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Controlling Soil Collapsibility Due to Water Intrusion by Rigid Foundation System with Reinforced Cushion

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Abstract

Since collapsible soils are been mostly transported by wind and deposited in arid or semi-arid regions, they founded in a state of unsaturated condition. In addition, engineering filling when placed in a certain none want density, undesired settlement will be predictable either due to wetting or due to loading on these soil deposits. Collapsibility study is important for the foundation design and construction on these soils. The most foundation systems used on these soils are isolated and strip footing connected with concrete tie beams. Therefore studying rigid foundation system resting on partially saturated collapsible soil/deposits is very important. The present work investigated using rigid strip footing resting in collapsible soils to study the effect of stress interference due to progressive wetting depth from leakage of surface water on collapsibility settlement. The study has been investigated the influence of different behavior of strip footing and inverted T-section strip footing rigidity system resting on unsaturated soil by numerical analysis using the finite element program PLAXIS 2D. The partially saturated collapsible soil is stimulated using the Mohr-Coulomb soil model. The significance parameters are considered two types of footing systems, collapsible soil thickness, use of sand cushion with geo-grid reinforcement at the bottom third of its thickness, and different clear spacing between source of surface water and strip footings on the stress-settlement relationship. The results of this study confirmed that the most important soil parameters in this problem are the use of reinforced sand cushion, decrease applied stress as well as rigid inverted T-section strip footing are more suitable for controlling Soil collapsibility, while the settlement is found to decrease. To avoid many observation of spread footing disaster that founded and rest on collapse soil. In addition, the results can be guide for design engineers, how to choose foundation type and the effect of spacing water resource.

Keywords

Collapsible Deposits, Hydro-Collapsibility, Rigid Foundation, PLAXIS2-D

1. Introduction

Many of the engineering problems confronted due to collapse soils by water wetting, soaking. Related to increase in moisture content, these soils go through radical rearrangement of their particles, causing rapid collapse by higher reduction in its volume sudden changes, causing differential settlement of foundation. The foundation or infrastructure has been disaster or failure when directly founded on these soils due increase in their moisture content. Study collapsibility positional is important for the design and construction on these soils. The most foundation systems used on engineering compacted deposits and collapsible soils are spread footing connected with concrete tie beams. Deformation behavior of unsaturated soil under field conditions depends mainly on soil initial conditions, wetting and history of loading. The soil can practice a complex volume vary reaction related to the applied external load intensity. Thus, compacted soils wetted under load can collapse due to their conditions and the magnitude of vertical stress. These soils are often known as collapsible or met-stable, and the procedure of their collapsing is often called collapse due to inundation or hydro-collapse. These soils also, compress when wetted under no variation in applied stresses. Volume decreases due to excess of water under the same stresses in partly saturated natural soil deposits have been termed collapse, [1] [2] [3] [4] [5]. With recent advances in computer and computer technology, many researchers have applied numerical modeling to analyze the influence of collapsible soil settlement on foundations system, using the numerical approaches, particularly finite element (FE) analysis, an elasto-plastic constitutive model for unsaturated soil has been developed in reference, [6].

Collapse development is practical in semi saturated soil layers, as compacted soil deposits as well as dry natural soils deposits. The collapse settlement tends to transform meta-stable soil to stable and non-collapsible soil after wetting and saturation. In Egypt, urban has been increased broadly extended to many desert areas where many new cities are being constructed. The collapsible soil is formatted in these areas and there is much danger would be expected if soil is exposed to foundation loads and wetting from leakage of surface water to foundation. Many cases of distress and cracks in new building in different sites founded on compacted deposits have been observed and recorded due to leakage of excess surface water from irrigated landscapes area or bad drained of surface water in winter season.

Also, many researchers have been reported that for an accurate collapse settlement prediction it is required to verify the degree of saturation and wetting extent in the site. The main step to predict collapse settlement, is evalulated the wetting zone depth in a collapsible soil due to the infiltration of surface water, or rainfall especially in silty sandy and fine sand arid soils, [7] [8].

After saturated of collapsible soils under foundation, significant settlements have induced in foundation of structures, which can lead to damage of structure. Much observation recorded for spread footing and much non-rigid foundation system that founded and rest on collapse soil, disasters. Collapsible soils optional, wetting sensitive with increase in water content, which is chief, trigger system for reduction in these soils volume [9] [10].

