Evaluation of Bearing Capacity of Compacted-Cemented Sand Replacement Overlying Weaker Soil using Plate Bearing Tests

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Abstract: The existing soil on a given site may not suitable for supporting the desired building because safe bearing capacity of soil may not be adequate to support the given load. To improve this soil type to allow building, it is necessary to create a compacted or cemented replacement top sand layer above this weak, compressible residual soil stratum to increase its bearing capacity, reduces displacement at failure and changed soil behavior to brittle behavior. This paper discuses the load-settlement response from three plate load tests carried out using a 300 mm circular steel plate on a thick homogeneous residual soil stratum as well as on layer system formed by two different top layers (1000mm thick) compacted sand and (600 mm thick) sand-cement overlying the residual soil stratum. Plate bearing test has been used to measure the compressibility of the top replacement soil layer as a criterion for accepting (or not accepting) this layer. The objective of this study is to find out a relevant method for evaluating the suitability of soil replacement using plate bearing tests. The plate load test on residual stratum strengthen by top cement sand layer was performed to a relatively high pressure, and gave a noticeable stiffer response than that carried out on the untreated soil stratum, since the failure occurs through the formation of a thick shear band around the border of the plate, which allowed the stresses to spread through a larger area over the residual soil stratum. This means that cement-sand soil replacement is capable of absorbing more strain energy prior to failure. After maximum load, the bearing capacity dropped towards approximately the same value found for the plate load test carried out directly on the residual soil. A punching failure mechanism was observed in the field for the load test bearing on the compacted sand top layer, with tension cracks being formed from the bottom to the top of the layer when mixed with cement.

[Samir I.S. **Evaluation of Bearing Capacity of Compacted-Cemented Sand Replacement Overlying Weaker Soil using Plate Bearing Tests.**. *Life Sci J* 2014;11(8s):613-617] (ISSN:1097-8135). http://www.lifesciencesite.com. 123

Keywords: Bearing capacity, Cement Sand, Layerd soil, Plate Load Test, Shallow Foundations, and Soil Replacement

1. Introduction

Thick residual soil strata with reduced bearing capacities are found to cover extensive area in the bands of the Nile river, including domestic area where buildings are demanded without the necessarily of using piles for founding. The underlying soils are highly drainable weakly bonded residual soils; direct foundations on such soils might lead to low admissible pressures associated with significant settlement. The solution adapted for supporting building loads is usually a deep foundation. An alternative for design is therefore proposed in this word by devising a system to increase bearing capacity of the existing weak soil by removing this layer up to a shallow depth and replaced by a granular soil that has been mechanically improved by compaction or incorporating a cementing material such as Portland Cement. There have been many studies of shallow foundations on layered systems, most of them concentrating on case in which a sand layer overlies a soft clay stratum [6]. The stress-strain-strength behavior of artificially cemented soils has been studied by [2-3-4]. In general, settlement is the governing criterion for designing a footing resting on a weak soil. Usually, for a given settlement, the load that footing can carry is obtained by using plate load test data. The overall response of shallow foundations placed on weak residual soil can be significantly improved by replacing a part of the top layers by a top compacted fiber reinforced cemented soil, in this case, an analytical solution for layered cohesive- frictional soil, such as methods proposed by [7-8] can be used.

The results presented in this work examine the effect of using compacted sand or cemented sand layer constructed over the weak residual soil stratum. Shallow footings were placed on the artificially replacement top layer and tested. The main purpose of the research is to investigate the effectiveness of using compacted or cemented sand for improving the strength and stiffness of the weak residual stratum. In the present paper the pressure-settlement characteristics of circular footing in stratified soil profiles consisting of compacted sand and cemented sand overlying weak residual stratum were studied to help the understanding of its behavior. The main purpose of the results presented herein is overall understanding of the different mechanisms of load transfer for shallow foundations bearing on layered systems overlying weak residual soil strata. Soil replacement can be considered a successful solution for construction over this type of problematic soil. Great attention should take place while founding the replacement soil, since poor quality of soil replacement may result in serious problems [5]. The function of the use of top compacted sand or cemented sand in the soil matrix is to increase the strength shearing resistance and reduce the deformation.

