3 Field Test on Stiffened Deep Mixed Columns

Guan-bao Ye, Yong-sheng Cai, and Qing Liu

Abstract

A composite column, referred to as Stiffened Deep Mixed (SDM) column, can be used to improve the soft soils. It consists of a Deep Mixed (DM) column inserted by a small-sized precast concrete pile (called core pile as well) in center. The past study (citation) shows that the SDM column can provide high bearing capacity as compared with the pile with the same material of the core pile and same configuration of the SDM column under the same geological conditions. Therefore, the technique of SDM columns has a significant effect on saving construction material and budget. The previous projects indicate that the SDM column can reduce 20–40 % of budget at least. However, its mechanical behaviors have not been well understood yet. To investigate the mechanical behaviors of SDM column, a series of plate loading tests including nine Prestressed High Strength Concrete (PHC) piles and 30 SDM columns in total are conducted in field. Axial strains of two columns are measured during tests by the Fiber Bragg Grating (FBG) Sensor Technology. The axial force distributions of the core piles can be obtained based on the axial strains. The test results show the bearing capacity of SDM column is extremely high and the side resistant ratio between SDM columns and PHC piles is approximately in a range from 1.3 to 2.5.

Keywords

Stiffened deep mixed (SDM) column • Plate loading test • Core pile • Bearing capacity

3.1 Introduction

Deep Mixed (DM) column has been widely used to enhance the bearing capacity and increase stability and reduce settlement of the soft soils around the world (Porbaha 1998; Bergado et al. 1999). However, the low strength and stiffness of DM columns limit its application, especially for certain projects being sensitive to deformation and requiring high bearing capacity on soft soils (Bruce et al. 1998).

A new kind of composite column, called concrete-cored Deep Mixed column or Stiffened Deep Mixed (SDM) column, was proposed in last two decades and provides a new economic alternative to improve the soft soils. The previous projects indicate that the SDM column can reduce 20–40 % of budget at least. This composite column consists of DM column inserted by a precast concrete pile (core pile) in center. The core pile with higher strength and stiffness carries most of the load from the embankments or surcharges. The load carried by the core pile which is, in turn, transmitted to DM column around through their interfaces and then to soil (Dong et al. 2002; Wu et al. 2004). The interface shear strength between the DM column and the core pile, which increases linearly with the unconfined compressive strength of DM column, is sufficient to ensure the core pile and soil-cement can work together (Ding et al. 2010).

G. Ye · Y. Cai (✉) · Q. Liu
Key Laboratory of Geotechnical and Underground Engineering of Ministry of Education, Tongji University, 1239 Siping Road, Shanghai 200092, China
e-mail: cys036@163.com

G. Ye · Y. Cai · Q. Liu
Department of Geotechnical Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China

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Table 3.1 Soil properties

No.	Soil layer	Thickness (m)	Void ratio	Cohesion (kPa)	Friction angle (°)	Compression modulus (MPa)
1	Clay	4.30	1.038	15.7	12.3	3.62
2	Sandy silt	12.90	0.782	4.5	28.6	11.5
3	Fine sand	7.70	0.674	2.5	33.2	17.4
4	Clay	7.60	0.908	29.7	14.8	6.2
5	Fine sand	8.00	0.730	3.1	31.4	14.2

This paper presents a series of plate loading tests of the SDM columns in field which have a long DM column and a short concrete core pile in center. The bearing capacity of the SDM columns are evaluated and the force axial force distributions of the core piles are calculated based on the test results of the axial strains.

3.2 Project Description

The field tests are conducted in a project of 16 residential apartments in Jiangsu Province, China. Pile foundation is adopted for their foundations and the desired bearing capacity is from 2,600 to 4,000 kN with the floors of the apartments from 17 to 26.

The geological condition in the area of the project is investigated and Table 3.1 shows the properties of the subsoil layers.

Layer 3 is selected as the bearing stratum for the pile foundation. In original scheme, Prestressed High Strength Concrete (PHC) piles are selected, but cannot meet the required bearing capacity if the piles seated on Layer 3. Thus, the pile length has to be increased to reach a deeper bearing stratum so that they can satisfy the desired bearing capacity. However, the increasing pile length would increase the budget. After that, the SDM column foundation with the core pile of PHC pile is recommended to replace the original scheme. Before construction, a series of field tests are conducted to determine the pile parameters such as pile length and diameter of both core pile and DM column.

3.3 Field Test

3.3.1 Procedures of Field Test

For feasibility study, plate loading tests are conducted to compare the bearing capacities of PHC piles and SDM columns. Nine PHC piles with different length are constructed individually in different areas as well as 28 SDM columns. The partial test schemes are listed in Table 3.2 in detail. The slow maintained load test method is adopted in the test. For SDM columns, the load plate covers the plan area of both core pile and DM column.

After feasibility study, two additional SDM columns consisting of the DM columns with a diameter of 800 mm and length of 14 m and the PHC piles with a diameter of 500 mm and length of 11 m are installed for the further study on mechanical behavior by employing Fiber Bragg Grating (FBG) Sensor Technology. Hill and Meltz (1997) indicated that “A fiber Bragg grating (FBG) is a periodic perturbation of the refractive index along the fiber length which is formed by exposure of the core to an intense optical interference pattern.”

FBG sensors are embedded in the core piles of SDM columns. To prevent the sensors from damage of construction, two grooves with roughly 1 cm-deep and 0.5 cm-wide along the pile shaft are cut symmetrically using grooving machine. The FBG sensors are pasted in the grooves at certain positions, i.e., 0.7, 2.7, 4.7, 6.7, 8.7 and 10.7 m from the pile top, respectively. Then seal the grooves with epoxy resin so that FBG sensors can be well protected.

