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Effect of Sand Wall Stabilized with Different Percentages of Lime on Bearing Capacity of Foundation

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***Abstract*—**Recently sand wall started to gain more attention as the sand is easy to compact by using vibroflotation technique. An advantage of sand wall is the availability of different additives that can be mixed with sand to increase the stiffness of the sand wall and hence to increase its performance. In this paper, the bearing capacity of circular foundation surrounded by sand wall stabilized with lime is evaluated through laboratory testing. The studied parameters include different sand-lime walls depth (H/D) ratio (wall depth to foundation diameter) ranged between (0.0-3.0). Effect of lime percentages on the bearing capacity of skirted foundation models is investigated too. From the results, significant change is occurred in the behavior of shallow foundations due to confinement of the soil. It has been found that (H/D) ratio of 2 gives substantial improvement in bearing capacity, and beyond (H/D) ratio of 2, there is no significant improvement in bearing capacity. The results show that the optimum lime content is 11%, and the maximum increase in bearing capacity reaches approximately 52% at (H/D) ratio of 2.

***Keywords*—**Lime-sand wall, bearing capacity, circular foundation, clay soil.

I. Introduction

PROBLEMS of bearing capacity of shallow foundations have been widely discussed in the geotechnical engineering literature. One of important problems in shallow foundations was based on soft clay. Till now, numerous methods have been presented to increase of foundation bearing capacity in soft clay. One of these methods used is skirt foundation. Building a skirted foundation led to confining the underlying soil, generates a soil resistance on skirt side that helps the foundation to resist sliding of soil [4]-[9]. The sand wall stabilized with lime around foundation is considered as skirt. Lime mixture with sand wall was used to increase the stiffness of wall. The cost of this method is cheaper than the other conventional methods (such as diaphragm wall, secant pile).

In the literature, several studies were addressed to the effect of skirted foundations on ultimate bearing capacity. [9] studied skirted foundations involving in dined skirt and vertical skirt that surround one side (or more) of the soil mass beneath foundation. Establishing vertical skirt at the base of foundation will confine soil leading to generating resistance on the side of skirt. This will make the foundation able to resist sliding. To investigate the behavior of one-sided skirted strip foundation under eccentric and inclined load on foundation, experiments and numerical analysis were carried out. The investigation included different angles of load inclination, load eccentricities, and lengths of skirt. A comparison was done between bearing capacity values for all cases. Hence, the favorable conditions of design were proposed. Ultimate bearing capacity improvement ratio was 5.50 times the free skirt foundation. Moreover, the foundation resisting against sliding increased owing to the reaction of the horizontal soil created as a result on the slide of skirt. [11] handled the behaviors of a structural skirted-strip footing adjacent to a sand slope by lab tests and numerical model. Considerations of skirt depth, skirted footing location with respect to the slope crest and the inclination of slope have been investigated. The results give a remarkable influence on increasing bearing capacity of the structural skirts surrounding a strip footing near a sand slope. When the depth of skirt increased and angle of slope decreased, the bearing capacity improved together with extra improvement in the case where the edge distance of footing from slope crest increased. To decrease the deformation of slopes and control the subgrade horizontal movement, skirt is considered an efficient technique.

This article is aimed to estimate the improvements in bearing capacity and settlement reduction ratio of foundation surrounded by lime - sand wall.

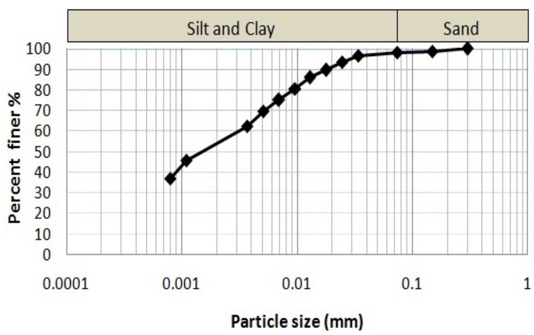

Fig. 1 Grain size distribution of clayey soil used

II. Experimental Work

A. Material Used

Brown clayey soil samples were obtained from site in east of Baghdad. The brown clayey soil was subjected to routine laboratory tests to determine physical and chemical properties. Table I shows the physical properties of the brown clayey soil.