Many researchers investigated and reported that collapse soil under constant applied load show decrease in its volume due to wetting, irrigation activities, induced collapse strain. The settlement that related to collapse strain in these cases studied which cause damage and structural distress consequent. Many studies were done to calculates the collapse strain and explain the observed collapse which has been occurred, [11] [12] [13] [14]. Also, in Egypt there are many cases of damaged recorded and observed in new and old building constructed on isolated footing rest on compacted filling and collapse soil [15].

Thus, the present research studies many attempts to predict the main parameters, which resist and control the collapse strain induced by wetting through near water source. These parameters effect in choose rigidity of foundation system rested on compacted filling and collapse soil related to water leakage source spacing, collapsible soil thickness and when using sand cushion with or without geo-grid reinforcement under foundation system. Two rigid footing types are analysis in this study, Inverted T-section Strip Footing, (ITSF), and rigid Strip Footing, (SF), as rigid foundation system to predicted behavior of foundation system under collapse soil settlement of and its improved behaviour.

2. Soil Characteristics and Simulation

In this study, the *in situ* soil sample, particle size analyses shown in **Figure 1**. The single odometer test (ASTM D5333-03), [16], conducted to study the soil collapse potential. The results of conducted Odometer collapse test at different applied stress on undisturbed samples illustrate in **Figure 2**. Laboratory characterization of collapse soil illustrates in **Figures 1-3**. The results are agree with that increasing dry density and liquid limit of collapsible soil reduced collapse potential and many laboratory tests should be conducted to identify attribute of collapse potential. In addition, *in situ* many practical plate load tests have conducted in field to evaluated the soil collapsibility and all soil natural and post inundation properties. As reported in many researches, [17] [18] [19], *in situ* Plate Load Test (PLT) is one of the most accepted and dependable testing for stress-settlement relation and bearing capacity estimating for shallow foundations of unsaturated soil. Thus *in situ* PLTs are typically and also, actual load foundation tests in dry and wet case are conducted on compacted unsaturated soils condition. The distribution of degree of saturation respect to depth recorded after end of the conducted tests. Then all obtained results of *in situ* tests

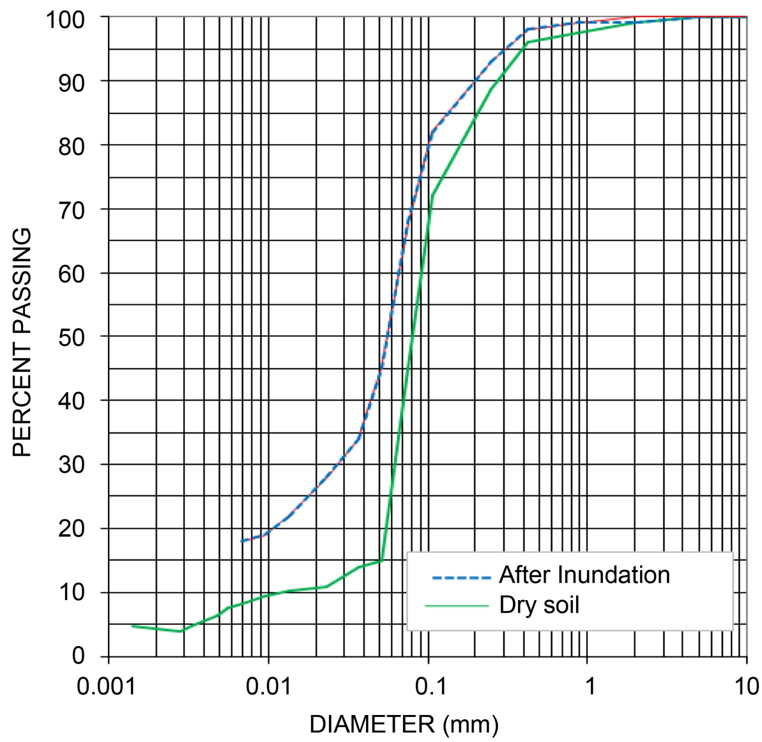

Figure 1. *In situ* collapse soil composition, (soil particle size distribution).

