Effect of the thickness of stabilized cemented sand soil in the bearing capacity of shallow foundation

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Abstract:

The main aim of this paper is to examine the effectiveness stabilized cemented soil on dense sand has been gathered from loading tests carried on model of square steel footing with (89,89,23) mm length, width and thickness, resting on cement-improved layers of various thicknesses, considering the affected of soil-cement layer thickness (H) on the bearing capacity of square footing. Four different values of the relation thickness of reinforced layer divided by footing width (H/B) were tested, corresponding to 0.1, 0.3, 0.6, and 1. The sand layers compacted with dry unit weight (15.8 kN/m^3), thus, achieving the state of dense soils (Dr=77%). Result showed that the (H/B) ratio affected the stress-settlement curves and increased bearing capacity with increasing H/B ratio. The results also showed two mechanisms of failure, the cement- reinforcement soil layer broke, showing a fissure was located close the footing's edge and central axis or it was located close the footing's edge only, according to the thickness of the reinforced layer.

Keywords: (Bearing capacity, cement, plate load test, sand, failure).

1. Introduction

When constructing foundations on soils with low bearing capacity, deep foundations or soil replacement are usually used. However, a significant amount of the project's overall cost may be incurred by these conventional solutions, for example, low-cost housing, in temporary buildings , pipeline supports in industries, small diameter storage tank bases, machine foundations, etc. , the soil has seen chemical stabilization or the addition of various natural and synthetic materials. Chemical stabilization is the process of changing the characteristics of soil by adding chemically active element to improve its characteristics and increase its bearing capacity [1]. The soil improvement by chemical stabilization methods is one of the successful solutions because in these situations, using deep foundations leads to less settlement, but the costs can become expensive. The most common construction materials used to stabilize soils are lime, cement and pozzolanic materials[2]. Types of additives are chosen, and their percentages are calculated depending on the soil classification and the degree of soil improvement needed [3]. A variety of materials contain cemented sand. It frequently exhibits the behaviors of both rock and soil at the same time[4]. The two primary design factors for artificially cemented soils are an increase in bearing capacity and a reduction in foundation settlement. Additionally, the cohesion of a cemented sandy soil indicates that it can withstand tensional, compressive, and shear stress pressures [5]. According to Stefanoff et al[6], suggested that by using cemented stabilized layers as top layers over natural soil will increase the foundation's bearing capacity and reduce settlement to an acceptable level.

Recent studies demonstrate that soil-cement reinforcement significantly increases bearing capacity and decreases settlement[7][8]][10][11] through soil-cement reinforcement. The results of plate load tests by Ismael [12] on very dense cemented sand samples using circular and ring plates had shown that the settlement of the circular plates was greater under all tested pressure levels while the difference between bearing capacity values in both circular and ring plates was negligible. Ismael and Al-sanad [13] performed several plate load tests on specimens of slightly cemented desert sand . Punching failure mechanisms were seen in all experiments. Consoli [8] resulted that adding a soil- cement reinforcement top layer to weak soil would not only enhance bearing capacity and reduce foundation settlements, but would also lead the soil to behave noticeably more brittlely than it would in naturally soil deposits. Plate load studies were conducted by Consoli et al. [14] on soil layers that had been compacted with lime and fly ash, resulting in an increase in bearing capacity and a decrease in settlement, in order to determine the ultimate bearing capacity of foundations on layered soils.

This research discusses an efficient technique for resolving problems on sandy soil that involves stabilizing a limited dimensions of the soil beneath the footing with cement before building a footings layer on top of this stabilized region.

2. Materials

The soil used in this study sand air-dried was taken from a location near the Nasiriya city in the southern of Iraq (Table 1.) explain physical properties of sand. The sand used in the study is classified as a poor sand (SP) by the Unified Soil Classification System (USCS), the (Figure 1.) shows that. The cement used to be resistant to sulfates. Type V Portland cement produced in Iraq by the (Al Jessir) factory (Table 2.) show the Physical and chemical of the characteristics cement. Tap water was used in all the experimental works except specific gravity test used distilled.

Table.1 physical properties of sand

(G_s)	(Cu)	(Cc)	Classification of soil (USCS)	$\gamma_{d\ min.}$ (kN/m³)	$\gamma_{d\ max.}$ (kN/m³)	$e_{min.}$	$e_{max.}$	The angle of internal friction(φ)at γ_d=15.8(kN/m³)
2.61	2.6	1.24	SP	13.5	16.6	0.54	0.89	35.5

Table 2. The Physical and Chemical characteristics of The Cement (Data sheet).