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The test results show that the soil consists of 3.2% sand, 96.8% silt and clay. According to the unified soil classification system, the soil is classified as CL as shown in Fig. 1. The sand properties are given in Table II. Fig. 2 illustrates the grain size distribution of the sand used in tests.

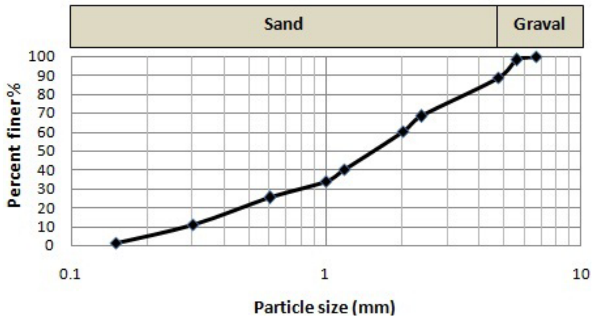

Fig. 2 Grain size distribution of sand used

TABLE I
PHYSICAL AND CHEMICAL PROPERTIES OF CLAY

Index property	Index value
Liquid limit %(LL)	42
Plastic limit %A(PL)	19.5
Shrinkage limit %(SL)	14.2
Plasticity index %(PI)	22.5
Activity (At)	0.60
Specific gravity (Gs)	2.69
Gravel %	0
Sand %	3.2
Silt and Clay %	96.8
Gypsum content %	2.92
Total Dissolved Salt TDS %	3.7
SO_3 content %	1.8
Organic matter O.M %	0.73
pH value	9.32
Classification (USCS)	CL
Saturated Unit Weight (kN/m^3)	15

TABLE II
PHYSICAL PROPERTIES OF SAND

Index property	Index value
Max. Dry Unit Weight (kN/m^3)	20.5
Min. Dry Unit Weight (kN/m^3)	16.5
D10 (mm)	0.28
D20 (mm)	0.48
D30 (mm)	0.8
D50 (mm)	1.6
D60 (mm)	2
Coeff. of Uniformity (Cu)	7.14
Coeff. of Curvature (Cc)	1.14
S_N *	7.26
Gravel (%) (G)	12
Sand (%) (S)	87
Fines (%)	1
Classification (USCS)	SW
Specific Gravity (Gs)	2.65

*S_N is suitability number for rating backfill proposed by [10] as cited by [1].

B. Model Preparation and Testing

Beds of fully saturated clay were prepared inside steel tank with dimensions 300 mm x 600 mm x 350 mm, and thickness of steel plates was 4 mm. Several trials of natural drying and mixing clay with water were achieved to warranty soft clay at undrained shear strength 16 kPa. Fig. 3 illustrates the undrained shear strength with different water contents.

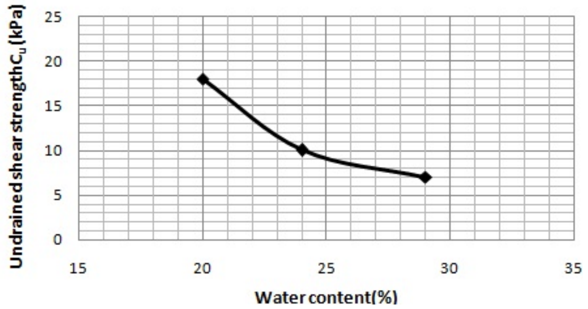

Fig. 3 Variation of undrained shear strength versus water content

The clay was placed in layers inside the tank, and each layer was tamped gently with a metal hammer of 9.87 kg and dimension of hammer 150 mm x 150 mm in order to remove any entrapped air. The process continues till reaching a thickness of 250 mm in the steel tank. Final layer surface was scraped, leveled, and then covered with polythene sheet to prevent any loss of moisture. A wooden board with dimensions 300 mm x 600 mm x 25 mm was placed on clay surface and put 5 kPa seating pressure for one day to regain part of clay strength. The clay was moved around the foundation with width 30 mm and vertically to the required depth. The well graded sand with different percentage of lime was carefully charged into the hole with five layers with gentle tamping at each layer to obtain dry unit weight of 19.3 kN/m^3. Seven days after completion of the construction of the wall, a circular foundation 64.6 mm was placed on clay between sand-lime walls and loaded gradually up to failure. The loading increments were carried out according to the ASTM D1194, 2004, and two dial gauges with accuracy (0.01 mm/division) were fixed in foundation to measure the settlements. A steel tank and load frame during the test are shown in Fig. 4.

