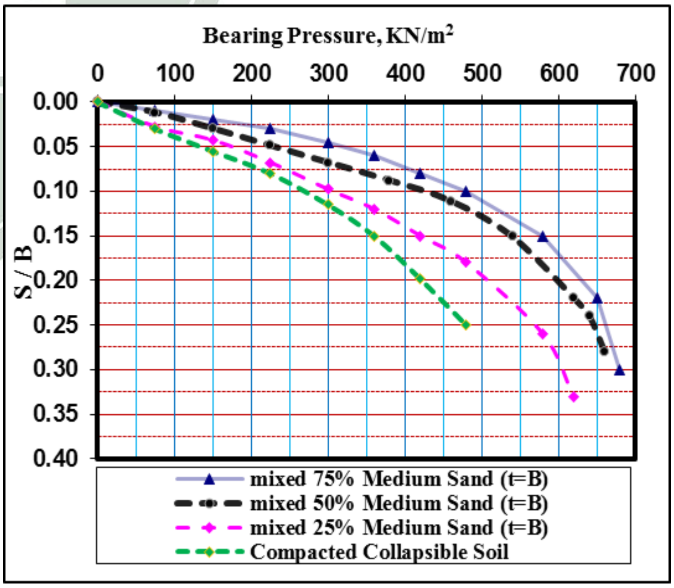

Fig. 3. Settlement versus applied vertical stress for replacement soil of mixture medium sand with collapse soil before flooding.

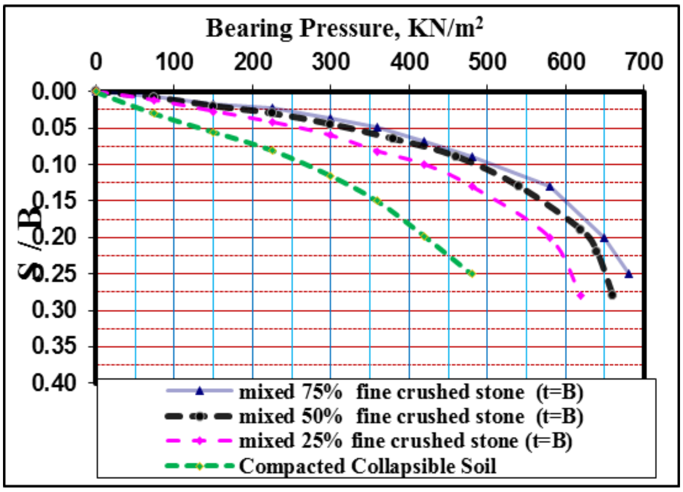

Fig. 4. Settlement versus applied vertical stress for replacement soil of mixture of fine crushed stone with collapse soil before flooding.

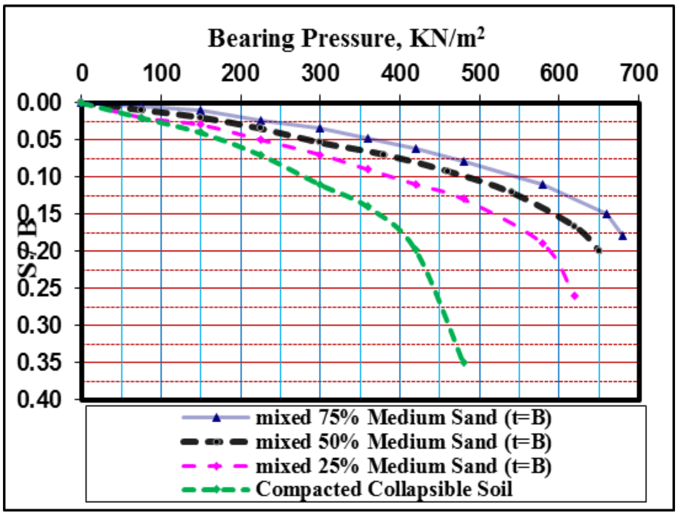

Fig. 5. Settlement versus applied vertical stress for replacement of mixture of medium sand with collapse soil after flooding.