2. Experimental Programme

2.1 Material Used

2.1.1 Residual Soil Stratum

The residual soil characteristics have been determined through an extensive testing Programme. The site investigation has reveal a homogenous upper layer of sand–silty clay, which is classified low plasticity clay (CL) according to the Unified Soil Classification System. Grain size data indicates that the soil is composed of 27% fine sand; 31% silt and 42% clay with specific gravity of 2.68. The average bulk unit weight ranged between 18.1 KN/m^3 and 18.6 KN/m^3; the moisture content was typically 21.5-27.0 %; the degree of saturation was around 80%, and the void ratio varied between 0.799 and 0.879. The liquid limit and plastic limit of the soil are found to be 48% and 21% respectively, which yield as a plasticity index of 27%. The soil has a maximum dry density of 19.6 KN/m^3 with optimum moisture content of 12.5%. The free swell index is 31%.

2.1.2 Sand

The sand used, is silica sand borrowed from EL haram region, is classified as non-plastic uniform fine sand (SP) according to the Unified Soil Classification System; the specific gravity of solids is 2.62 and the grain size distribution is 100% fine sand with an effective diameter of 0.16 mm, the uniformity and curvature coefficients are respectively 1.9 and 1.2; the minimum and maximum void ratios are respectively 0.585 (γ_{dmax}=16.5 KN/m^3) and 0.88 (γ_{dmin}=13.9 KN/m^3).

2.1.3 Cement

The used cement is commercially available and known as Kawmeya Portand Cement, produced by Kawmeya Company at Torra-Cario. A cement ratio of 6% by weight of dry sand was determined to mix with sand soil.

2.1.4 Water

Potable water was used in sand compaction and in sand-cement mixing. It is worthy to point out that a moisture control study was performed to determine the target moisture content for the sand-cement mixtures. The moisture content was selected so that small change in the amount of water did not significantly change the desired density.

2.2 Field Experimental Setup

Three bearing capacity tests using large scale plate load test were conducted one without soil treatment and the other two tests with compacted sand layer or compacted sand-cement layer on the top of weak residual stratum.

2.2.1 Field Work

Before the construction of the soil replacement top layer a 1500 mm thick layer of the upper residual soil, was removed. After removal, four improved sand-cement soil layers 150 mm thick or four layers of compacted sand, 250 mm thick were built over the residual soil. Vibratory plate was used to reach the specific relative density of 85%. Sand-cement mixture was allowed to cure for 7 days before being tested. The improved sand-cement top layers were prepared using a rotary drum by mixing air-dried sand, Portland cement (6% by weight of dry sand), and water (10% moisture content). The top replacement layer were taken less than three times plate diameter (3*30=900 mm). This depth was chosen based on Boussinesq stress distribution theory. Using this theory the stress below a footing dissipate to effectively zero at a depth of about three times footing diameter below the footing. Therefore, using a replacement depth less than three times footing diameter ensure that the residual original soils were affected by tests.

The field testing Programme was carried out at the experimental site using 300mm circular steel plate of 25.4 mm thick. The plate is firmly seated in the test location and if the ground is slightly uneven, a thin layer of fine sand is spread underneath the plate. The load was applied trough a system comprising a hydraulic jack with sufficient capacity to provide a maximum load of 500 KN, and measured using a proving ring with capacity of 150KN, four dial gauges with divisions of 0.01 mm and 50mm travel were used for settlement measurement. The gauges were fixed to a reference beam and supported on external rods. The experimental setup is shown in figure 1. The load was applied in cumulative equal increments of not more than one-tenth of the estimated ultimate bearing capacity. For each load increment, measurements of settlement was made at the following fixed times 0,0.5,1,2,4,8,15,30, and 60 minutes and thereafter at hourly intervals until the rate of settlement becomes less than about 0.02 mm per hour. After this, the next load increment is applied, the maximum load that is to be applied correspond to 1.5 times the estimated ultimate load.

Figure 1. Experimental setup for plate load test.

