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Soil Improvement Techniquesof Collapsible Soil

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Abstract— Collapsible soils make the construction of foundations extremely difficult in its natural state. It may cause high differential movements in structures through collapse settlement. This paper gives an overview of formation and structure of collapsible soil, mechanism of collapse and the techniques that are commonly used to improve its performance. Then, this study concluded that there is an essential need to study soil replacement technique taking into consideration geotechnical requirements and cost to achieve the optimum replacement layer thickness corresponding to minimum cost of foundation works and reduce the collapse settlement under foundation as well.

Index Terms— collapsible soil, soil improvement, soil replacement, dynamic compaction, prewetting, stone column, chemical stabilization.

1. Collapsible Soil

In many areas of the world, certain soils make the construction of foundations extremely difficult. For example, expansive or collapsible soils may cause high differential movements in structures through excessive heave or settlement[1]. Collapsible soils are covering vast areas of many arid and semi-arid countries Particularly in Egypt. Collapsible soils were observed within the northern portion of the western desert including Borg El-Arab region, and around the city of Cairo in Six of- October, and Tenth-of-Ramadan city. [2]

2. Formation and structure of collapsible soil

Das [1] reported that the majority of natural collapsible soils are mainly wind – deposited sand and / or silts, such as loess, eolic beaches, and volcanic dust deposits. These deposits have high void ratios, relatively low unit weights and low natural moisture contents and are cohesion less or slightly cohesive. The cohesion in collapsible soils may be the result of the presence of clay coatings around the silt, which hold them in a rather stable condition in an unsaturated state. The cohesion may also be caused by the presence of chemical precipitates leached by rainwater.

Abdelaziz[3] reported that Houston et al.[4] attributed the formation of collapsible soils to the arid climate where potential evaporation greatly exceeds rainfall When the near surface water begins to dry, capillary tension causes the remaining water to withdraw into the narrow spaces close to the soil grain interface bringing with it soluble salts, clay colloids, and silt particles . As the soil continues to dry, the salt, clay and silt particles come out of solution and tack weld the large soil grains together at their interface. Figure (1) illustrates the main forms of collapsible soil structure.

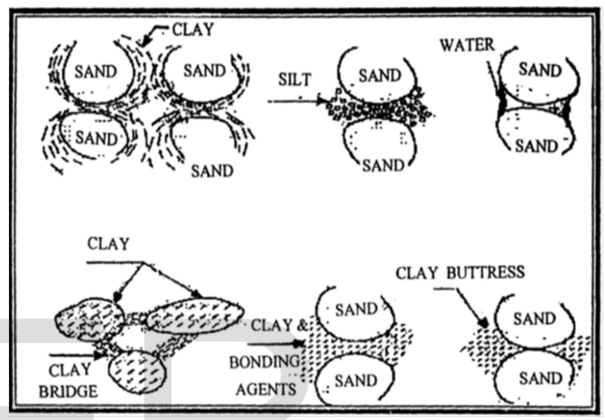

Fig.1: Main Forms of Collapsible Soil Structure (After Egyptian Code of Practice, 2001)

3. Mechanisms of Collapse

The usual mechanism for soils to collapse is loading and wetting; where these soils can show high apparent strength in its natural state but collapse occurred as the bonds between the grains break down when the soil is wetted or loaded. The increase in load or more properly stress, will typically derive from an accumulation of deposits over a long period of time, although dynamic stresses from an event such as an earthquake would provide an obvious trigger mechanism as would stress increases caused by construction operations. Wetting usually refers to an increase in saturation ratio, often approaching full saturation from a partially saturated state.[5].