Causes of immediate/ sudden foundation failure due to inundation of collapsible soil are identified based on pressure-settlement curves, (Kakoli, et al, 2011). The demonstration of pressure-settlement response of collapsible soil, in relation to the change in soil moisture, guides the practicing engineers to obtain a safe design load on foundation and its type. Figures 5 and 6 present relationships between applied pressure and settlement of the footing after inundation (test groups C and D). After soaking, the bin is left for 24 hours to ensure that all soil was completely soaked. The load was then applied to failure, which was indicated by the increase of settlement rate at a nearly constant loal. From figures, it is quite clear that replacement on top of improved collapsible soil presents better footing performance in terms of settlement against applied stress. Due to inundation, the predicted ultimate bearing capacity values decreases for the cited combinations. The results indicated that the wetting of compacted soil significantly increases the expected footing settlement under the effect of load, and this settlement decrease when the material under footing has low prim ability to avoid the extend of wetting to sub grad collapse soil.

Figure 5, indicates that the predicted ultimate bearing capacity values in cases (group C), using partial replacement with mixtures prepared from a mix of collapsible soil finer than 0.425mm with sand coarser than 0.425mm in percentages of 0%, 25%, 50% and 75% by weight with thicknesses equal to footing width, B under concentric footing load decreases by flooding to 310, 380 and 440 kN/m2 respectively with reduction of 0.127, 0.165 and 0.11 respectively. But Figure 6, indicates that the predicted ultimate bearing capacity values in anthor cases (group D), using partial replacement with mixtures of fine crushed stone under concentric footing load decreases by flooding to 325, 420 and 485 kN/m2 respectively with reduction of 0.11, 0.16 and 0.10 respectively. The low-collapsibility nature of compacted mixtures, may counteract the process of collapsibility through surface friction among soil particles. It is noticed that the increase of medium sand or fine crushed stone percent to collapsible soil reduced its collapse potential. As shown in figures, the influence of soil wetting on foundation settlement decreases abruptly when replacement material has low permeability. With such replacement, collapse due to wetting was greatly reduced or eliminated, irrespective of the compaction water content.

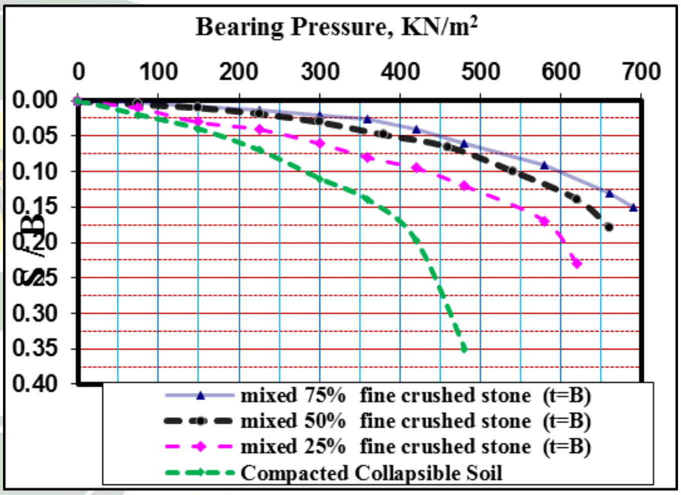

Fig. 6. Settlement versus applied vertical stress for replacement soil of mixture of fine crushed stone with collapse soil after flooding.

The problem of wetting inducing collapse involves many uncertainties related not only to the soil variability, but also to the driving stress. Collapsing increased continuously with applied stress. The results presented show the compressibility for the purpose of different improvements of collapsible soil using mixtures of medium sand or fine crushed stone with excavated collapse soil added more effect in reducing the collapse settlement of the footing and increased the bearing capacity. Wetting may reduce or soften bond or cementation between soil particles leading to their rearrangement near the water source causing differential soil collapse settlement.

The collapsible soils are "hydro-comp-active soils" because they compact after water is added. The amount of collapse depends on the thickness of the soil that becomes wetted. Thus these collapse soil require special consideration that is unique to regions where deep or thick layers of collapse soil are present. Figures also, indicate that compressibility of improved soil before inundation is low and increase gradually during inundation. Using fine crushed stone mixed with excavated collapse soil added more effect in reducing the collapse settlement of the footing and increased the bearing capacity.