III. RESULTS

Before discussing the results of models' tests, it is important to mention that the failure represents a stress corresponding to a settlement 10% of foundation diameter based on the proposal given by [3] as cited by [2].

A. The Effective Sand-Lime Wall Depth on Foundation

The first set of model tests is performed to assess the effect of existence of wall at different depth. Fig. 5 shows foundation with different sand-lime wall depth. Fig. 6 shows q/cu versus $S/D_{foundation}$ (where S and D are settlement and diameter respectively) for 7% lime mix with sand. The results indicate that the bearing capacity increases with the increase in wall depth, which may be referred to the increase the confinement of soil under the foundation. Failure stress versus different sand – lime wall depth is shown Fig. 7. An abrupt improvement in q_{ult} is occurred at H/D=0.5, an improvement in q_{ult} of about 10% was achieved. Also, an obvious increment in q_{ult} about 11% occurred when the sand - lime wall penetrated the soil down to H/D=1. It is noted that the increment in q_{ult} is resumed at H/D=2 and 3 in the extra increase in failure stress.

B. Effect of Lime Percentages in Wall on Bearing Capacity of Foundation

Five models are performed with different lime percentage in sand wall around foundation tested after seven-day curing. The depth of wall is twice foundation diameter for all cases. The maximum percentage of lime 11% is adopted because when the lime percentage increases more than 11 %, this will lead to an increase in the amounts of fine particles, and this leads to decrease in the suitability number for rating backfill (S_N), thus it is difficult to compact, and considerable effort is needed to reach the proper relative density of compaction. In addition, the construction of wall will be uneconomic. Fig. 8 shows bearing ratio (q/c_u) versus settlement ratio ($S/D_{foundation}$) for different lime percentage. From results, it can be observed that, when the lime percentage increase in the sand wall this will lead to increase in the bearing capacity due to the increase in the stiffness of wall. Failure stress versus lime percentages is shown Fig. 9.