4. Foundations on Collapsible Soils

If the foundations rest on collapsible soil, several design techniques may be considered to avoid foundation failure. Shallow foundation is found safe and suitable only for light weight structure, as under small inundation pressure cause relatively small amount of additional soil volume reduction. Otherwise, pile is the only available type of foundation.[6]

4.1. Shallow Foundations

Isolated footings may be used as a foundation on collapsible soil (which has weak collapsibility and the expected depth of wetting is about 1.5 – 2.0 m). In this case, rigid semells have to be constructed at the same level as the isolated footings. [7]

Continuous strip footings may be safer than isolated footings over collapsible soils in that they can effectively minimize the differential settlement. Then, their section has to be inverted T-section to produce sufficient rigidity [1]

Mat foundation may also be used over collapsible soils. It has an advantage that it distributes the loads, so minimize the contact pressure transmitted to the soil. In case of constructing mat foundation, it has to be slab and inverted beams system to produce high rigidity enough to resist the predicted deferential settlement.[7]

4.2. Deep Foundations

Piles may be used to transmit the loads to a firm soil layer which is below the collapsible soil layer. Piles also may be used if the expected depth of wetting is large. In case of using piles, the skin friction is neglected; moreover, the negative skin friction has to be taken into consideration. Sometimes, the pile length may be ended within the collapsible soil layer provided that the soil moisture content at the pile base will not increase. [3]

5. Treatment of Collapsible Soils

Many research works concerning ground improvement techniques are recommended in difficult ground conditions, examples of which are swelling soils, collapsible soils, soft soils and organic soils. When a project site comes across any of the above difficult conditions, possible alternative solutions may be one or more of the following as needed for a particular site: design the planned structure, remove and replace unsuitable soils, attempt to modify existing ground, enable cost effective foundation design, reduce the effects of contaminated soils and ensure sustainability in construction projects usingsoil improvement technique.[8]

Several soil improvement techniques can be used to increase the bearing capacity and reduce settlement of shallow foundation. Examples of these techniques are soil replacement, prewetting,dynamic compaction, stone columns and chemical stabilization. [9]

5.1. Dynamic compaction of soil at natural moisture content

Collapsible soil may be moistened and recompacted by heavy rollers or heavy tamping. Spread footings and mats may be constructed over the compacted soil. Heavy tamping consists primarily of dropping a heavy weight repeatedly on the ground. The height of the drop can vary from 8 to 30 m. The stress waves generated by the dropping weight help in the densification of the soil.[1]

Abdelaziz[3] quoted that Rollins and Rogers [10] conducted in situ tests using this method where concrete block has been used with specified weight and was dropped from a specified height using a crane. The conclusion of this method indicated that the final collapse settlement was reduced to about 1% of the value in case of no treatment.

When collapsible soil is compacted to 95% of its dry density, the bearing capacity increased by about 24–30% and the collapse potential decreased to be about 0.15–0.23 from its original value for natural soil, which changed the classification of natural soil.[2]

5.2. Prewetting

Prewetting means flooding or wetting the soil which is expected to exhibit collapse upon saturation before the structure is built, so that soil collapse will be minimized after the structure is built. Prewetting was found to be one of the easiest and least costly treatments but it proved to be completely ineffective in reducing collapse potential.[11]

Abdelaziz (2007) also stated that Rollins and Rogers [10] studied the effect of prewetting and found that the final collapse settlement after prewetting was nearly identical to the settlement where no treatment was performed.prewetting must combined by preloading, surcharging to be effective

5.3. Dynamic Compaction after Prewetting the Soil

Wetting and dynamic compaction can be used to control or limit collapsibility potential by increasing the moisture content of soil before dynamic compaction to increase the compaction efficiency. Rollins and Rogers [10] investigated the influence of prewetting the soil and dynamic compaction on the collapse settlement, the collapse settlement in this method was about 4% of the value in case of no treatment. In comparison with compaction at the natural moisture content, the densification over the entire area was more uniform.

Abdelmohsen and Ali [12] had developed experimental work program to investigate the effect of relative compaction and amount of initial water content on collapsibility potential. The study showed that increase of relative compaction energy and degree of saturation minimizes the risk of collapsibility potential.

