The Assessment of the Collapse Potential of Fills during Inundation using Plate Load Tests

Samir Ibrahim Shalaby

Associate Professor of Soil Mechanics &Foundation Engineering, Faculty of Petroleum & Mining Engineering, Suez University, Suez, Egypt.
shalabysamir@ymail.com

Abstract: Fill materials which have been inadequately compacted or placed excessively dry usually undergo a reduction in volume when their moisture content is increased. This phenomenon can occur without any increase in applied stress and is commonly termed collapse compression. The increase in moisture content can be caused either by downward infiltration of surface water or by a rising ground water level, and the associated ground movements can have a serious effect on structures which have previously been built on the fill. The purpose of the present study was to highlight the different types of soil that could exhibit collapsing and to propose an approach for more accurate and comprehensive evaluation of this phenomenon. In this paper, the influence of replaced compacted soil on collapse strains is studied using field plate load tests, one build on natural soil and other on replaced compacted soil, are used in the analysis .Results of load tests showed a sensible influence of compaction in reducing collapse settlement and suggest that this method of soil improvement can be useful to get a better performance of shallow foundations on collapsible soils. The demonstration of pressure. Settlement response of collapsible soil, in relation to the change in soil moisture, will guide the practicing engineers to obtain a safe design load on foundation and the type of foundation.

[Samir I.S. **The Assessment of the Collapse Potential of Fills during Inundation using Plate Load Tests**. *Life Sci J* 2014;11(8):1001-1006] (ISSN:1097-8135). http://www.lifesciencesite.com. 145

Keywords: Collapsible soil, Collapse compression, Poorly compacted fills, Plate load test, Soil inundation

1. Introduction

Man-made earth structures such as soil replacement beneath footings, embankments, road fills, and earth dams often exhibit collapse when compacted dry of optimum. Compacted soils that exhibit collapse typically have an open type of structure with many void spaces, which give rise to a metastable structure. The bulky grains are held together in a honey comb type of fabric by some type of bonding material or force at the points of contact.