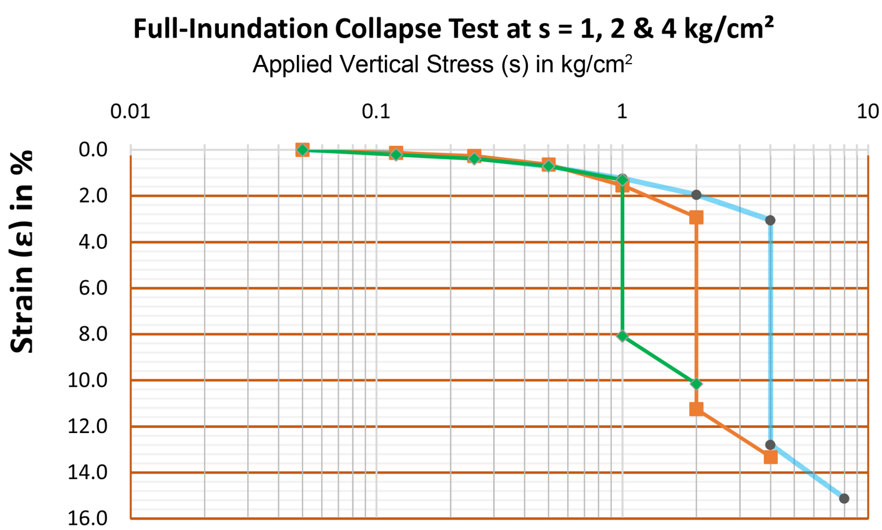

Figure 2. ASTM oedometer collapse test at different applied stress.

models in terms of scale effect analyzed. Figures 1-6 are Illustrated the unsaturated soils gradation and the filed obtained results. These results of tested compacted unsaturated soils up to 95% agree with the conclusion of many researches, [20] [21]. It easy to predicted that the collapse occurs in compacted unsaturated deposits at degree of saturation less than 60%, as shown in Figure 4 and Figure 5. For this reason, the numerical analysis in this study considered the equations in Figure 6, are represented the relation between different degree

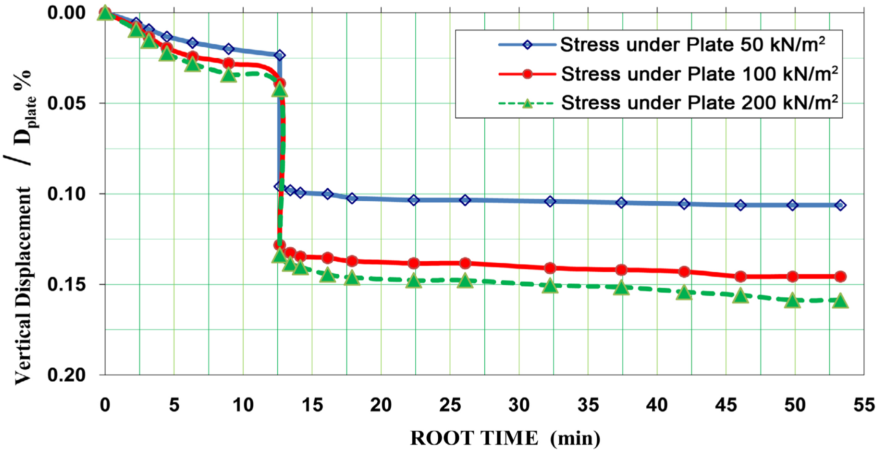

Figure 3. Obtained normalized settlement versus time at different vertical stress.

Figure 4. Plate load tests, (PLTs), resting on horizontal ground surface.

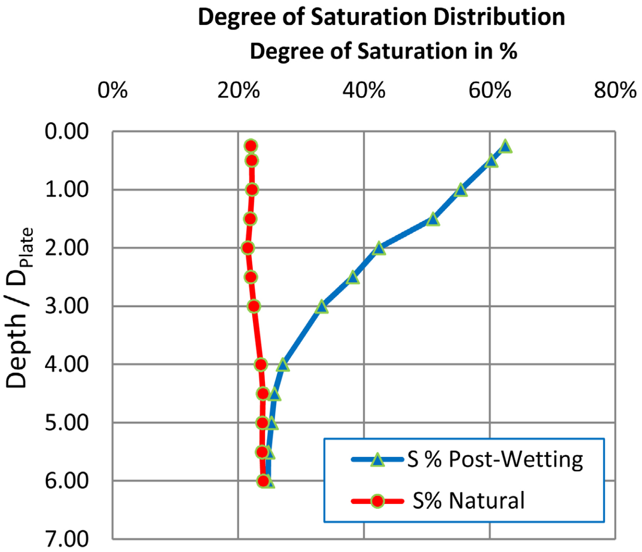

Figure 5. Distribution of degree of saturation respect to depth under (PLT).