5.4. Stone Columns

Vibroflotation may be used to densify the collapsible soils.The process involves the use of vibrating unit shown in figure (2). It can vibrate horizontally with an eccentric weight inside it; there are also water jets at the top and bottom of the unit. This method is suitable for collapsible soil with low fines.[1]

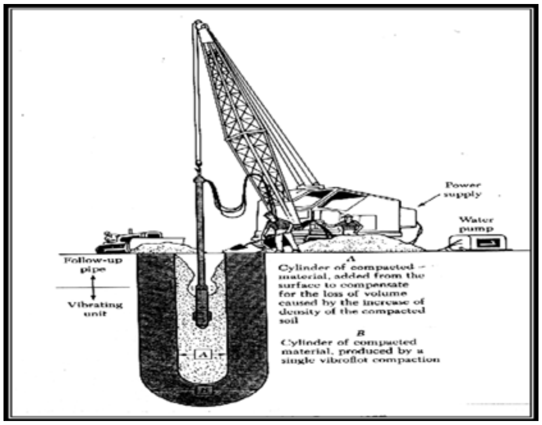

Fig.2: Vibroflotation Unit (After Das, 1983)

5.5. Chemical Stabilization

Chemical stabilization is the modification of the soil properties to improve its engineering performance. The most commonly methods of chemical stabilization are lime stabilization and cement stabilization, other chemical additives that the soil can chemically react with are treatment with salts (ammonium sulfates (NH4)2SO4 and potassium chloride KCL). Also fly ash can be added to the soil-lime and soil-cement in order to enhance the properties of the stabilized soil. The increase in lime or cement content results in decreasing in the compression and no collapse potential had been occurred for treated soil.Foundation trenches can be also flooded with solutions of sodium silicate and calcium chloride to stabilize the soil chemically. The soil will behave like soft sandstone and resist collapse upon saturation. This method is successful only if the solutions can penetrate to the desired depth; thus, it is most applicable to fine sand deposits. [1]

5.6. Soil Replacement

Soil replacement is one of the most familiar techniques in dealing with collapsible soils. It is implemented by removing the weak soil and replacing it with a better compacted soil [13]. Unfortunately, the determination of replacement layer thickness is questionable because it is based on experience. [9]

Rollins and Rogers[10] reported that this method offers several advantages, the first that it decreases the amount of collapsible material in the zone of significant stress, the second that it increases the depth to which water must percolate before reaching collapsible material, and the third that it decreases the induced stress to which the collapsible soil is subjected. This reduction in the induced stress many keep the stress below the critical value necessary to produce significant collapse settlement. In addition, this technique minimizes the differential settlement under the footing.

Experimental tests had been also conducted on circular footing resting on collapsible soil and water was allowed to infiltrate into soil from the bottom. Using compacted sand cushion with thickness equals twice the footing diameter resulted in a significant reduction in collapse settlement.[3]

Naema, Ali [14] proved that the improvement of collapsible soils by sand/crushed stone replacement is possible to control/mitigate their risk potentials against sudden settlement when exposed to water. She also found that the soil replacement with compacted cohesion less soil reduces the foundation settlement by about 50% and increases bearing capacity by about 100%. The subgrade should be improved with compaction and pre-wetting before placing the top compacted sand replacement to obtain good results of higher bearing capacity, and low and uniform settlement. The most effective thickness for the compacted sand layer, within the tested range, was found to be equal to the plate width.

6. Conclusion

There are many available improvement techniques that can be used for the purposes of increasing bearing capacity and decreasing settlement of collapsible soil such as soil replacement, prewetting, stone columns, stabilization with additives and dynamic compaction. Most of researches investigated the effect of using different soil improvement techniques on increasing soil bearing capacity and /or decreasing the expected settlement while, there is a lack of researches which consider the cost of foundation works as one of the governing factors when selecting between different soil improvement techniques. Thispaper concluded that, there is an essential need to study soil replacement technique for improving soil behavior taking into consideration geotechnical requirements and cost to achieve the optimum replacement layer thickness corresponding to minimum cost of foundation works.

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