Most poorly compacted fills undergo a reduction in volume when inundated or submerged for the first time and, if this occurs subsequent to construction on the fill, buildings can suffer serious damage. The phenomenon was described as collapse settlement because it was considered to be associated with a collapse of the soil structure. It has been termed “hydrocompression”, “hydrocompaction”, “hydro consolidation” and “saturation shrinkage”. However, collapse compression remains the most widely adopted expression to describe all those situations in which a partially saturated fill undergoes a reduction in volume that is attributable to an increase in moisture content without their being any increase in applied stress, irrespective of the type of mechanism which caused the volume change and the rate at which the volume change occurred. According to (Day, 2001) collapse behavior could happen in fill material as a result of decrease in negative pore water pressure (capillary tension), when the fill becomes wet. Common causes of the wetting can be either natural, such as rainfall and fluctuation in ground water table, or man-made, such as excessive irrigation and leakage from water and sewer lines. Collapse may be triggered by water alone or by wetting and loads acting together. The failure mechanism in “hydrocollapse” occur since the particles are arranged in honeycombed structure, held together by small amount of cementing agent like clay or $CaCo_3$; introducing the water leads to dissolve or soften the bonds between particles, and hence undergoes denser packing under loading . Full-scale field test on collapsible soil with practical foundation size and load intensity, could provide a reliable information on load-settlement response and collapse potential (Adams et al., 1997 and Rollins et al., 1994). The causes of immediate foundation problem and of sudden collapse during inundation of collapsible soil has not yet been addressed. As a result, foundation design in collapsible soil is still based on conventional soil mechanisms, which gives unsafe design values during inundation and may result total failure of the structure. Several researches have reported that soils exhibit collapse if the dry density of the spectrum is less than 16 KN/m³. (Jennings and knight, 1975) reported that the above conclusion is a misconception and should be dispelled. It was also suggested that the collapse behavior is also dependent on other variables such as clay content and clay type. (Holtz and Hilf, 1961) described the mechanism of collapse accompanying wetting as the result of capillary pressures approaching zero and the degree of saturation increasing to 100%. The mechanism for cohesion less soils was explained on the basis of the " reduction of shear factor" (i.e. shear strength – shear stress) against collapse. It was postulated that during inundation, the Mohr circle translates horizontally by an amount equal to the negative pore – water pressure existing in the soil before inundation. Due to this transition, the effective stress path intersects the Mohr-Coulomb failure envelope, resulting in a general shear failure and associated settlement. (Burland, 1965) explained the collapse mechanism in terms of the stability at the interparticle contact points. Due to inundation, the negative pore-water pressure at the contact points decreases, giving rise to grain slippage and distortion. (Larinov, 1965, Dudley, 1970 and Barden et al., 1973) described the collapse phenomena in terms of the bonding materials present at the contact points. It was suggested that in the case of silt bond, the temporary strength was mainly due to capillary tension. In this case, the temporary strength would be lost during inundation, resulting in a decrease in volume. (Rollins and Rogers, 1994) evaluated treatment methods for collapsible soils using 85 kPa load tests on 1.5 m square footings. To assess excavation and replacement, they removed a 0.75 m layer of collapsible soil in a test cell and replaced with a well-graded, sandy gravel compacted to 95% of modified proctor. Under load, the test cell was inundated with 9000 liter of water. The footing settled less than 25 mm. By comparison, the application of 9000 liter resulted in 240 mm of settlement in the no-treatment case and 100 mm of settlement in the pre-wetting with water case. In addition to reducing total settlement, the removal and replacement with compacted fill caused the footing to settle very uniformly in comparison with footings in the other treatment methods that underwent large differential settlement. The (Rollins and Rogers, 1994) study suggests that removal and replacement with compacted fills is a more effective approach than pre-wetting to mitigate foundation settlement. (Houston et al., 1995) proposed an in-site collapse test using soil boxes on a concrete pad. The soil boxes filled on top of the footing provide the desired overburden pressure, and once the pressure is reached, water is added to the soil and collapse settlement was measured. (Feda, 1988) proposed an equation for assessment of soil collapsibility potential as follow:

$$i_c = \frac{\frac{m}{Sr} - PL}{P.I}\ \%$$

wherein: m and Sr are the natural water content and soil saturation ratio respectively . The PL and PI are plastic limit and plasticity index of soil. Based on the above criterion, if the collapsibility index i.e. is less than 1, it means that soil is susceptible to collapse. Based on (Denisov, 1964) proposed criterion, if $\frac{e}{e_{L.L}} > 1$ then the soil is collapse susceptibly where: e and e_{LL} are the soil void ratio in natural and liquid limit water content respectively. Proposed criterion of (Clevenger, 1985) for collapsibility evaluation is based on the soil dry density. He declares if the soil dry density is lesser than 12.8 KN/m^3 then the soil will collapse after minor water content changes. On the other hand, if the soil density is more than 14.4 KN/m^3 then the lesser collapse settlement could be expected. For medium range of soil density, the medium collapse settlement could be evaluated. According to (Lin and Wang, 1988) criterion, the collapsibility index of soil in self weight condition is defined as follow: $i_{cz} = \frac{h_z - h_{zs}}{h_1}$

Where: h_z and h_{zs} are the soil sample thickness in odometer test regarding overburden pressure in natural and saturation conditions respectively and h_1 is initial soil sample thickness.

2. Identification of collapsible soil

The dry density and liquid limit graph (Gibbs and Bara, 1962) are recommended as quick identification methods for collapsible soils. Soil of sufficiently low natural density, which has sufficient void space to hold its liquid limit moisture at saturation, is susceptible to collapse upon wetting, figure 1.