of saturation and collapse potential of tested compacted unsaturated soils, to overcome the lack of simulation of collapsible soil in PLAXIS program. The effect of wetting has modeled by different degree of saturation zones with depth

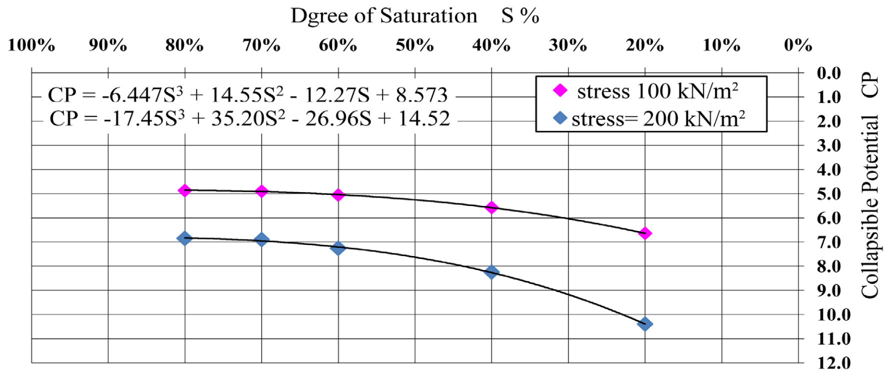

Figure 6. Degree of saturation versus collapse potential at different vertical stress.

near the source of water leakage, **Figure 6**. Collapse soil before wetting has been divided into S1, S2, S3 and S4 with degree of saturation, S% equal 10%, 20%, 40% and (60% - 100%) respectively and underlying sand which is not affecting with wetting. For each degree of saturation, S%, and each collapse potential the modulus of elasticity can be calculated, [20].

3. Finite Element Model Description

Case studies of two type of footing system are numerically analyzed, Inverted T-section Strip Footing, (ITSF), and rigid Strip Footing, (SF), which resting on compacted collapsible soil. Finite element program PLAXIS 2-D performed using Mohr-Coulomb model considering compacted unsaturated soil. The results presented in terms settlement under footing, and differential settlement to compare for reasonable and best foundation system in such case. Water source ate distance, D, from first footing, F.A, which has been wetted the compacted unsaturated soil under foundation to simulate the leakage of surface water. The model has been considered top layer of compacted unsaturated collapse soil with thickness 4.0 m, overlying layer of medium sand extended to depth 6.0m under top layer. The rigid concrete foundations with 2, 3 and 4.0 m width, B, are considered. Three parallel strip footings resting on the surface of a compacted unsaturated collapse soil are studied the effect of stress interference on settlement and effect of spacing between strip footings **Figure 7**. Also, parametric study is performed for different clear spacing between the footings and sand cushion with and without a layer of geogrid reinforced at bottom third of sand cushion thickness. Footing density considered, 24 kN/m^3, Poisson's ratio = 0.15 and Young's modulus = 2E + 07 kN/m^2. Compacted sand cushion with thickness 1/4 and 1/2 the collapse soil thickness, were been studied considering constrained its yield modulus not less than 80 MPa. Compacted collapse soil has redefined due to the inundation by the reduced soil stiffness with the soil degree of saturation, S% from field plate test results.

