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BEARING CAPACITY OF SOFT CLAY IMPROVED BY HEATING THROUGH DIFFERENT SPACING CASED BOREHOLES

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ABSTRACT

This paper presents the effect of heat treatment on ultimate bearing capacity and total settlement of soft clay. The soft clay that was used in this study was prepared by mixing Baghdad's clay with sufficient water content which gives a shear strength of 7 kPa.Seven model tests were carried out on soft clay inside a cubic steel box of 750 mm side length after heat treatment, two of which were used as a reference without treatment for comparison. A special heating system was designed and manufactured for this purpose by using the gas as a source of heating through boreholes. Four square patterns casing boreholes having 3.5 cm in diameter and 30cm in length with spacing 3d, 4d, 5d, 6d and 7d (were d is the diameter of the borehole) and the time of heating was six hours for each model. A monotonic load was applied on an aluminum square model footing of 150 mm length and 20 mm thick placed on the center of surface area of the soft clay until the settlement exceeds 10% of the width footing. The results showed that the bearing capacity increases and the settlement decreases with spacing increasing until some limiting value (5d) then the bearing capacity decreases and the settlement increases. The 5d spacing is the best one where the bearing capacity increases nine times and the settlement decreases to one tenth compared with that without heating.

KEYWORDS: Soft Clay, Heating, Borholes, Casing and Spacing

1. INTRODUCTION

Soft soil is defined as the clayey soils with undrained shear strength less than 40 kPa (Brand and Breuner, 1981; British Standard BS 8004, 1986; Kempfort and Gebreselassic, 2006). The design and execution of civil engineering structures on such soils usually associated with substantial difficulties to avoid reducing or controlling such problems, there are several methods and techniques of soil improvement and stabilization illustrates and categories in the literatures, (Kempfort and Gebreselassic, 2006; Mitchell, 1981; Bowels, 1996; Das, 2004).

Heat treatment is one of these methods that used the exhaust gases from burning oil which are driven into boreholes 2 to 3 m in apart to stabilize clay and loess (Lancaster et al., 1978). Many researchers have investigated the effect of heat treatment under laboratory condition on clay samples after burning at different temperatures ranging from 100-1000 ˚c to study its effect on physical and mechanical properties (Mitchell, 1969; Joshi et al., 1994; Abu-Zrieg et al., 2001; Ozcan et al., 2003).

The previous studies showed that the physical and mechanical properties were investigated for clay samples after exposing to different range of temperature by using furnaces without mentioning about the presence of heat inside a soil layer and its effect on bearing capacity and settlement, for this purpose on experimental study was performed through a model tests. Factors that should be considered in choosing this method are available of heating source (gas) low cost, short time duration, (immediate results) a rapid increase in strength occurred after dehydroxylation temperatures were attained and permanent improvement (the atomic arrangement that took place following dehydroxylation caused sufficient increase in bonding of particles and thus increased the strength of the clay), (Joshi et al., 1994; Arunsingh, 2016).

2. MATERIALS USED

2.1. Soil

Soil samples used in this study were obtained from a location in Basmaya site in Baghdad. This soil is collected by disturbed sampling from borrow pits at a depth of 1.5 m. The properties of the soft soil used in this investigation are given in Table 1. According to the USCS classification system, the soil is classified as CL soil. The grain size distribution is shown in Fig. 1.

Table 1. Physical properties of natural soil used.

Index Property	Index Value
Initial water content (WC) %	13
Depth (m)	1.5
Liquid Limit (L.L) (%)	42
Plastic Limit (P.L) (%)	21
Linear Shrinkage (SL) (%)	20
Plasticity Index (P.I) (%)	21
Activity (At)	0.50
Specific Gravity (Gs)	2.69
Sand (0.06 to 2mm) % (S)	4.2
Silt (0.005 to 0.06) (M)%	27.8
Clay (less than 0.005mm) (C)%	68
Classification (USCS)	CL (lean clay)

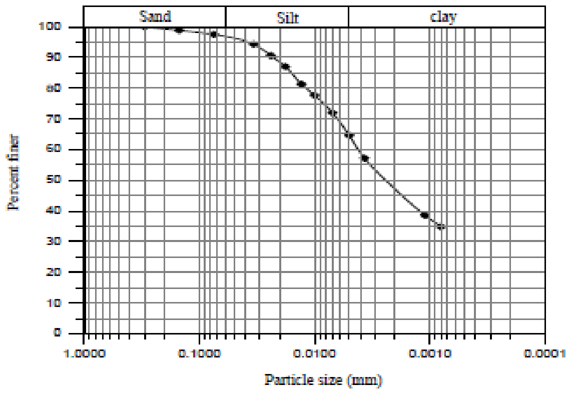

Fig. 1. Grain size distribution for soil.