3.3.2 Test Results and Discussion

3.3.2.1 Feasibility Study

The bearing capacities of both PHC piles and SDM columns are summarized in Table 3.2. For SDM columns, only several representative columns are presented. The values of the ultimate bearing capacity of SDM columns are in a range from 4050kN to 5500kN. All of them are greater than those of 28 m-long PHC piles and close to those of the PHC piles with length of 33–38 m. It indicates that the existence of DM column surrounding the core pile can significantly increase the total amount of side resistance and the load can transfer from the core pile to the DM column and then to the surrounding soil effectively. Moreover, the Load-settlement curves (Q-s curves) in Fig. 3.1 indicate that the settlement of SDM columns is close to those of PHC piles.

In addition, the average side resistances of PHC piles and SDM columns are calculated while ignoring the tip resistance as the side resistance contributed the most part of the bearing capacity. The side resistances of SDM column ranging from 124.0 to 164.1 kPa are significantly greater than those of PHC piles with a range from 65.5 to 98.4 kPa, and the side resistance ratio between SDM columns and PHC piles is approximately from 1.3 to 2.5.

Table 3.2 Test scheme and results

No.	PHC pile			DM column		Ultimate bearing capacity (kN)	Side resistance (kPa)
	Length (m)	Diameter (mm)	Thickness (mm)	Length (m)	Diameter (mm)		
1	28	500	125			2880, 3520	65.5, 80.0
2	33	500	125			4,800	92.6
3	34	500	125			4,440, 4,680	83.1, 87.6
4	36	500	125			4,440	78.5
5	37	500	125			4,840, 5,720	83.3, 98.4
6	38	500	125			5,720	95.8
7	12	400	95	16.5	800	4,950	164.1
8	13	400	95	17.0	800	4,960	151.8
9	13	400	95	16.5	800	4,050	124.0
10	13	500	125	18.0	800	4,950	151.5
11	14	400	95	18.0	800	5,150	146.4
12	14	400	95	17.5	800	5,040	143.2
13	14	400	95	18.0	800	5,400	153.5
14	14	500	125	18.0	800	5,500	156.3
15	15	500	125	18.0	800	5,500	145.9

Note 1. No. *1–6* represent PHC piles and No. *7–15* represent SDM columns
2. For some SDM columns, no significant failure occurs and the max load applied is considered as the ultimate bearing capacity
3. For SDM column, the core pile length is considered as the pile length when calculating the side resistance, because the axis force is small below the core pile (Ding et al. 2010)

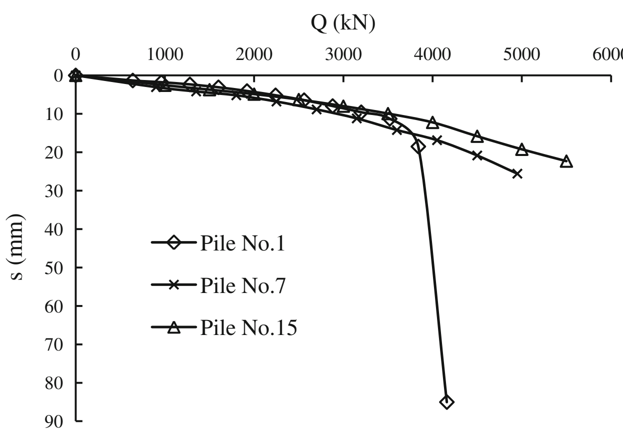

Fig. 3.1 Q-s curves of plate loading test

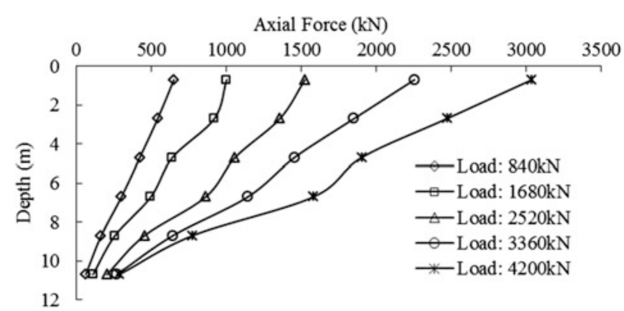

Fig. 3.2 Axial force distribution of core pile

Table 3.3 Axial force distribution on top of SDM column

Load (kN)		840	1,680	2,520	3,360	4,200
Core pile	Force (kN)	699	1,114	1,687	2,420	3,269
	Percentage(%)	83	66	67	72	78
DMcolumn	Force (kN)	141	566	833	940	931
	Percentage(%)	17	34	33	28	22

Generally speaking, the test results indicate that the bearing capacity of SDM column is extremely high and the settlement is small.

3.3.3 Axial Force Distribution

The max load applied on two additional SDM columns is 4200 kN and no significant failure occurs, so the bearing capacity of single pile meets requirement. The axial force distribution of the core pile at different load steps is shown in Fig. 3.2. It shows that the axial force decreases rapidly and almost linearly along the pile length from the top to the pile base. Based on least squares method, the axial force of core pile on top can be calculated. Then, the axial force of DM column on top can be obtained, shown in Table 3.3. It indicates that the core pile carries the most part of load from 66 to 83 % and the percentage increases with the applied load applied excluding 840 kN load.

3.4 Conclusions

Based on the analyses on the plate loading tests of the SDM columns in field, the following conclusions can be drawn:

- Bearing capacity of SDM column is extremely high because the DM column around the core pile can significantly increase the total amount of side resistance.
- The side resistance ratio between SDM columns and PHC piles is approximately from 1.3 to 2.5.
- The core pile of SDM columns carries most part of the external load from 66 to 83 % and the axial force of core pile decreases almost linearly along pile length.

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