4. Numerical Case Study

Plain strain analysis using finite element method (FEM) based software PLAXIS

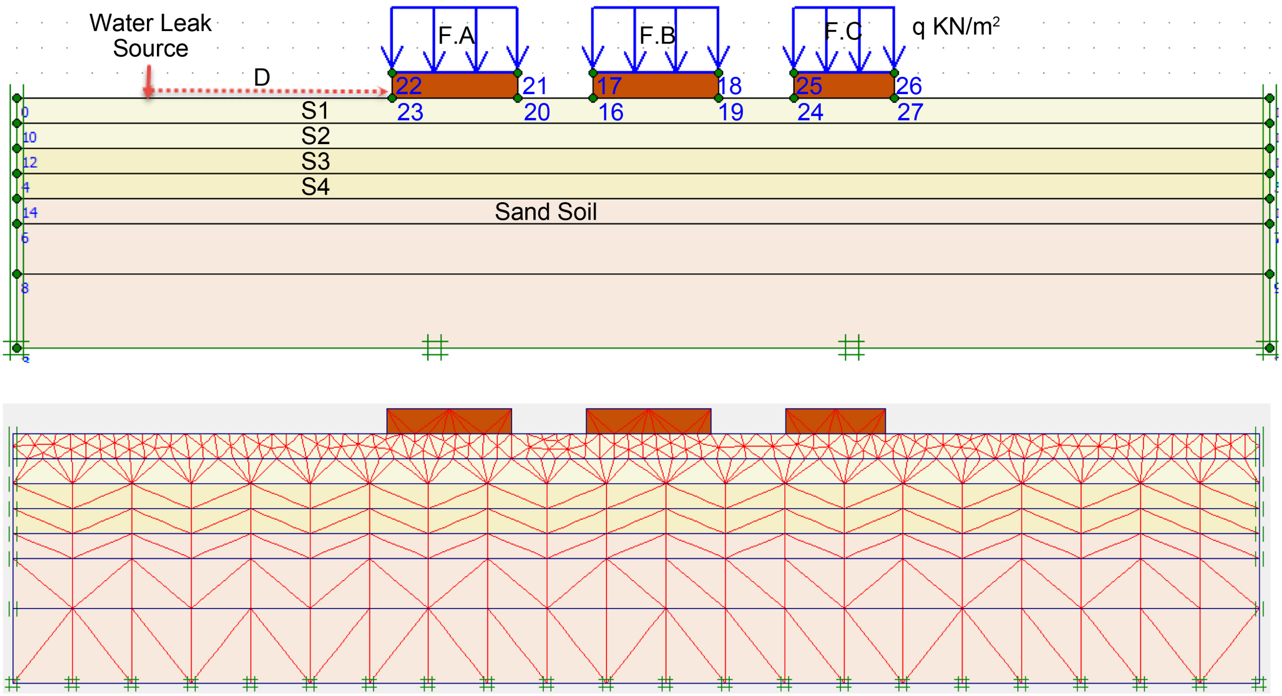

Figure 7. Finite element mesh and strip footing soil arrangement system.

2D, used to accomplish the deformation and settlement under considered foundation system types, (ITSF), and (SF), resting on the surface of compacted collapse soil, as shown in Figure 7.

The geometry of foundation soil model, first, a geometric model created with dimensions 50 m (length) × 10.0 m (height). A strip shape footing of different width was located on the top surface of the soil model. The three (SF) or (ITSF) footing shapes were located at the distant 2.0 m and located on center of the soil model. The Mohr-Coulomb soil model that follows linear-elastic perfectly plastic behavior adopted for dry sandy soil and the linear-elastic model implemented for foundation. In the 2D analysis, the Medium-mesh created as shown in Figure 7.

5. Results and Discussion

Some results of this study record and illustrate in the flowing figures. Figure 8 and Figure 9 shown the total settlement below the loaded strip footing increase with the decreases of distance, D, of water leak source. The figures indicated that when source of inundated become near the foundation system at distance, (D = B/2 = 2.0 m) the settlement of loaded strip increase by 220% than another one at distance, D = 2B, at the same stress under strip foundation, 75 kN/m^2. The settlements of nearest foundation increase due to increase in saturation of soil under foundation that decreases soil stiffness. Thus in most cases of collapsible soils saturation before construction can be helpful to stabilize collapsible soils.