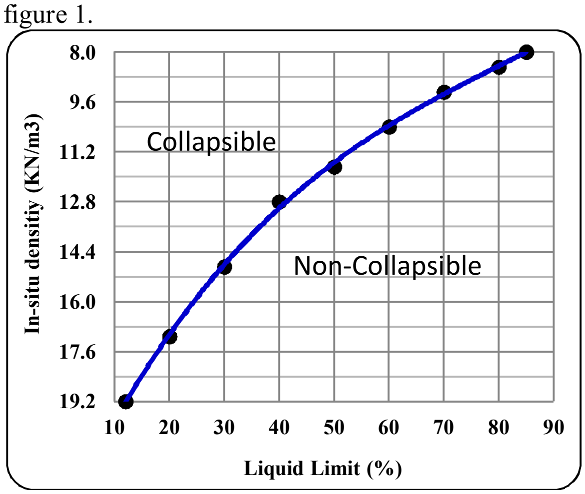

Figure 1. Identification of collapsible plastic soils

3. Estimation of collapse settlement

The quantification of volume change occurs when soil undergoes collapse is obtained from oedometer test, one or more of the following oedometer tests should be conducted on undisturbed sample.

3.1 Single oedometer collapse test

The undisturbed soil specimen at natural moisture content loaded in the conventional oedometer to a stress level ranging between 200 and 400 KPa and then inundation by distilled water is applied to induce collapse, after 24 hours, the oedometer test is carried out by increasing load to its maximum loading. (Abelev, 1948) defined the collapse potential (Ie) as: $Ie=\frac{\Delta e_c}{1+e_1}$ where:

Δe_c : Change in void ratio resulting from saturation.

e_1 : Void ratio just before saturation.

While, (Jennings and Knight, 1975), recommended the using of stress level of 200 KPa, and calculate the collapse potential according to the following equation:

$Ie = \frac{\Delta e_c}{1+e_0}$ where:

Δe_c : Change in void ratio resulting from saturation.

e_0 : Natural void ratio.

The stress level of 200 KPa was adapted by (ASTM D 5333-96, 2000) to classify the severity of the collapse problem (Day, 2001).Since the idea behind this test is to predict the amount of deformation that a foundation may experienced upon subsurface wetting; a loading to the anticipated field loading conditions is recommended. A typical result obtained from this test is shown in Figure 2.

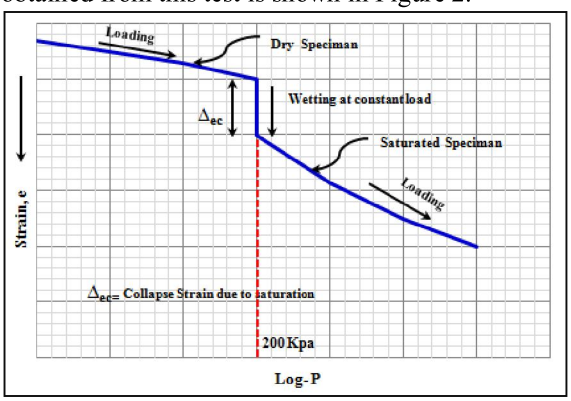

Figure 2. Schematic diagram of single oedometer collapse test.

3.2 Double oedometer collapse test

(Jennings and Knight, 1975) proposed a method for calculating collapse settlement of as soil for design purposes using the results of a double oedometer. Two identical samples are placed in oedometers, one tested at in-site natural moisture content and the other is fully saturated before the test begins, and then subjected to identical loading. Two stresses versus strain curves are generated. The difference between the compression curves is the amount of deformation that would occur at any stress level at which the soil get saturated. Results from double oedometer test are shown in Figure 3.

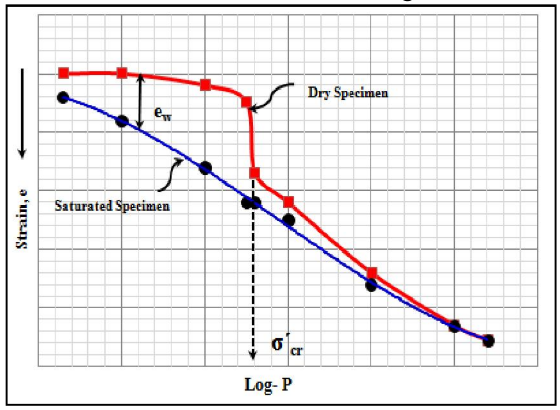

Figure 3. Schematic diagram of double oedometer test.