Physical properties				
Specific gravity (G.S)	Compressive strength, age 3 days,(Mpa)	Compressive strength, age 7 days,(Mpa)	initial time of sitting (min.)	final time of sitting (hour)
3.15	17	26	93	4.28

Chemical properties							
C3S %	C3A%	C2S%	SiO2 %	CaO%	MgO %	SO3%	L.O.I %
57	3.27	29	19.79	63.8	3.19	2.15	0.89

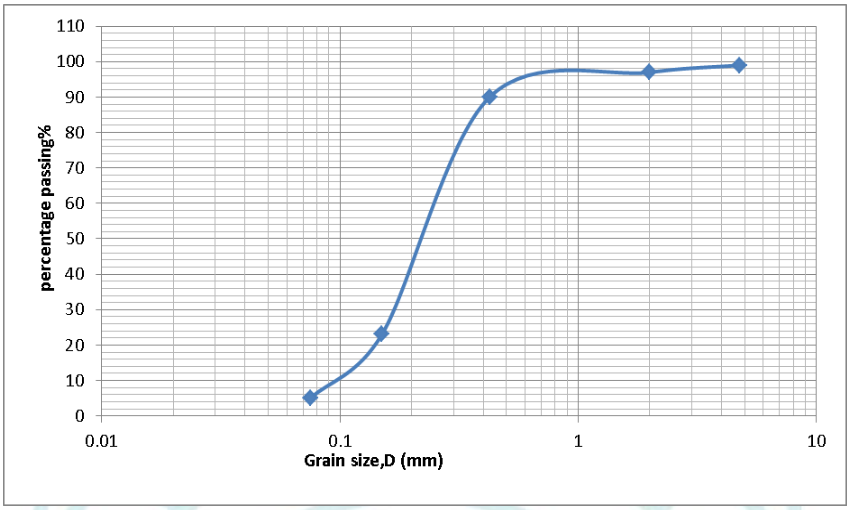

Figure 1. Results of sieves analysis test

3. Small-Scale Model Tests

3.1Testing Apparatus and Equipment

3.1.1 The Model Footing and Soil Tank

Model footing constructed from a steel plate with a side dimension of (89 mm) and thickness (2.3 mm) is employed in all tests as a shallow footing model. The internal dimensions of the soil tank are(600,600,600) mm (length, width, and height), This tank was manufactured from a steel with6 mm thick.

3. 1.2 The Testing Frame and Electronic Systems

To impart static vertical load to the footing, a testing frame was designed and manufactured. The two-ton capacity piston of a hydraulic jack was supported by a testing frame .The hydraulic jack is attached to a 180 mm long nickel shaft that has a hole on the other end that connects to the load cell when the load is applied. The hydraulic jack contains a gauge that measures the amount of pressure being applied. The load cell is made of stainless steel and has capacity of 2 tons. The amount of applied load was recorded using a digital weighing indicator model (SI 4010). The two dial gauges connected to magnetic supports in order to measure the average settling during the test, with a precision of (0.01 mm) as shown in (Figure 2.). (Figure 3.) shows drawing of the cross section for plate load test.

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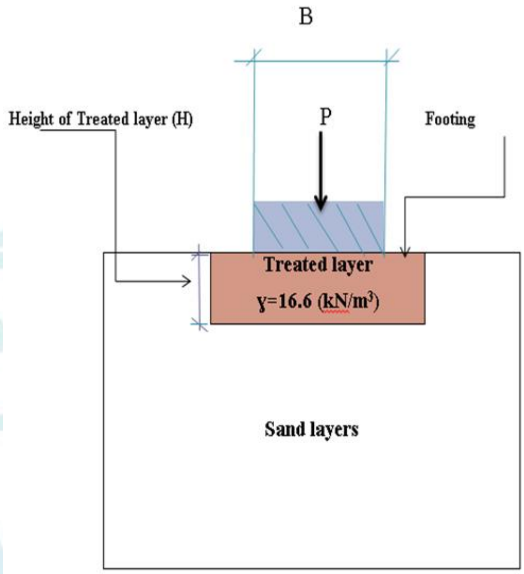

Figure 2. A picture of the test machines

Figure 3. drawing of the cross section for plate load test

3.2 Preparation of Sand Layers

Two series models were tested, with the dry unit weight (15.8) kN/m3 .Tests on unreinforced soil layers were conducted in the first series. In the second series, tests were carried out on artificially cement soil layer. The soil container had been filled in 5 layers, of 0.12 m height each, except for the last layer, it was at different heights, depending on the thickness of the soil cement reinforcement that would be placed inside , until reaching 0.6 m of height. At γ_d=15.8 KN/m3, the sands' effective peak strength values were c = 0 kPa and Φ =35.5˚.

