Laboratory study on the bearing capacity of cemented layer overlaying dredged sediment

Chunlei Zhang i), Qingsong Liu ii), Fanlu Min iii) and Liang Wang iv)

i) Lecturer, College of Environment, Hohai University, 1 Xikang Road, Nanjing 210098, P.R.China.
i) Engineer, BGI Engineering Consultants Co., Ltd., 15 Fuxingmenwai Yangfangdian Road, Beijing 100038, P.R.China.
iii) Lecturer, College of Civil and Transportation Engineering, Hohai University, Nanjing 210098, P.R.China.
iv) Senior Engineer, South China Sea Marine Engineering and Environment Institute, SOA, 53 Xingang Road, Guangzhou 510300, P.R.China.

ABSTRACT

To study the bearing capacity of cemented layer overlaying dredged sediment, a series of plate load tests were carried out by bearing on double-layered systems formed by an artificially cemented top soil layer. And three different top layers overlaying an ultra-soft dredged sediment had been studied. Applied pressure-settlement behavior was observed for tests carried out using circular steel plates ranging from 50 to 150 mm diameter on top of 40 to 80-mm-thick artificially cemented layers. The effects of cemented layer unconfined compressive strength (UCS), thickness, plate size, and the sediment undrained shear strength on the ultimate bearing capacity (UBC) of this foundation were studied. Test results demonstrated the UBC increases linearly with cemented layer UCS strength, cemented layer thickness, DS undrained shear strength, and the ratio of cemented layer thickness to plate diameter. The UBC decreases linearly with the plate diameter. The pressure and settlement curves can be normalized in terms of pressure/pressure at 3% settlement (p/p 3%) versus settlement-to-diameter (h/D). This result can be used to estimate the pressure-settlement curves for footings of different sizes on different thicknesses of a cemented upper layer by a single curve.

Keywords: dredged sediment, solidification, layered foundation, bearing capacity

1. INTRODUCTION

Nowadays, a large amount of dredged sediment (DS) would be generated in dredging projects in China (W. Zhu, et al, 2002). However, the current upland disposal facilities occupied many land resources and would threaten the environmental safety potentially (W. Zhu, et al., 2007). With the increasing pressure from urbanization, sites occupied by DS formerly need to be reinforced for reclamation. As the low strength properties of DS, traditional soft ground improvement machines, such as bulldozer, excavator and plug board machine, cannot be used in the DS sites (B.R. Ye, 1994). Whereas, it would be a long time before the surface of DS ponds forming a rigid crust by evaporation sufficient and could bear the upper load.

A fast crust forming method was proposed in the paper by building an artificial crust with cemented DS over mud. And then the construction machines could be placed on this layer in a few days. As the cemented layer lied on the mud with very low strength, the properties of bearing capacity were different to current studies on cemented soil over soft clay foundations (G.L. Yang, 1995; C.Y. Hao and G.J. Chen, 1993; Consoli, et al., 2009; Thomé, et al., 2005). Thus, a series of plate load tests were carried out to investigate the behaviours of the layered foundation in the laboratory. And the effects of cement layer UCS strength, thickness, plate diameter, and DS undrained shear strength on the ultimate bearing capacity of foundation were studied.

2 EXPERIMENTAL STUDIES

2.1 Materials

In the test, the dredged sediment was taken from Baima Lake at Jiangsu Province, China. The gravimetric water content is 106%, liquid limit 89%, plastic limit 38%, specific gravity 2.65, bulk unit weight 14.3 kN/m3, organic matter content 2.8%, and clay content (<2μm) 20%. According to the Unified Soil Classification System (USCS), Baima Lake sediment is classified as clay with high plasticity (CH).