The collapse potential can be determined at any required stress level. Critical stress (σ'_{cr}) represents the stress level at which the dry sample loose structure breaks down and beyond it the two curves converge. This behavior could be explained also by that at a high stress level, the limiting void ratio for saturated sample is approached for particles packing (Lutenegger and Saber, 1988).

3.3 Field plate load test

Plate load tests are the most common field tests for the evaluation of allowable pressures under foundations. These tests are normally conducted near the ground surface. In this test, the water is introduced to the loaded soil and the resultant displacement due to wetting is recorded. The results of bearing plate tests are shown in the form of plate load-settlement curve (Figure 4) where the proportionality limit (P_{pr}) on this curve is accepted as the safe bearing capacity for foundations. The advantages of plate load test include the minimization of soil sample disturbance, larger volume of soil being tested, and the test followed the actual field situation.

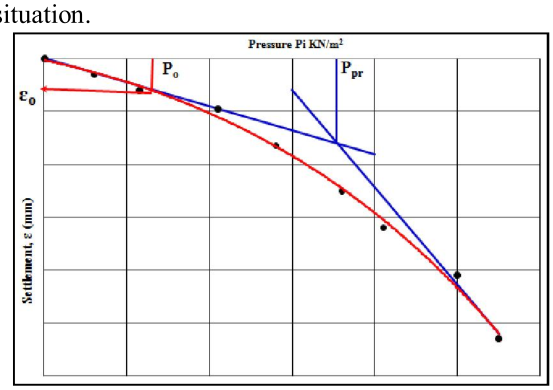

Figure 4. Diagram illustrating load intensity-bearing plate settlement curve.

4.Experimental work

4.1 Materials

The collapsible soil used in this experimental program were collected from a trial test pits in a newly developing district in the northern extension of Sixth of October City – Giza governorate, where the presence of collapsible soil layers was detected near the ground surface by site investigations. Laboratory tests were performed on good quality samples trimmed from a block that was manually extracted at a depth of 2.0 m from ground surface. The tested engineering properties are listed in table 1. According to the criteria given by (Clemence and Finbarr,1981), the soil has a collapse potential as reflected by low density, and low moisture content.

The sand used as a compacted replacement layer above collapsible soil, is silica sand borrowed from Sixth of October quarries. Engineering properties of the sand are also listed in table 1.

Table 1. Engineering properties of soils.

i) Collapsing soil	
Specific gravity	2.55
Liquid limit, WL (%)	32
Plasticity Index,IP (%)	17
Natural water content,w (%)	8.0 average
Dry density (KN/m^3)	13.6
Natural degree of saturation, Sr	0.233
Initial void ratio,e_0	0.875
Void ratio after saturation	0.730
Clay fraction (% < 2 μm)	14
Silt fraction (%)	81
Sand fraction (%)	5
Carbonate cement (%)	6
Soil type (USCS)	ML
ii) Replacement compacted sand	
% passing N°4 US sieve	98.5
% passing N°200 US sieve	1.5
$D_{10\%}$ (mm)	0.33
Uniformly coefficient (Cu)	5.45
Curvature coefficient (Cc)	0.95
Max. dry density (KN/m^3)	18.6
Min. dry density (KN/m^3)	14.7
Compacted dry density (KN/m^3)	17.67
Permeability coefficient (cm/sec)	9.5*10^{-2}

The replacement compacted sand is considered highly permeable relative to the collapse soil to assume uniform and continuous wetting during soaking, it is also compacted to nearly 95% of its maximum dry density to ensure it does not contribute to plate settlement and can be assumed a rigid layer during strain calculation.

4.2 Soil collapsibility evaluation

Based on preliminary extracted parameters from site investigation in conjunction with laboratory tests, the basis engineering judgments concerning soil collapsibility have been summarized in table 2. The collapse characteristics are evaluated by oedometer and plate load tests.