Fig. 4 Steel tank and loading assembly

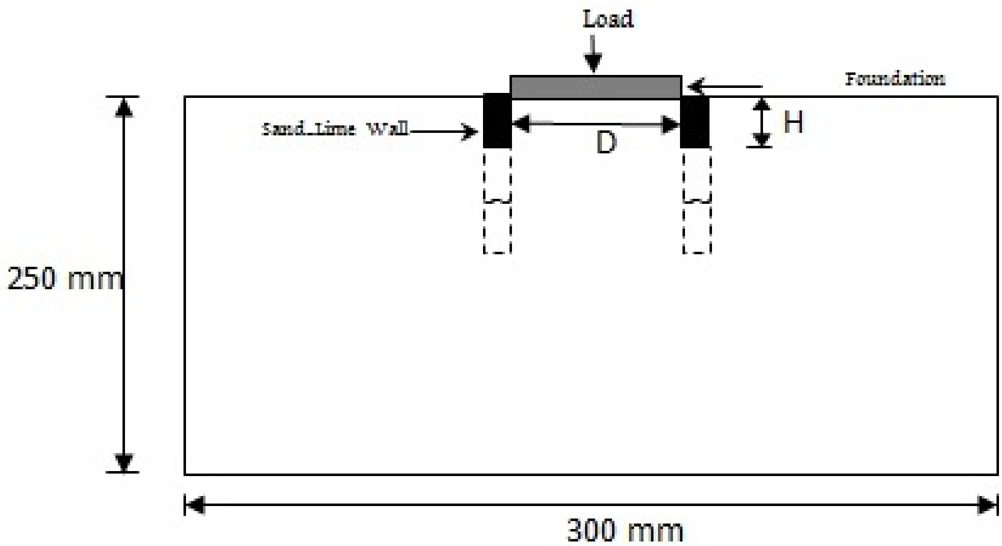

Fig. 5 The foundation with different sand-lime wall depths

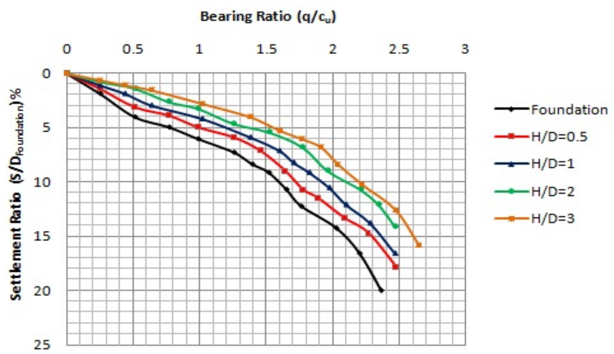

Fig. 6 The bearing ratio vs. settlement ratio for different sand – lime wall depth

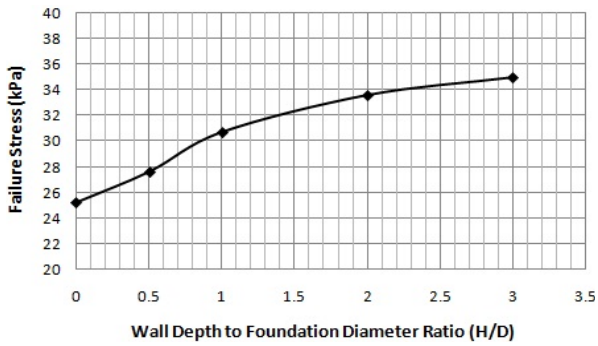

Fig. 7 Failure stress vs. different sand – lime wall depth

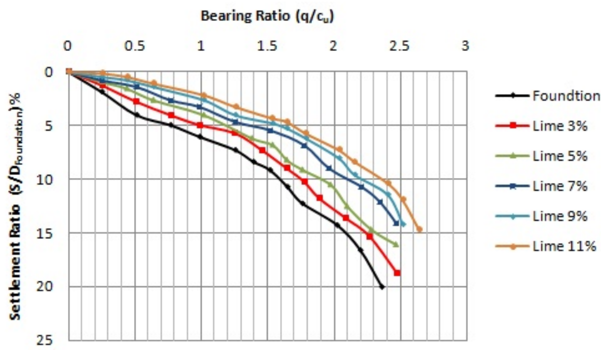

Fig. 8 The bearing ratio vs. settlement ratio for sand wall treated with different lime percentage

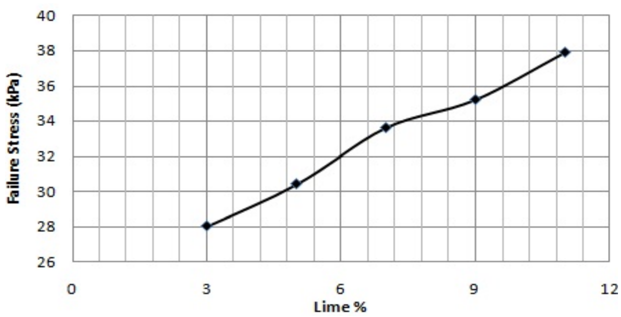

Fig. 9 Failure stress vs lime percentages

IV. Conclusions

1) Sand-lime wall can be considered as a successful future technique for improvement of clay.
2) Lime mixture with sand wall is used to increase the stiffness of wall; this will lead to increase the wall resistance to moving soil under foundation.
3) The bearing capacities are affected by sand-lime wall depth that, the bearing improvement ratio is increased by (9.5, 21.8, 33.3, and 38.8%) for H/D (0.5, 1, 2, and 3) respectively at lime content 7%.
4) Optimum lime content in sand – lime wall is 11%, providing bearing improvement ratio of 52% at H/D equal 2.

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