3.Test Results and Discussions

3.1 Plate load-settlement response

The load intensity and settlement observation of the plate load tests have been analyzed to study the effect of soil replacement of the top soil on the strength of the residual bottom layer. Figure2. Shows the load-settlement curves of the plate load tests carried out. The ultimate loads were calculated from the tangent intersection of the two straight portion of the curve at the initial straight portion of the load settlement curve and the steeper straight portion at the end of the curve [1]. Study of load-settlement behavior from figure 2 shows that at each load increment, the settlement in the residual origin soil is much more compared to the treated cased with compacted sand or cement sand layers. Thus it is revealed that the inclusion of top soil replacement increases the stiffness of the soil.

Table 1. summarized the results of the tested plate load tests. The study of these results showed that the ultimate load of the treated soil with top compacted sand or sand-cement increases by 83% and 165% respectively as compared to the origin soil.

It is often helpful to present relationships in terms of dimension less variable, so the advantage can be taken of the scaling effects of continuum mechanics [9]. Figure 3. Shows the load settlement behavior in a non dimensional form. Settlement (S) is expressed as a fraction of the diameter of the test plate (D) and called settlement ratio (SR), SR=S/D, and load (P) is expressed as a fraction of the ultimate load of the residual soil case at initial condition (P_{uo}) called load ratio (PR), PR= P/P_{uo} . SR versus PR plotting thus obtained is presented in figure 3.

The meditation of the results shown in figure 3 showed that the rate of settlement decreases with the presence of top compacted sand or sand-cement layer beneath footing, maximum decreases being observed when the sand replacement layer was mixed with cement. It is also observed that SR ratio for residual soil case increases linearly up to PR ratio equal 65%, beyond which it changes abruptly to a steeper slope. Similarly, almost liner variation is observed up to PR ratio equal 200% for soil replacement with sand or cemented sand with a slope flatter compared to original residual soil. For PR ratio beyond 200% a gradual increase in slope is observed. This indicates that the presence of sand cushion on the top of the residual soil is capable of absorbing more strain energy prior to failure.

Table 1. Summary of Plate load test results

Treated soil layer	Thickness (mm)	Load at Failure (KN)	Ultimate load (KN)	Settlement at ultimate load (mm)	Failure mode
Plate directly on the residual soil	None	65	37	15	Punching
Compacted sand top layer	1000	88	68	12	Heave of surrounding top soil followed by punching
Sand +6% cement top layer	600	115	98	17	Formation of shear band around the plate border

3.2 Progressive failure mechanism

During the plate load tests, cracks developed on the top of the treated layer. The cracks were concentric to the plate end. First began to appear at about 80% of the failure load. The failure load is taken as the load at which the plate starts sinking at a rapid rate. When the failure load was reached, large settlements of the plate occurred, which produced penetration of the plate into the treated layer. By increasing the applied load on the plate high shear stresses developed in the strong layer just below the edge of the test plate. Once they reach the shear strength of the treated layer a failure shear surface is postulated to progress down wards. As loading on the test plate increases, the tensile failure at the bottom and the shear failure at the top evolve into a single vertical failure surface producing a punching failure. In cement-sand top layer tension cracks spreading from bottom to top are created. At larger displacements, the load transfer at interface between the improved top layer and the residual soil stratum seems to be restricted to the area of the plate only. Such pattern is corroborated by the load-settlement curves presented in figure 2. Where the failure load of the plate on compacted sand top layer approaches the value obtained for the plate placed directly on the residual soil.