2.2 Test method

Table 2 shows the test programs of this paper. The effects of cement layer UCS strength, thickness(H), plate diameter(D), and DS undrained shear strength on the ultimate bearing capacity of layered foundation were studied. The UCS strength of cemented layer was tested after three days hardening, with cement-DS mixture in cylindrical with 3.91cm diameter and 8.0
height. The undrained shear strength \( (c_u) \) of DS was tested by a falling cone test according to the “Geotechnical investigation and testing-Laboratory testing of soil”(ISO/TS 17892-6:2004). \( c_u \) can be calculated by equation (1).

\[
c_u = k(\alpha) \frac{W}{d^2}
\]

(1)

Where, \( c_u \) is the undrained shear strength of DS, g/mm²; \( d \) is the cone penetration depth, mm; \( W \) is the weight of falling cone, g; \( k(\alpha) \) is a parameter about the cone angle and friction coefficient between cone and soil, for the cone angle of 30°, the \( k(30) \) can be set as 0.83 according to the research of Zreik (Zreik, et al., 1995).

| Table 2. Test program. |
|------------------------|
| Cemented layer | Plate diameter (D) (cm) | Duged sediment | UCS strength* (kPa) | thickness (h) (cm) | water content (%) | undrained shear strength \( c_u \) (kPa) |
|------------------|------------------|----------------|------------------|------------------|------------------|------------------|
| 50, 75, 100, 150 | 35, 121, 205, 359 | 4 | 10 | 106 | 0.63 |
| 75 | 121 | 4, 6, 8 | 106 | 0.63 |
| 75 | 121 | 4, 5, 10, 15 | 106 | 0.63 |
| 75 | 121 | 4 | 10 | 85, 106, 128 | 128, 0.18 |

* mass of cement (kg) in m³ DS;
** three days UCS strength of cemented layer.

Figure 1 shows the plate load test apparatus used in the test. The DS foundation was simulated in a cubic tank with 40 cm length of each side. The depth of DS was fixed at 30 cm. The cemented layers were made with a mechanical mixer to mix cement with DS at different cement content (50, 75, 100, 150 kg/m³), after mixing the mixture was put into a square organic glass mold with 41 cm size and different depth (4, 6, 8 cm). The molds with solidified DS were put into a curing box with 20°C and humidity higher than 90% for three days. Then the cemented layer was taken out, the prefabricated cemented layer was cut to fitting the tank size and layered on top of DS.

The load was applied through a system comprising loads, a dowel steel and a loading platform. Three dial gauges with divisions of 0.01 and 50 mm travel were used for settlement measurement. Settlements on the top of the plate were taken at three points, separated 120° from each other. The dial gauges were fixed onto the frame. The load was applied in equal increments of not more than one-eighth of the estimated ultimate bearing capacity. For each load increment, measurement of settlements was made at the following fixed times: 0, 10, 20, 30, 45, 60 and 90 min. In accordance with Chinese Standard GB50007-2002, each increment was maintained for a minimum of 30 min, and the next increment was not applied until the settlement reduced to 0.1 mm in two continuous hours.

3 TEST RESULTS AND ANALYSIS

3.1 Effect of the cemented layer UCS strength on the bearing capacity.

Figure 2 shows the relationship of applied pressure versus settlement for four different cemented layer UCS strength. As shown in the figure, along with the increase in cemented layer UCS strength, the settlement at ultimate bearing capacity correspondingly increased. It was mainly due to the increase in surface layer strength could make the load spread wider, so that a wider range of cemented layer assumed deflection deformation, the load displacement along the center of the deflection was increased. In addition, the value of UBC also can be get as arrows marked in Figure 2.

Figure 3 shows the relationship between UBC and the UCS strength of cemented layer. And a lineal relationship could be found between UBC and UCS strength. It might be attributed to the special properties of the cement solidified crust and dredged sediment, the cemented layer was brittle material with high stiffness, while the DS was saturated and in semi-solid state.
Under the confining effect of cemented layer over DS, it might produce large stress in the DS. Thus, when the cemented layer reached the maximum strength, the DS had not yet any bearing capacity, and the double layer reached the ultimate bearing capacity.

3.4 Effect of the cemented layer thickness on the bearing capacity.

Figure 4 shows plots of applied pressure versus plate settlement for three different cemented layer thickness. As shown in the graph, the UBC settlements of three cemented layer thickness were approximate 6.5%. With the increase of thickness, the pressure-settlement curves turned to the right. It meant that the cemented layer thickness benefited only the shear strength rather than the deformation.

