Missouri University of Science and Technology
Scholars' Mine

International Conference on Case Histories in Geotechnical Engineering

(2004) - Fifth International Conference on Case Histories in Geotechnical Engineering

15 Apr 2004, 7:00pm - 8:30pm

Load Transfer of Cement-Soil Column by Full Scale Load Test in Soft Clay

Jiwei Duan
Converse Consultants, Parsippany, New Jersey

Issa Oweis
Converse Consultants, Parsippany, New Jersey

Follow this and additional works at: https://scholarsmine.mst.edu/icchge

Part of the Geotechnical Engineering Commons

Recommended Citation

Duan, Jiwei and Oweis, Issa, "Load Transfer of Cement-Soil Column by Full Scale Load Test in Soft Clay" (2004). *International Conference on Case Histories in Geotechnical Engineering*. 17.
https://scholarsmine.mst.edu/icchge/5icchge/session08/17

This work is licensed under a Creative Commons Attribution-Noncommercial-No Derivative Works 4.0 License.

This Article - Conference proceedings is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in International Conference on Case Histories in Geotechnical Engineering by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

Proceedings: Fifth International Conference on Case Histories in Geotechnical Engineering
New York, NY, April 13-17, 2004

LOAD TRANSFER OF CEMENT-SOIL COLUMN BY FULL SCALE LOAD TEST IN SOFT CLAY

Jiwei Duan
Converse Consultants
Parsippany, New Jersey-USA-07054

Issa Oweis
Converse Consultants
Parsippany, New Jersey-USA-07054

ABSTRACT

The deep mixing method (DMM), by which, soil and cement are blended together in situ to form soil-cement columns, is used throughout the world. In this paper, load transfer behavior of cement-soil columns was performed by full-scale load tests in situ. By developing Chin's method (Chin, 1970), a method is presented to estimate the pile ultimate capacity based on the load to settlement curve of pile static load test. The measured results showed that the strain near the pile tip was small. The major deformation of the pile is in the range of 0 to the effective length, beyond which the strain of the pile is less than 10%. The increase of the load mainly affected the deformation of the pile within the range of 0 to l_c, but hardly over l_c.

INTRODUCTION

On the southeast coast of China, soil consists of soft clay or peat. This soil is about 40 to 60m deep and has low shear strength, high compressibility, and low permeability. For low buildings with 3 ~ 4 stories, pile foundations are not economical. Some ground improvement methods, therefore, are often applied such as wick drain, pre-loading, deep mixing and jet grouting. Since 1980 deep mixing has been widely used in China.

The deep mixing method (DMM) is that soil and cement are blended together in situ to form soil-cement columns, which may be used as a foundation of low buildings, tanks, retaining walls, highway embankments and for waterproofing the excavation system. This method is low cost, and has low noise, and no vibration. It is especially well suitable for city construction where noise and vibration is limited.

Because the strength and stiffness of cement-soil column are much less than those of common piles such as concrete and steel piles, they are considered as flexible piles (Duan, 1993,1996, Duan et al., 2000). In this paper, load transfer behavior of cement-soil columns was studied by full-scale load tests. A method was presented to estimate pile ultimate load. The load transfer behavior was demonstrated by the measured results.

SITE CONDITIONS

The Zhejiang Shan Gao Chemical Company is located in the north of Ningbo, Zhejiang, China. By September 1991, 24 cement-soil columns constructed by deep mixing were completed. The static load tests were performed from October through November in 1991. The tests included 11 single piles, 5 groups of a single pile with a concrete cap, and 2 groups of 2×2 piles with a cap. Three piles, composed of 2 single piles and a single pile with a square cap, were chosen to investigate load transfer behaviors.

The site soil profile consisted of:
(1) Top soil: 0.2 to 0.4 m, soil with roots, and trace of organic material.
(2) I_2 layer: 1.07 to 2.8m, brown and gray yellowish varved clay with silt.
(3) I_3 layer: 0.91 to 8.8 m, gray soft clay.
(4) II_1 layer: 3.4 to 16.22m, gray soft clay.
(5) II_3 layer: 8.56 to 21.40m, gray soft clay.
and its properties are listed in Table 1.

Table 1. Properties of soil in the field

No	Depth from Ground (m)	Unit Weight (KN/m^3)	Water Content (%)	Plasticity Index (%)	Vane Strength (kpa)	SPT
I_2	1.63	19.06	33.02	23.22	36.42	3
I_3	3.79	18.09	41.70	15.28	22.72	2
II_1	16.05	16.93	54.15	20.69	17.07	WOR *

* Weight of Rods

METHOD

In order to obtain load transfer of cement-soil columns, several methods were considered: One was to directly attach strain gauges on the surface of the column (Lu Y., et al., 1989). This method, however, was only performed in the lab and was difficult to implement because it was not possible to attach gauges on the shaft of the column in the field. Another method (Isenhower 1999) was to insert steel strain gauges into the columns in the field. However, because the strength and stiffness of the steel rod were much higher than that of the soil-cement column, this might cause stress concentration on the rod. In order to solve this problem, an acrylonitrile-butadiene-styrene (ABS) plastic pipe was finally selected to mount the strain gauges. Electric strain gauges were attached on the pipe. The elastic modulus and Poisson's ratio of plastic pipes were 2.18*10^3 Mpa and 0.34, respectively based on the lab test. Young's modulus, hence, is greater than that of cement-soil column, but much less than that of steel.