Table 2. The basic engineering judgment for job site collapsibility

Proposed criterion	Collapsibility coefficient formula	Collapsibility coefficient range	Collapse intendancy
Abelev (1948)	$S_s=\frac{e_0-e_1}{1+e_0} = \frac{0.875-0.73}{1+0.875}*100=$ 7.73 %	7.73>2	High collapsibility
Feda (1988)	L_{cr}= (m/sr-PL) / P.I = ($\frac{8}{0.233}$-15) / 16 = 1.137	1.137>1	High collapsibility
Denisov (1964)	$\frac{e}{e_{L.L}} = \frac{0.875}{0.73} = 1.2$	1.2>1	Medium collapsibility
Clevenger (1985)	γ_d = 13.8 KN/m^3	1.28<1.36<1.44	High collapsibility
Lin and Wang (1988)	$i_{cz} = \frac{h_z-h_{zs}}{h_1} = \frac{1.8-1.66}{1.9}*100 =$ 7.36 %	5<7.36<10	High collapsibility

4.3 Laboratory evaluation of soil collapse potential

The single oedometer test procedure employ one oedometer test loaded initially dry up to a prescribed pressure, 200 KPa, then soaked, and the collapse magnitudes were observed. Loads were applied in cumulative increments prescribed as following, 15, 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. Collapse potential (CP) is defined as the collapse strain due to wetting at applied pressure of 200 KPa (Jennings and Knight, 1975).Figure 5 depicts the results of single oedometer tests performed on undisturbed soil blocks extracted from the sides of open pits at the studied site. The study of these results indicates that the amount of collapse varies inversely, in a linear fashion, with initial water content for a particular initial dry density. The linear relationships between the amount of collapse and the initial properties are in agreement with the observations made by (Popescu, 1986) and Foss, 1973) . Figure 5. also indicates that CP ranges between 6.6 and 9.4%. The variation in CP is mainly due to variations in the fine content and density.

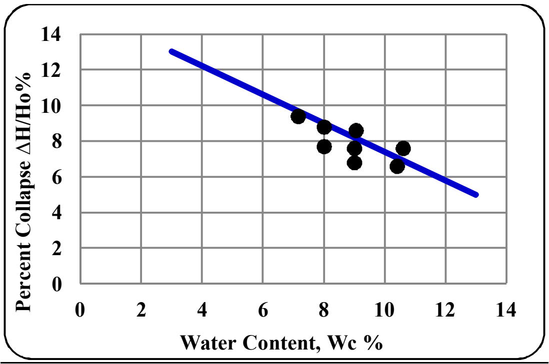

Figure 5. Effect of the initial water content, dry density on the amount of collapse

4.4 Field load tests

Field tests were performed at Sixth of October city (Giza governorate) in an area where thick layers (beyond 10 m in depth) of collapsible soils are found. Four plate load tests (plate with 80cm in diameter) at a depth of 2.0 m were performed considering the following soil conditions: natural soil loaded to 75 KPa and then flooded; compacted soil (1 m below plate base) ; compacted sand soil loaded to 75 KPa and then flooded .In tests where soil was flooded holes of diameter 75 mm at a spacing of 0.75 m extending 4.0 m below foundation were drawn and filled with pebbles to facilitate soil wetting. (Alawaji, 1997) stated that collapse extends to a depth 4 times the plate diameter, which is for beyond 1-2 plate diameter zone commonly used in practice for soaking and analysis of plate load tests. Compacted sandy soil was built over the collapsible soils in four layers, 250 mm thick. Vibratory plate was used to reach the specific relative density of 95%. The load was applied through a system compressing a hydraulic jack, and measured using a proving ring with capacity of 150 KN; four dial gauges with divisions of 0.01 mm and 50 mm travel were used for settlement measurement. The load was applied in cumulative increments such that the net pressure follows, in general, the following path: 0.0, 13, 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 creased .When the rate of deformation reaches less than or equal to 0.001 mm /min .During the soaking the pressure was kept constant for at least 12 hr and until collapse settlement has ceased. At the end of each soaked test, samples were obtained for moisture content and dry density determination. Measurement points are uniformly distributed in the bottom, middle, and the top of soil, which help the assessment of the extent of wetting front. Figures 6 and 7 show plate load –settlement curves obtained for natural and compacted soil, respectively. The ultimate bearing capacity (q_{ult}) was determined by the slope tangent method, (Ismael, 1996), the bearing capacity is determined at the intersection of the tangents to the initial linear portion and the sleeper linear portion following failure.