![Fig. 4 Pressure-settlement curves of layered foundation with different cemented layered thickness](image)

Figure 5 illustrates the relationship between UBC and the cemented layer thickness. It revealed a good linearly relationship between UBC and the cemented layer thickness. As the bearing capacity of such special foundation mainly contributed from the shear strength of cemented layer, the failure angles of the cemented layers with different thickness were of the same. Thus, the acting range of shear force of the cemented layers increased correspondingly with the increase of its thickness. And the UBC increased linearly with cemented layer thickness.

![Fig. 5 Effect of cemented layer thickness on the UBC of layered foundation](image)

3.5 Effect of the plate diameter on the bearing capacity.

Figure 6 shows plots of pressure-settlement curves for three different plate diameters. As shown in the figure, the smaller of plate diameter was, the higher bearing capacity and smaller deformation was. While compared the relationship between the UBC values taken from Figure 6 and plate diameter (as shown in Figure 7), the UBC declined with plate diameter. The reason could be ascribed to that the load applying on the foundation was borne by the under soil ranged 1.5-2.0 times of plate diameter. So when the plate diameter is small, the load was borne mainly by the cemented layer itself, the layer has higher strength and rigidity, so the settlement is small and UBC is large. Thus, with the increase of plate diameter, the press was distributed into the DS layer, and the deformation was large and UBC was small.

![Fig. 6 Pressure-settlement curves of layered foundation with different plate diameter](image)

While compared the relationship between the UBC and cemented layer thickness/plate diameter (H/D) in Figure 8, a lineal relationship could be found between UBC and the ratio of cemented layer thickness/plate diameter, except for the 4/5 point which was attributed to the size effect. In addition, the UBC of any cemented layer and DS combinations could be estimated by few tests.

![Fig. 8 Relationship between UBS and the cemented layer thickness/plate diameter](image)

3.5 Effect of DS undrained shear strength on the bearing capacity.

Figure 9 shows the pressure-settlement curves under different DS undrained shear strength. With the increasing of DS undrained shear strength, the curves turned to right. It meant that the undrained shear
strength attributed to the bearing capacity of cemented layer special foundation.

Figure 10 illustrates the relationship between UBC and the DS undrained shear strength. It reveals that UBC have good lineal relationship with DS undrained shear strength. This is mainly because the bearing capacity comes from the combined action of cemented layer and DS layer. The high strength cemented layer attribute more to the UBC than DS strength.

**Figure 10**

![Figure 10](image)

**3.6 Normalization of the pressure-settlement curves**

Thomé et al. (Thomé, et al., 2005) had studied the foundation bearing capacity of cemented layer over soft soil, the normalized the pressure-settlement by divided the pressure with the value of the settle at 3% load plate diameter. The found the pressure-settlement curves comes together by this normalization method, so it’s easy to postulate the bearing capacity of more layered foundations.

**Figure 11**

![Figure 11](image)

According to Thomé’s method, we normalized the pressure-settlement curves of this study as show in Figure 11. It shows that for different cemented layer UCS strength, DS thickness, load plate diameter and DS undrained shear strength, the curves comes closely. The figures shows the UBS settlement occurs at the 6.5% plate diameter. Figure 8 can be used to estimate the pressure-settlement curves of the combination of different factors by few experiments.

4 CONCLUSIONS

(1)The bearing capacity of dredged sediment pond can be increased by forming a cemented layer, which can provide a platform for ground improvement machines to shorten the construction period.

(2)The ultimate bearing capacity increase linearly with cemented layer UCS strength, cemented layer thickness, DS undrained shear strength, and the ratio of cemented layer thickness to plate diameter. The UBC decreases linearly with the plate diameter.

(3)The pressure and settlement curves can be normalized in terms of p/p3% versus δ /D, this result can be used to estimate the pressure-settlement curves for footings of different sizes on different thicknesses of a cemented upper layer by a single curve.

**ACKNOWLEDGEMENTS**

The authors are grateful for the financial support from the Natural Science Foundation of China (51108156, 51408191), the funds of Jiangsu province science and technology support program (BE2014721) and the special funds on Taihu water pollution control of Jiangsu province (TH2013212).

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