2.2. Heat source (Cooking gas)

The gas that is used inside the cylinder is a domestic compressed gas; it is composed of methane, but also contains ethane, propane and heavier hydrocarbons. It also contains small amounts of nitrogen, carbon dioxide, hydrogen sulfide, and trace amounts of water (Use this gas because it is available and cheap). Natural gas is about 40 percent lighter than air. It has a high ignition temperature and a narrow flammability range, meaning natural gas would ignite at temperatures above 1,000 degrees and burn at a mix of approximately 4-15 percent volume in air, (ASTM D1835 – 11, 2012).

2.3. Preparation of soil bed and borehole

Prior to the stage of preparing the bed of soil, trail tests were performed to control the efficiency of the method of preparation. Control tests were carried out to determine the variation of shear strength at different water content measured by vane shear device. It was noticed that the 30% water content gave 7 kPa undrained shear strength. The soil was mixed with enough quantity of water .The wet soil was kept inside tightened polyethylene bags two days to get uniform moisture content (Rahil, 2007). After that the soil was placed in 10 layers inside a cubic container of 750mm length to ensure homogeneity in all layers. Each layer was pressed gently with a wooden tamper of 75mm *75mm in order to remove entrapped air. A seating pressure of 5 kPa was applied over the surface of the final layer and left for two days to regain parts of its strength. The construction of the boreholes started after that by bushing 3.5 cm dim steel closed end pipes(casing) down the bed of 30 cm, after several experiments this less diameter is possible to achieve ignition within the soil using gas and air either the depth (30) cm to achieve depth equal to twice of the footing width. A square pattern of 4 boreholes was used with different spacing. This means that the casings are distributed in the soil in a square shape.

2.4. Heating system

To study the behavior of soft clay improved by heating method, it is necessary to simulate the condition as close as possible to these accurse in the field through model tests. To achieve this goal, a special heating system was invented and manufactured. This system has the capability of applied temperature inside the boreholes greater than 1000˚c by the pipes primers, which consists of two pipes (carbon steel) one to pump gas and the other to supply air, Plastic pipes that transport gas and air from the source to The pipes primers, Gas valve, Air valve, Gas bottle and Gas regulator. Plates 1 and 2 illustrate the heating system.

The temperature was measured by a thermo cable connected to the heating control board as shown in plate 3. The heating source is the domestic gas mixed about (10%) with (90%) of air from the compressor to achieve a uniform temperature during the boreholes depth.

2.5. Testing program and testing procedure

Seven model tests were performed, five of which were used to study the effect of spacing after heating. The spacing used were 3d, 4d, 5d, 6d and 7d where d is the diameter of boreholes casing (the spacing were determined depending on that the least spacing between the piles is 2.5 d). The heating time was fixed as six hours for the five models. The other two models were tested without heating as s reference and for comparison one of which consists of four boreholes with 5d spacing and the other without boreholes.

After the model preparation, the square model footing 150 mm length × 20 mm thick manufactured from aluminum was placed on the surface of the soil bed in such a manner that the center of footing coincided with the center of the bed.

A vertical monotonic load was applied through a 10 ton capacity mechanical jack with a constant loading rate of 1mm/ 1min. The load is read from a digital weighing indicator connected to the load cell and the displacement of the footing is read by a dial gage of 0.01mm sensitivity. The load increments are continued until the total settlement exceeds 10% of the model footing width.

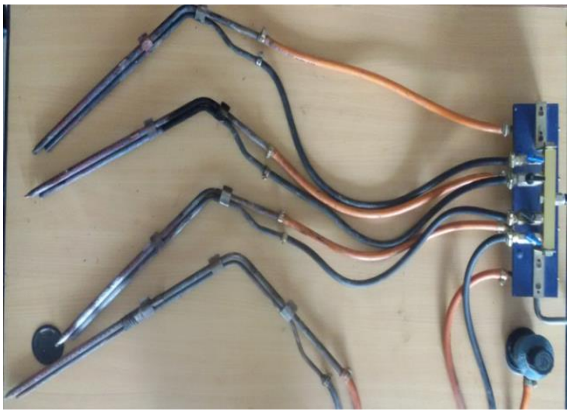

Plate 1. Heating system.