5. Results and Analysis

The load intensity and settlement observation of the plate load tests have been analyzed to study the effect of compacted sand replacement of the top collapsible soil on the settlement-strength of the collapsible bottom layer. Figures 6 and 7 show plate load-settlement curves obtained for natural collapsible soil and natural soil treated by top compacted sand, respectively. As it can be seen, due to use of top compacted sand layer ultimate bearing capacity enhanced by 254% (it increases from 82.5 to 270 KN) while collapse settlement was reduced by 45.5% (it decreased from 22 to 10 mm).

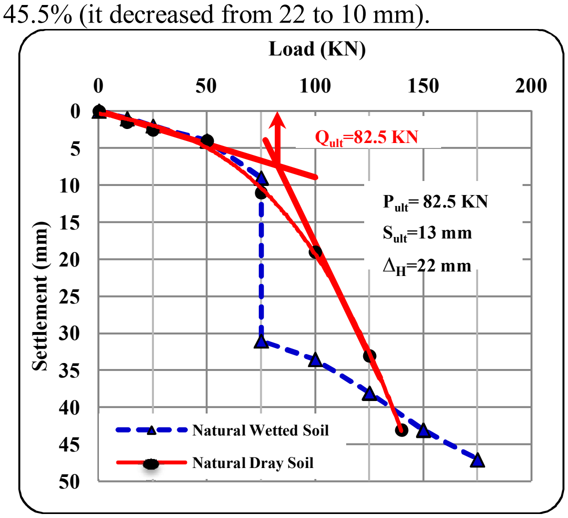

Figure 6. Load-settlement response for plate tests on natural and wetted soil.

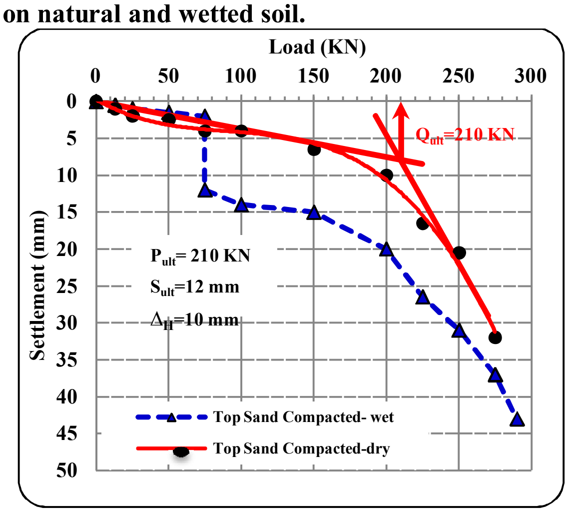

Figure 7. Load-settlement response for plate tests on top sand compacted and compacted wetted.

The meditation of the results shown in figures 6 and 7 showed that the rate of settlement decreases with the presence of top compacted sand layer beneath footing. It is also observed that soil after soaking exhibits large settlement than dry soils and can sustain large loads; this is evident for both tests on natural soil or on treated soil by top compacted sand replacement.

6. Conclusions

The following conclusions can be drawn from the results presented in this paper:

- Buildings founded in soils subjected to collapse have shown inadequate behavior specially when shallow foundations are used.
- Improving soil behavior by using top compacted sand replacement allows a better performance of shallow foundations.
- Plate load tests have shown that use of top compacted sand layer can reduce collapse settlement of about 45% and increase ultimate load to 254%.
- Inundation of soil specimen in the consolidation test for the purpose of measuring the soil collapsibility could under estimate the collapse potential.