Figure 10 shows the effect of sand cushion thickness on settlement of

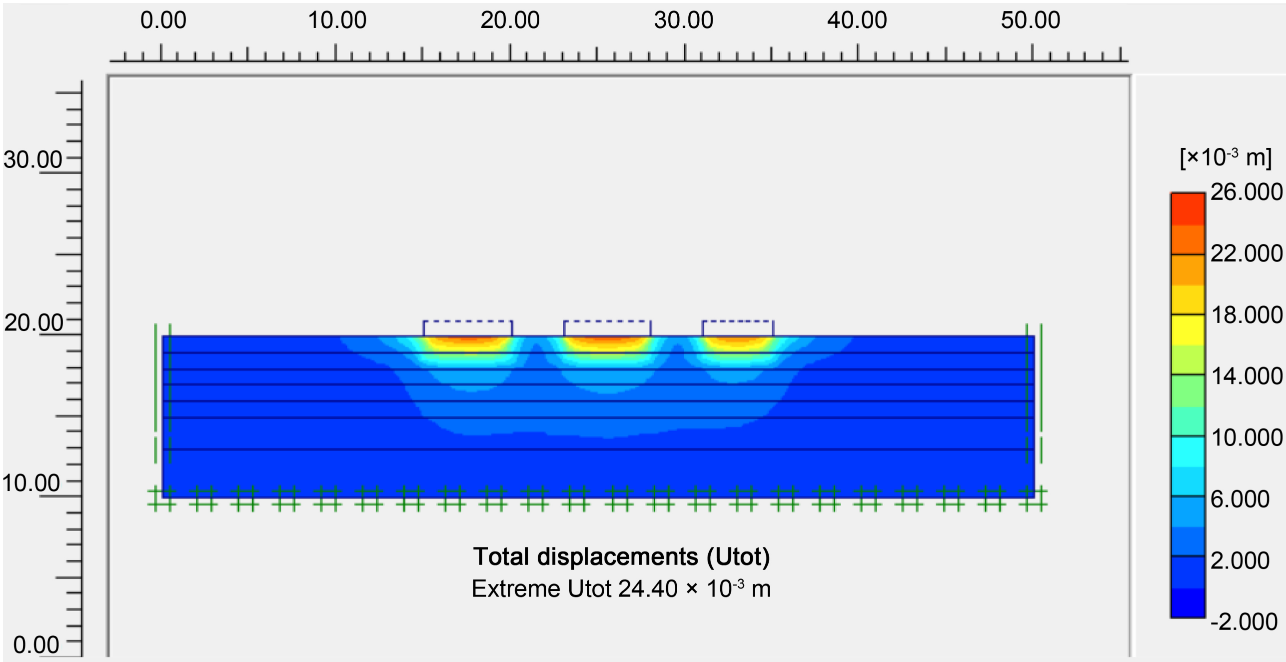

Figure 8. Total vertical displacement—source of water at (D = 8.0 m).

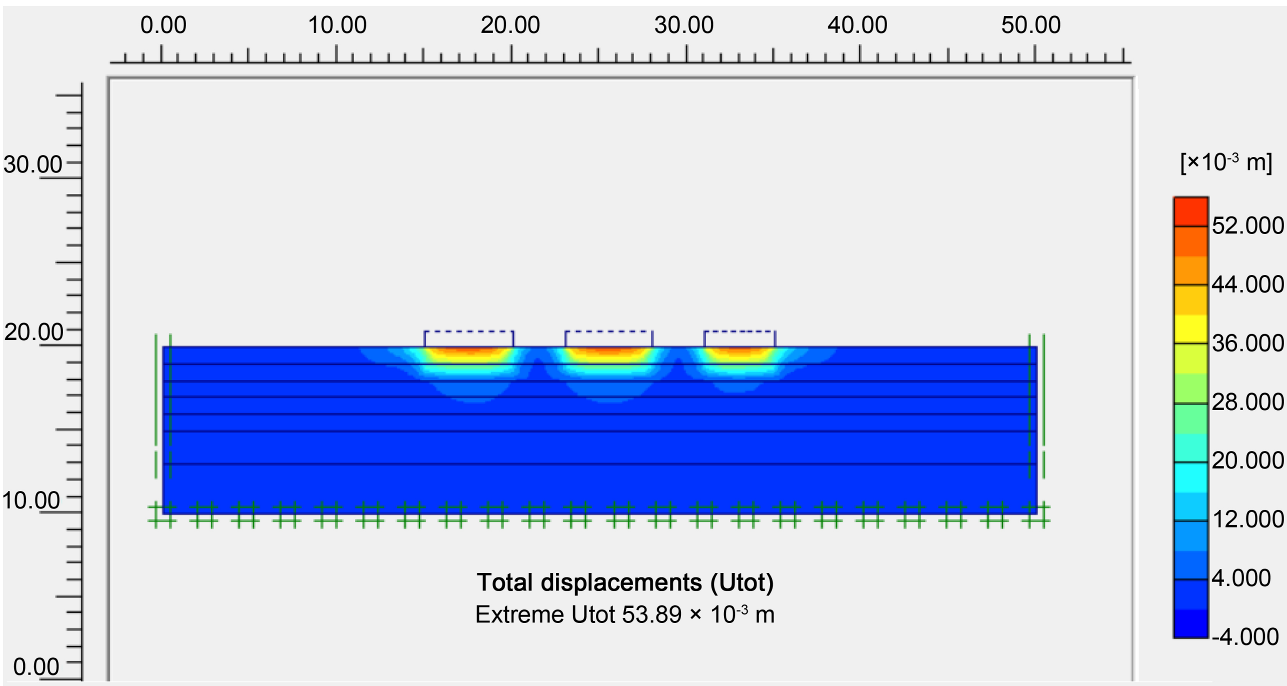

Figure 9. Total vertical displacement—source of water at (D = 2.0 m).