Plate 2. Heating system inside casing to during soil improvement.

Plate 3. The heating control board.

3. RESULTS AND DISCUSSION

The results of experimental study are presented in this section. The presentation focus on the effect of boreholes spacing after heat treatment on bearing capacity and settlement of soft clay that have undrained shear strength of 7 kPa.

For all model tests, the failure was defined as to 10 % of the footing width depending on the proposed given by Terzaghi (1943).

The variation of the applied vertical stress (q) with settlement (s) for all models as shown in Fig. 2. It is clearly seen that the model of failure of model tests without heat treatment is of the local type. The ultimate bearing capacity being (31.5 ,38.6 , 202 , 211 ,266, 198 and 153) kPa for untreated soil without casing boreholes , untreated soil with casing boreholes and treated soil with spacing 3d , 4d , 5d , 6d and 7d respectively .

Fig. 3 Represents the bearing ratio (q /Cu) defined as the applied stress divided by the undrained shear strength plotted against deformation ratio (S_e/b) defined as the settlement divided by the footing width. The bearing ratio of the untreated soil is 4.5. This value is within the acceptable rang of the bearing capacity factor Nc which ranges from 4 to 6.28 for saturated clay at $\Phi = 0$.

The results demonstrate in general that the bearing ratio increases after using the heating treatment comparable with that without treatment and there is a peak value of increment than decreases when increasing the spacing of the boreholes above the optimization distance. This state is true since the increase in temperature decrease the soil water content resulting increase in shear strength. when the burning fuel gas are driven into the borehole, the heat is distributed in a circular path and transferred uniform through the surrounding soil. The temperature decreases with increasing distance from the heating source to the center of square pattern resulting that the undrained shear strength is very high near the source because the soil has become similar to the igneous rock and also decrease with increasing distance from the source as shown in Fig. 4 and Fig. 5. These figures represent the data at the ideal spacing (5d) where distance (d) in these figures represented the diagonal distance from the casing to the center of square pattern (treated zone). The temperature and Cu were measured at specific point on diagonal distances (d) as shown in plate 4.

When the spacing is small, there is an overlap between the effect of temperature of the two boreholes and resulting the overall area affected is small, while with increasing spacing, the overlap decreases and the overlap area increase and the applied load distributed over a large area. When increasing the spacing above the optimization distance, overlap cannot exist and the treated unit cell of each borehole work alone resulting low undrained shear strength in between them.

Fig. 6 represents the bearing improvement ratio (q tr / q unt) versus spacing ratio (spacing/ b). It is clear from the figure that the maximum value of bearing improvement ratio is (8.5) occurred at 5d spacing.

The variation of settlement reduction ratio versus the spacing ratio is shown in Fig. 7. Since the failure was defined as the applied pressure that correspond to S_e/b= 10%, then the settlement reduction ratio was determined as (s tr/ S unt) where(S untreated)represents a settlement at a constant value of 10 % of the footing width of the untreated soil . The (S tr) represents the settlement of the treated soil corresponding to the failure pressure of untreated model. It is clear from the figure that the max value of settlement reduction ratio is (0.67) occurred at 5d spacing.

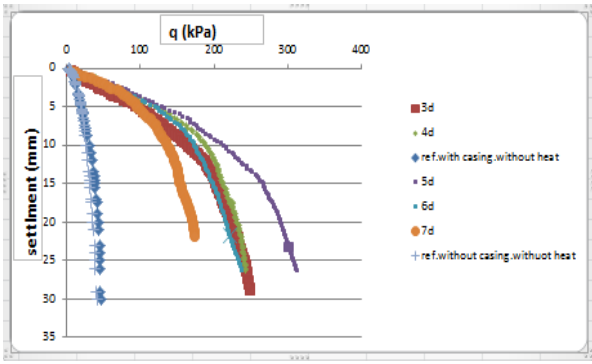

Fig. 2. Relationship between bearing pressure & settlement for all spacing and reference.