Notation

The following symbols are used in paper

i_c : Collapsibility index; % (Feda, 1989)
m : Natural water content ; %
S_r: Soil saturation ration
PL: Plastic limit; %
PI: Plasticity index; %
e : Natural void ratio
e_u: Liquid limit void ratio
i_{cz}: Collapsibility index (Lin et al., 1988)
h_z: Soil thickness in natural conditions
h_{zs}: Soil thickness in saturation conditions
h_1 : Initial soil sample thickness
Δe_c: Change in void ratio resulting from saturation
e_1 : Void ratio just before saturation
e_0 : Natural void ratio
I_e : Collapse potential(Jennings et al., 1975)

References

1. Abelev, Y.M., 1948, "The essentials of designing and building on microporous soils", Stroitel naya Promyshelmast, No.10.
2. Adams, M. and Collin, J., "Large model spread footing load test on geosynthetic reinforced soil foundation", J.of Geotch . Engr., ASCE, 123, No.1 (1997), 66-72.
3. Alawaji, H, "Model Plate load tests on collapsible soil overlying sand pads", Proc. Int. Conf. on Found. Failure ICFF, Singapore, (1997), 385-392.
4. Barden, L., McGrown, A., and Collins, K (1973), "The collapse mechanics in partly saturated soil", Engineering Geology (Amsterdam), 7: 49-60.
5. Burland, J.B,1965, "Some aspects of the mechanical behavior of partly saturated soil", In moisture equilibria and moisture changes in soil beneath covered areas. Butterworths, Sydney, Australia, pp.270-278.
6. Clemence, S.P. and Finbarr, A.Q., “Design consideration for collapsible soils”, J.Geotech. Eng. Div., ASCE, 107, No.3 (1981), 305-317.
7. Clevenger, W.A., 1985, "Experiences with loess as a foundation material", Transactions American Society for Civil Engineers, 123, pp: 51-80.
8. Day, R.W., 2001, "Soil Testing Manual",1st Edition, McGraw-Hill, New York, ISBN: 0-07-136363-7.
9. Dudley, J.H.,1970, "Review of collapsing soils", ASCE Journal of the soil Mechanics and Foundation Division, 96(SM3): 925-947.
10. Denisov, N.Y., 1964."About the nature of high sensitivity of quick clays", Osenov.Fun dam, Mekk.Grunt, 5, pp: 5-8.
11. Fedo, J., 1988,"Collapse of loess upon wetting", Engineering Geology, 25, pp: 263-269.
12. Foss, I..1973," Red soil from Kenya as a foundation material", Proceedings,8th International Conference on Soil Mechanics and Foundation Engineering, Moscow, USSR, vol.2,3,pp:73-80.
13. Gibbs,H.J. and Bara, J.P,1962,”Predicting surface subsidence from basic soil tests”. Soil Engineering Report No. EM658.US Department of the Interior Bureau of Reclamation Division of engineering, Denver, Color., June 25,1962.
14. 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.
15. Holtz, W.G., and Hilf, J.W.1961, "Settlement of soil foundations due to saturation", Proceeding, 5th International Conference on Soil Mechanics and Foundation Engineering, Paris, vol.1, pp: 673-679.
16. 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.
17. Jennings, J.E and K,Knight,1975. "A guide to construction on or with materials exhibiting additional settlement due to collapse of grain structure", 6th Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Durban, September 1975, South Africa, pp: 99-105.
18. Larinov, A.K., 1965, "Structural characteristics of loess soils for evaluating their constructural properties", Proceedings, 6th International Conference on Soil Mechanics and Foundation Engineering, Rio de Janeiro, pp: 619-622.
19. Lin, Z.G., and Wang, S.J., 1988, " Collapsibility and deformation characteristics of deep-seated loess in China", Engineering Geology, 25 pp: 271-282.
20. Lutenegger, A.J. and Saber, R.T.," Determination of collapse potential of soils", Geotechnical Testing Journal (1988) 11(3):173-178.
21. Popescu, M.E.,1986, "A comparison between the behavior of swelling and collapsing soils", Engineering Geology (Amsterdam), 23:145-163.
22. Rollins, K.M., and Rogers, G.W., 1994, ”Mitigation measures for small structures on collapsible alluvial soils”, J. Geotech. Engrg., 120(9), 153-155.

7/21/2014