foundation system, using thickness, B/4, B/2 and B under different strip footing vertical stress, 125, 100, 75 kN/m^2. The figure illustrates there high reduction in footing settlement with increase in sand cushion thickness. It can explained that as increase in sand cushion thickness there are decrease on collapsible soil depth and also, increase of surcharge load from own weight of sand cushion. One can

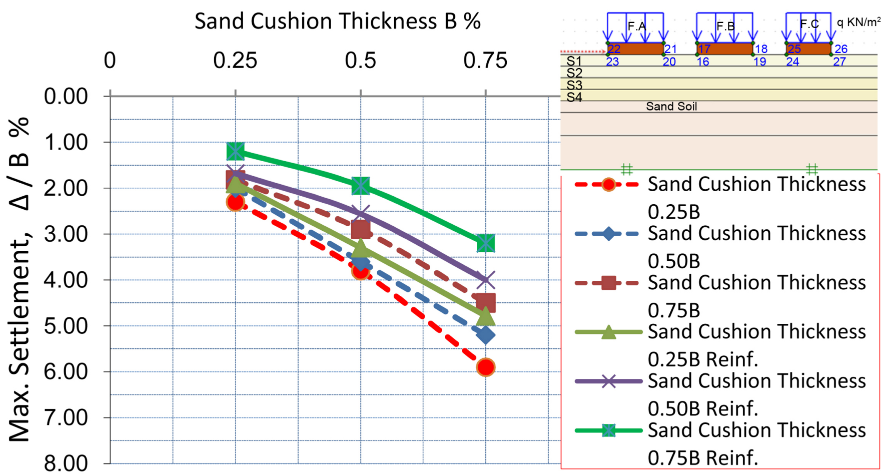

Figure 10. Total vertical displacement versus sand cushion thickness relationship under central footing 75 kN/m² applied stress.

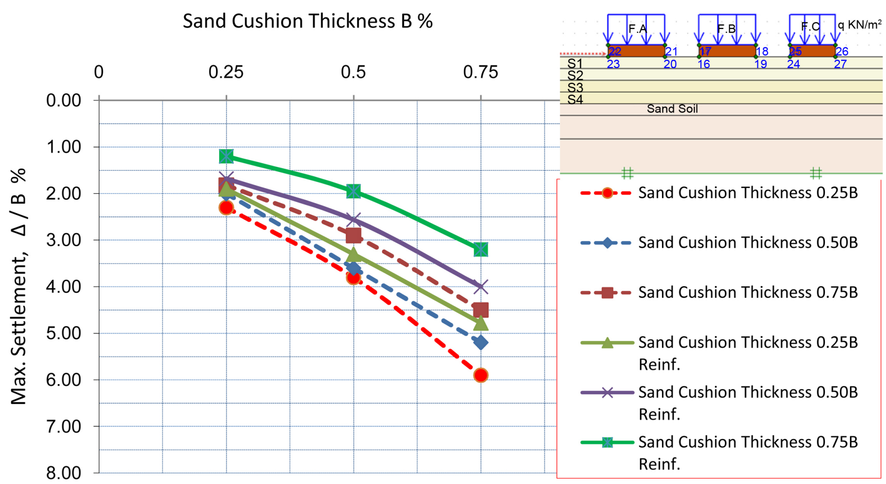

Figure 11. Total vertical displacement versus sand cushion thickness with geogrid relationship under central footing 125 kN/m² applied stress.

observe the increase in footing settlement reduction when reinforced the sand cushion with geogrid, with strengthens sand cushion as shown in Figure 11, due to increase of sand cushion strength due to using impeded geogrid. From figure it can noted that the effect Another parametric study on different type of (SF) and (ITSF) footing shapes with the same width, B, which the stiffener of footing (ITSF) reduced the footing settlement at the same inundation and applied stress. Figure 12 shows the reduction in case considered (ITSF) footing arrive to 35% than considered (SF) footing.