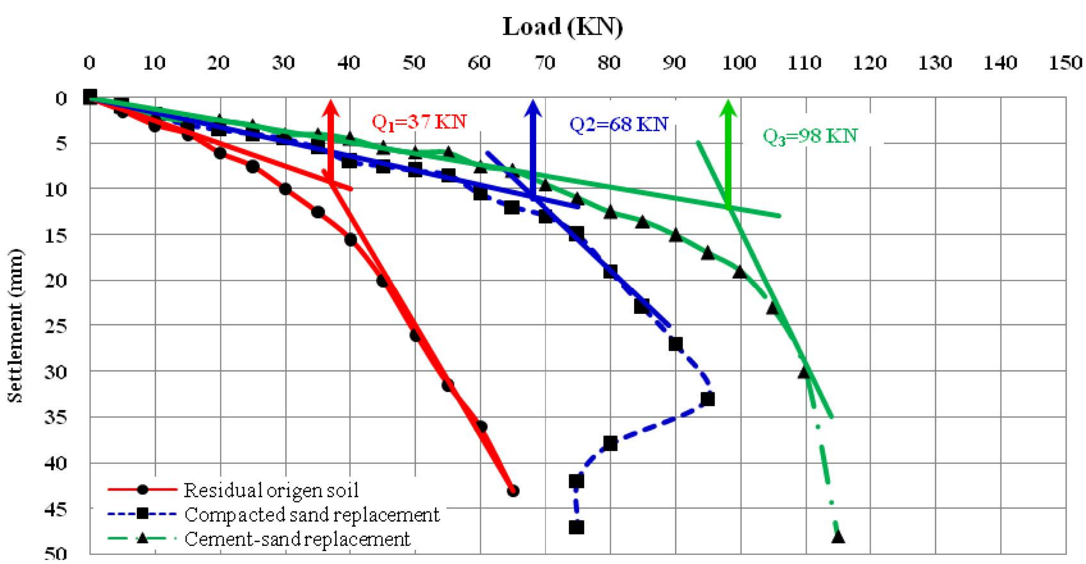

Figure 2. Load settlement response for plate load test.

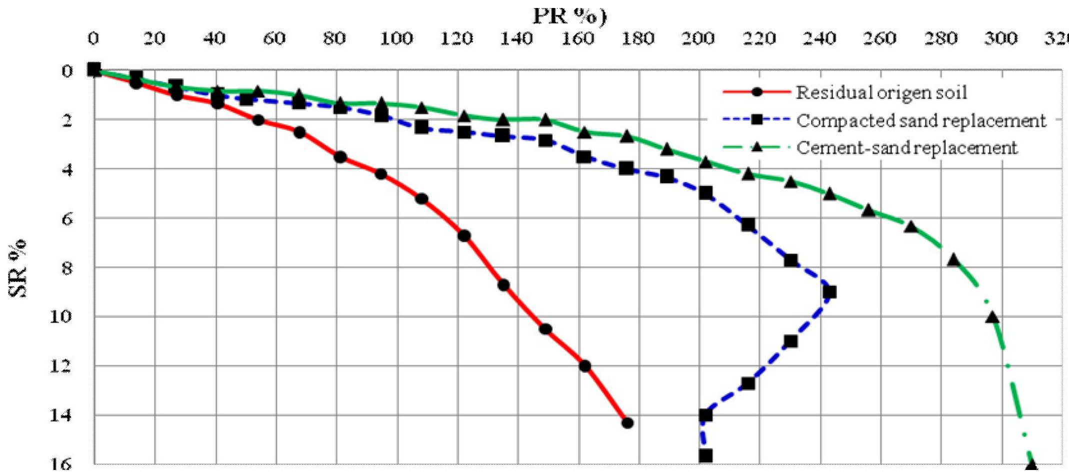

Figure 3. The relation between SR% versus PR %.

4. Conclusions

The following observations and conclusions are made regarding the results of plate loading tests carried out directly on residual homogenous soil stratum as well as on a layered system formed by two different top layers 1000mm thick compacted sand and 600 mm sand-cement overlying a residual soil stratum.

1-The utilization of a layered system made up of a top compacted sand or sand-cement layer overlying a residual soil stratum has proved to marked by increase the bearing capacity obtained from a plate loading test, reducing displacement at failure and changing soil behavior into a noticeable brittle behavior.

2- The ultimate load of the treated soil with top compacted sand or top sand-cement mixture increases by 83% and 165% respectively as compared to the origin soil.

3- Cement- sand mixture is capable of absorbing more strain energy prior to failure.

4- Even though the sand-cement layer conducts to a higher bearing capacity, when compared to the compacted sand layer, the latter, in terms of post-peak behavior, leads to a more reliable solution and possibly to a reduction in the design safety factor.

Notation

The following symbols are used in this paper

D =Diameter of plate load test, mm

S = Settlement, mm

SR = Settlement ratio (S/D)

P = load, KN

P_{uo} =Ultimate load of the residual soil, KN

PR = Load ratio (P/P_{uo})

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5/24/2014