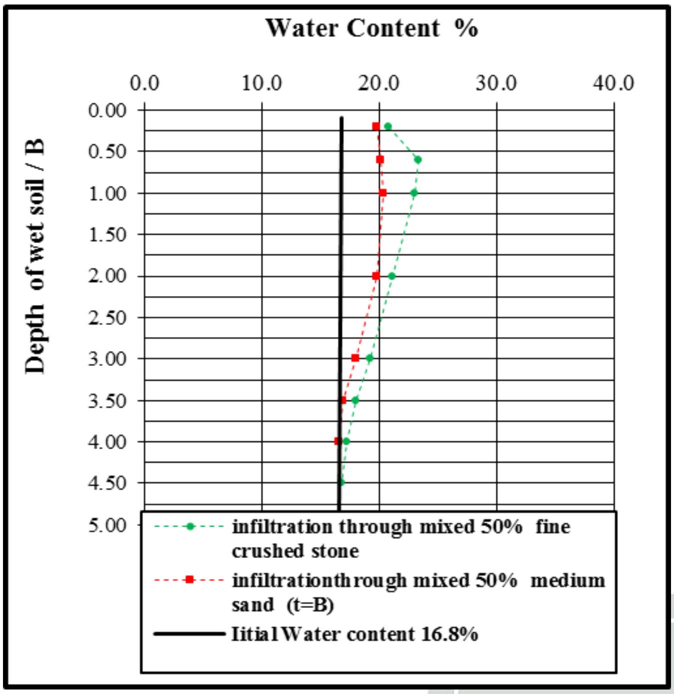

Fig. 7. Water content along improved soil depth.

Figure 7 shows the variation of water content before and after wetting with depth under footing which explained increase in the collapse settlement. For cases study, water penetration reached as far as 3.5 / 4.0 footing width B for tests group C and group D at the same time. One can observe the retarder moisture infiltration. The inundation in the two cases study use the same amount of water (4000 cm3) but one can observed that there are different in depth of saturation. Quick substantial settlement causes an increase in surface water infiltration. Higher conductivity of replacement layer allows great lateral movement of water which can result in wetting of the surface. From figure one can predict that site drainage is an important factor to be considered during design and construction. Thus subsurface drains, top and interceptor drains shall be provided as a requirement in engineering standards. The structural stability of collapsible soils is related to the lateral and vertical removal of the fine soil particles by subsurface flow which often leads to collapse settlement. The total amount of collapse potential depends on the environmental conditions, such as the extent and duration of wetting, and the pattern of moisture migration.

Conclusion

Based on the laboratory results presented in this paper, conducted investigation and analyses the following conclusions can be advanced:

- Egyptian collapsible soils conform to the proposal of (Kakoli and Hanna 2011). In order to obtain safe design load for shallow foundation on natural unsaturated moisture condition, pressure-Settlement, response at fully saturated stated is recommended.
- Removal of some thickness of collapsible soil and replacing it by compacted mixtures of excavated collapse soil with medium sand in this study reduces the foundation settlement by about 40% and increased bearing capacity by about 65%. Also, caused very uniformly footing settlement and minimums the large differential settlement under wet. Water penetration reached as far as 3.50 footing width B.
- Partial replacement by mixtures of excavated collapse soil with fine crushed stone can be used to minims the risk against sudden settlement and improve the bearing capacity by about 80%. It is economical methods of soil improvement because of the ease of construction and low cost.
- Adding medium sand to collapsible soil has significantly influenced the results concerning applied pressure and settlement relationships; at the same applied pressure the settlement is significantly lower. The largest reduction was achieved at the largest percentage of added medium sand / fine crushed stone. Also, the settlement decreased with the increase of the Sand percentages mixed with the collapse soil.
- The severity of the collapse depends on the extent of wetting, depth of the deposit and load from the overburden and structure.
- Satutation or flooding of collapse soil and compaction or preloading before construction is useful in stabilized collapsible soils, and it is useful to cause collapse of the soil deposit prior to construction of a specific structure.
- Results proved that improvement of collapsible soils is possible to mitigate their risk potentials against sudden settlement when exposed to wetting; helps retard water infiltration to the underlying collapsible soil and provide economic remediation for design and construction.

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