Based on the numerical analysis, output, a graphical relationship developed between the types of stiff strip footing and using sand cushion with and without geogrid reinforced in improved and controlled settlements of the footings under the same applied stress, Figure 13. The figure summarizes that the more foundation rigidity may less affected by collapse soil inundation and using sand

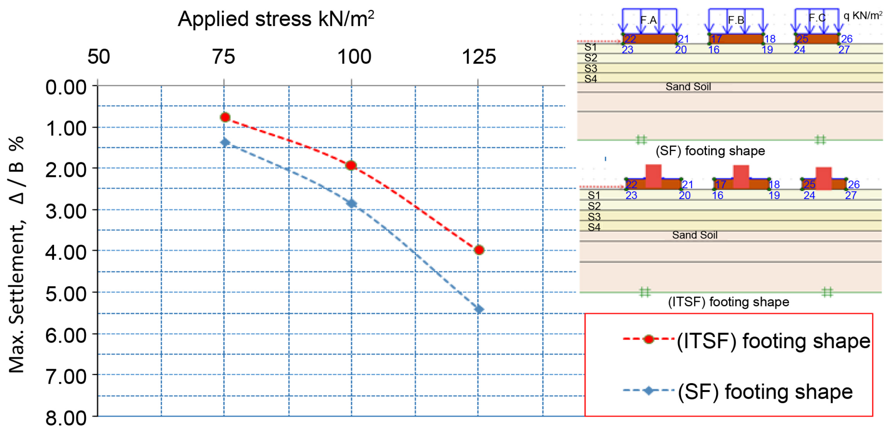

Figure 12. Total vertical displacement versus different type of (SF) and (ITSF) footing shapes relationship under central footing varies applied stress.

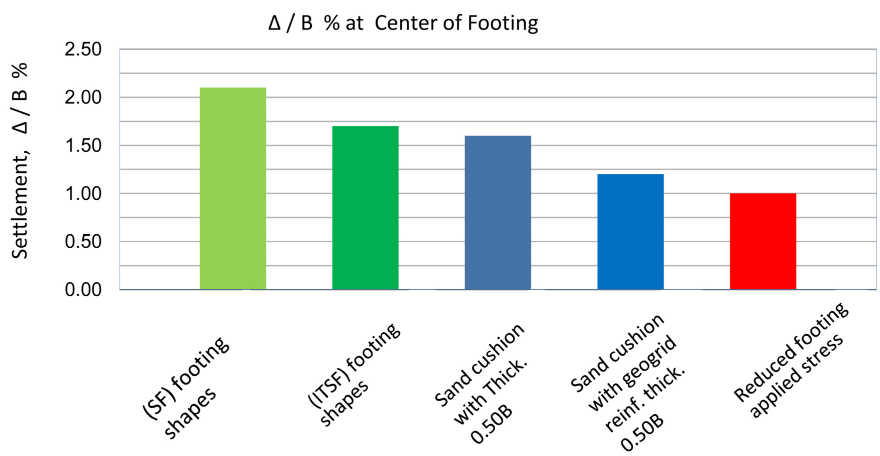

Figure 13. Total vertical displacement considering the different types of footing, using sand cushion and reduced footing applied stress.

cushion with geogrid reinforced improved characteristic of collapse soil under inundation. In addition, it indicates that the collapse soil saturating and pre-loading together is best method in improves such soil collapsibility and limit the settlement induced due to inundation.

6. Conclusions

The developed Finite Element, (FE) model estimate the rigid foundation behavior resting on compacted collapsible soil deposits under water leakage.

The numerical approaches study applied using the field and Laboratory results to developed overall behavior of foundations rest on compacted collapse soil. Also, take into account more factors than can possible in simpler methods can be investigated.

1) The (FEM) model developed can be help in predicting the overall behavior of footing system on compacted collapsible soil deposits and similar soils as, compacted partially saturated soil considering redefined the reduced soil stiff-

ness with the soil degree of saturation, S% from field plate test results.

2) Result indicate that the collapse soil saturating and preloading together is the best method in improving soil collapsibility and limiting the settlement induced due to inundation.

3) Using sand cushion is the major parameter affecting on reduction of the total settlement, at thickness = B/4 reduces total settlement by 15%, and increasing sand cushion thickness to B/2 reduces total settlement by 35%.

4) Using inverted T-section strip footing, (ITSF) with different contact stress gives the best results on reducing the total settlement than strip footing, (SF).

5) Reducing contact stress from 125 kN/m^2 to 75 kN/m^2 reduces settlement by 30%.

6) Using sand cushion reinforced with geogrid with great thickness up to B reduces the effect of the other parameters.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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