3. 3 The Soil-cement Reinforcements

The Soil-cement treated layers with 5% cement content, dry unit weight (16.6) kN/m3, and 10% of moisture content . The treated soil layers were cast in wood moulds, outside from the tank, to prevent disturbing the loose sand there. Following material mixing, the sample was manually compacted in layers with equal thickness , ensuring that each layer satisfied the required moisture and dry unit weight requirements. To prevent changes in moisture content after molding, the specimen was immediately placed in a plastic bag and closed. The samples were removed from the mould after 7 days of curing, and their dimensions and mass were measured with accuracy of around 0.1 mm and 0.01 gm.

The samples was placed in the middle of the tank. At the reinforcement sides, more soil was manually added until it was level with the top. After that, the displacement gauges and loading piston were placed, the small-scale square footing model was set up on the reinforcement and the displacement gages and loading piston positioned. The thickness of the reinforcement, expressed by the ratio H/B: 0.1, 0.3, 0.6, 1. The reinforcement's width, curing period and the foundation's width were kept constant.

4. Test Results and Interpretation

(Figure 4.) shows the results of a small-scale load test on both treated and un treated layers. The characteristics, bearing capacity, bearing capacity ratio BCR, failure modes ,and order of each reinforcement layer are shown in (Table 3.). In this study, bearing capacity was determined from plat load tests. The sand stress at γ_d=15.8 kN/m^3 is 255 KPa. (Figure 4.) shows stress–settlement curves for plates of soils with (γ_d=15.8). The (Figures 4.) shows results for treated layers varying in H/B (0.1,0.3,0.6,1), and illustrate that increasing the treated layer's. (Figure 4.) shows the bearing capacity of the cement-sand increased from (255-270) kPa ,(255-433) kPa, (255-764.5) kPa ,(255-1000) for treated layers varying in H/B (0.1,0.3,0.6,1) respectively. Thickness results in greater failure load values and stiffer stress-displacement responses. Is that by increasing the stabilized soil's height, resistant soil will cover a larger part of the failure zone, and this trend also improvement of a shallow foundation's bearing capacity. The test findings appear to be substantially correlated with the ratio H/B. The behavior stiffens and gets stronger as H/B increases in soil. In (Figure 4.) It can be seen that the stress-settlement curves with H/B = 0.1 and untreated sand only coincide up to a certain load. This similarity, which is only true up to a certain load, is certainly not coincidental. Up until a certain point, untreated sand distributes its load through the same area of the artificially layer with H/B= 0.1. In other words, the H/B=0.1 sand-cement layer is acting like it is a part of the foundation structure. Thus the artificially layer with H/B=0.1 shows a slight improvement, so we consider at H/B = 0.6 the effective percentage of stabilization Figure (5.) shown The relationship between bearing capacity and H/B ratio for cement treated -soil.

The unreinforced soil have a failure was noticed in plat load tests. Foundation on sand with γ_d=15.8 kN/m^3 , the failure appearance suddenly at the sand surface and significant bulging of the sheared mass of sand accompany the failure. This type of failure is similar to what Terzaghi [15] and by De Beer and Vesic [16] had identified as General shear failure. The sand-cement layer has occasionally fractured at specific settlements. A sudden stress drop in the stress-settlement curves was a definite indicator of the start of cracking. The fissuring noticed at the reinforcement’s sand, near the edges of the foundation when using H/B ratio 0.6 and 1, or at the footing’s central axis and near the edges of the footing when using H/B ratio0.1 and 0.3, Figure (6.) explain Fissured failure mechanism at H/B=0.1, 0.3, 0.6, 1. Once the stress had dropped, it gradually increased again until, eventually, another stress drop connected to an increase in the fissuring took place. Throughout the duration of the test, the top of the plate settlements were always downward. However, until the cemented top layer physically failed, displacements outside the plate were downward. at which time there was a sudden reversal in the movement's direction. In addition to scale-related issues, the deformability of the soil will have a significant impact on the bearing behavior of various foundation sizes (Lambe and Whitman 1979)[17]. Gibson (1967)[18] demonstrated that the settlements are unrelated to the size of the foundation. Lambe and Whitman(1979) stress that these common behaviors are only appropriate under low stress levels relative to the bearing capacity.[19] suggests that the foundation and reinforcement behave like a single element with a virtual width equal to the reinforcement's in the case of punching failure.