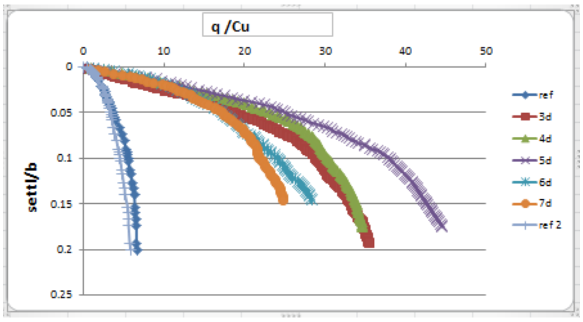

Fig. 3. Relationship between bearing ratio & settlement ratio for cu = 7Kpa.

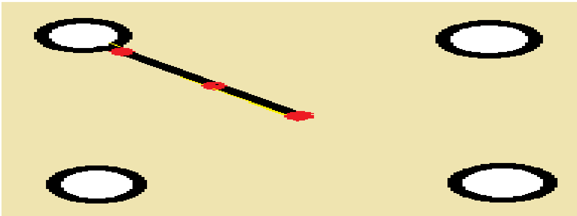

Plate 4. The distance (d) and point (1, 2 and 3) in Figs. 4 and 5.

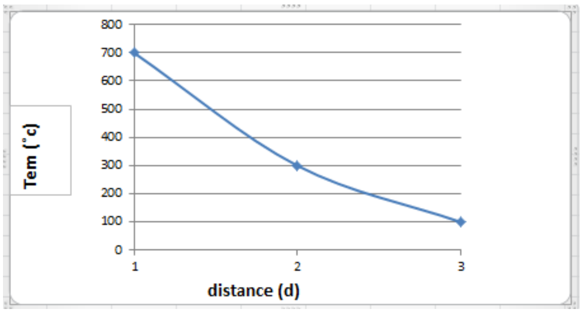

Fig. 4. Relationship between temperature and distance.

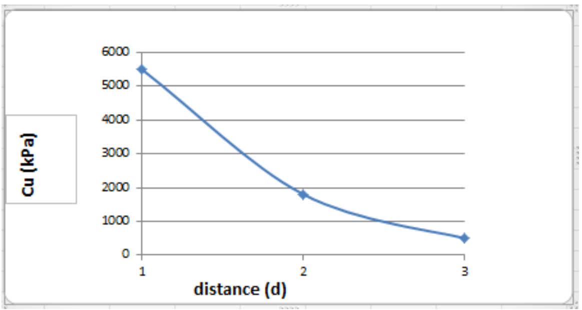

Fig. 5. Relationship between undrained sheer strength and distance.

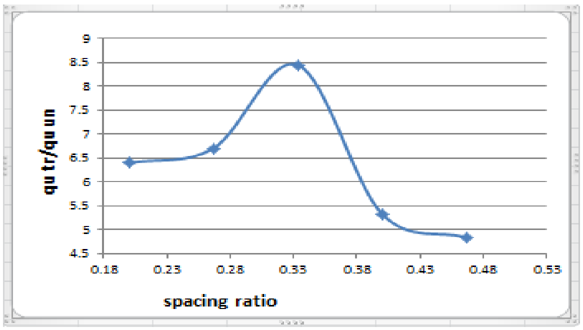

Fig. 6. Variation of bearing improvement ratio versus Spacing ratio.

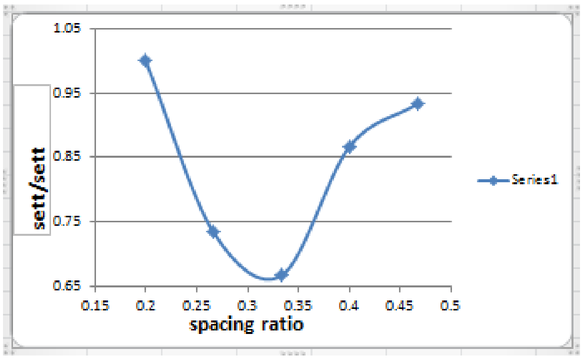

Fig. 7. Represents the relationship between spacing ratio and Settlement reduction ratio.

4. CONCLUSION

The main conclusion in this paper as fallowing:

1. Bearing capacity increases with increasing the spacing between boreholes until some limiting value (5d) then decreasing. The optimization spacing is 5d, its achieve increase nine time in bearing capacity compared with untreated soil.
2. Settlement decreases with increasing spacing between boreholes to some limiting value then increasing. The value of settlement redaction ratio is one tenth compared to untreated soil.
3. As a result of high temperatures, the soil near the boreholes casing turns into a very strong soil as the same to the igneous rock has a very high undrained shear strength, as temperatures decrease, undrained shear strength decreases.

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