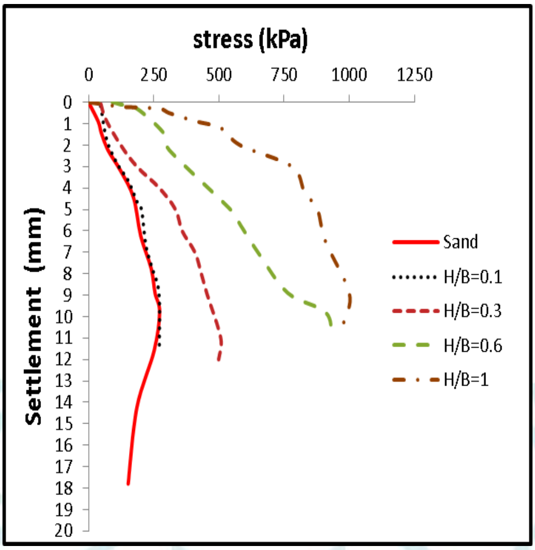

Figure 4. Results of small-scale test

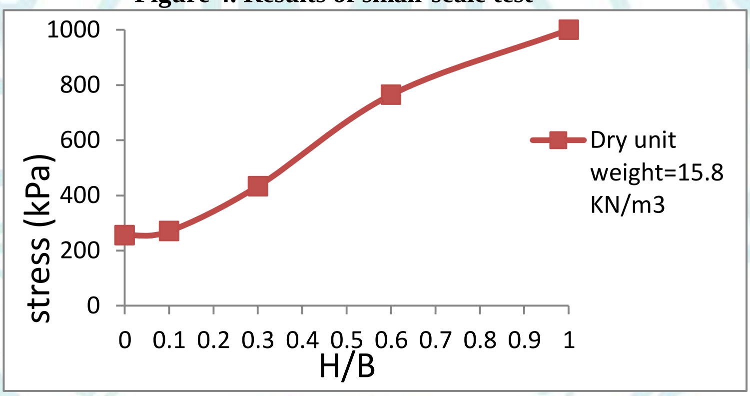

Figure 5.The relationship between bearing capacity and H/B ratio for Cement treated -soil.

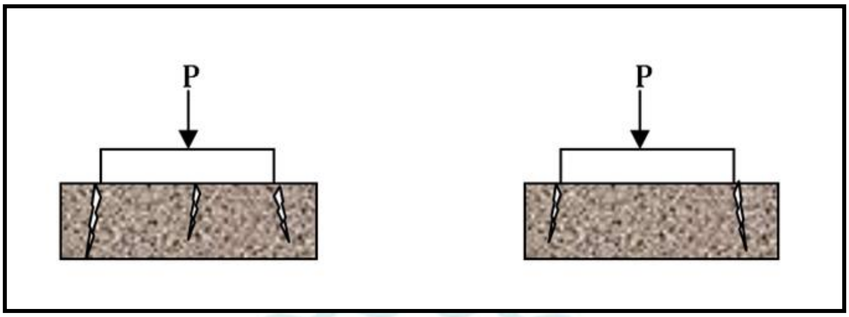

Figure 6. Fissured failure mechanism (a) at H/B=0.1, 0.3 (b) at H/B= 0.6, 1.

Table 3. Results of small scale tests

Test No	γ_d (kN/m^3)	Cement content %	H/B	S/B 10%		Failure
				qu (kPa)	BCR	
1	15.8	5%	0	255	1	General
2			0.1	270	1.05	Fissure
3			0.3	433	1.5	Fissure
4			0.6	764.5	2.7	Fissure
5			1	1000	3.5	Fissure

According to (B. M. Das & Omar, 1994)[20] The (BCR) was defined as the bearing capacity ratio is non dimensional form for the enhanced of the ultimate bearing capacity:

$$BCR = qu(R)/ qu \qquad (1)$$

Where q$u(R)$ and qu are the ultimate bearing capacity of reinforced and unreinforced soil respectively.

5. Concluding

- H/B ratio is seen as identical parameter regarding the bearing capacity of sand soil. since increasing H/B ratio causes increasing bearing capacity and decrease settlement ,where the bearing capacity increased from 255 kPa to1000 kPa .
- The bearing capacity increases significantly and noticeably at H/B = 0.6, so we consider

at H/B = 0.6 the effective percentage of stabilization.

- Showed The result of small scale load tests of square footing resting on the cement-reinforcement soil layer broke, showing a fissure was located close the footing's edge and central axis with H/B (0.1,0.3) or it was located close the footing's edge only with H/B (0.6, 1).

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