The plastic pipes were divided into about 1 meter to 1.5 meters segment in length. Four strain gauges were glued in the middle of the pipe for each segment and shown in Fig.1. Then, they were covered by epoxy for waterproofing. Due to plastic creep, the condition stable time, was defined as the time beyond which the plastic creep ends and was determined in the lab. Thus, readings at each load increment had to be taken after the conditional stable time in the field to eliminate the plastic creep.

When the cement-soil column was completed over one month, a 108cm auger was used to drill a hole in the center of the pile all way down to the pile bottom. The strain gauge pipes were pushed in and welded to each other. As they reached the bottom of the pile, the grout was pumped into the hole from the pile tip.

The soil-cement was sampled as an 108cm-auger was drilled and the samples were delivered to the lab for unconfined compressive strength tests. The lab results are given in Fig.2. From the chart, the strength was relatively small because the curing time was short (one month). On the other hand, the strength in the upper layer (0 ~5m) was greater than that in the deeper layer. The data for three-test piles are listed in the Table 2.

Table 2. Three Test Piles Information

Pile No.	Pile Length (m)	Pile Diameter (mm)	Weight Ratio of Cement to Soil (%)	Number of Strain Gauges
#1	15.0	500	15	10
#2	12.5	500	15	8
#3	12.5	500	15	9

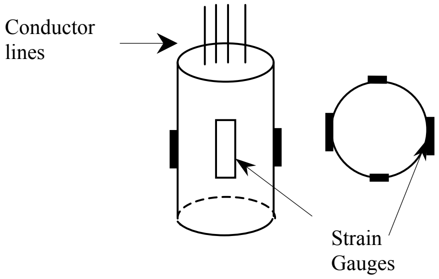

Fig. 1 "Plastic Pipe Strain Gauge"

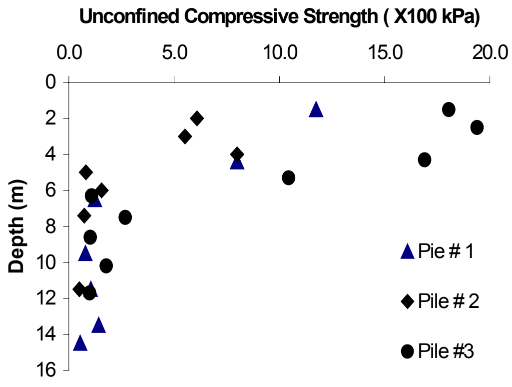

Fig. 2 In-situ Unconfined Compressive Strength of Cement-soil Column along Depth

ANALYSIS OF MEASURED RESULTS

Procedure of Static Load Test

Static load tests were performed in accordance with the " Zhejiang Foundation Design Building Code on Soft Soils (in Chinese)". According to this Code, the test is "quick test", that is, readings that are taken in an hour after a new load increment is exerted. The full load is defined as:

(1) pile top movement greatly increases at certain load and top damage is obviously observed;
(2) the settlement at certain load is five times greater than that at previous load and the total movement is greater than 50 mm;
(3) The total settlement is greater than 100 mm.

Linear Limit and Ultimate Loads for Test Piles

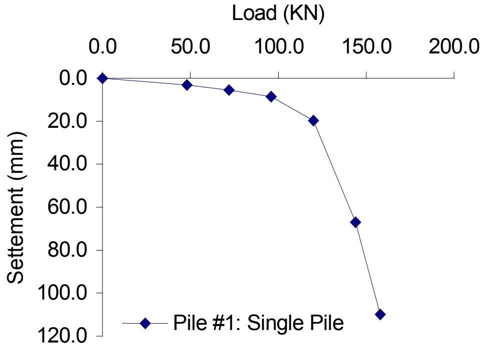

Fig.3 Load vs. Settlement Curve for Pile #1 (Single Pile)

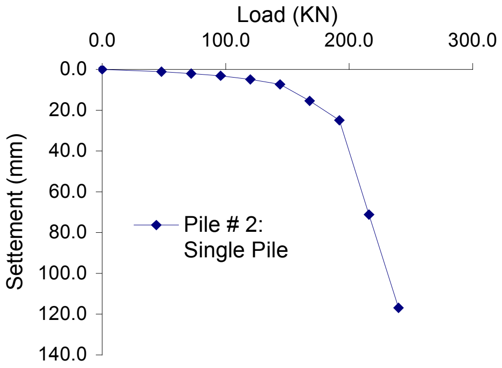

Fig.4 Load vs. Settlement Curve for Pile #2 (Single Pile)

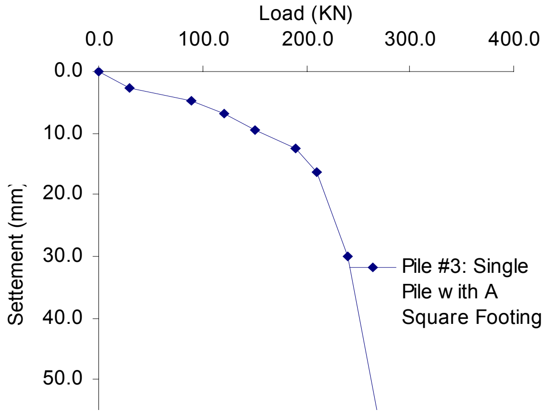

Fig.5 Load vs. Settlement Curve for Pile #3 (Single Pile with a Square Footing)

Figs 3 to 5 showed curves of applied load against settlement on the pile top for three test piles, which are called P-S curves herein. By developing Chin's method (Chin, 1970), a method was presented for determining ultimate capacity (Duan, 1997). In Chin's method, a few initial points on the curve approximately depict linear and excluded. The rest of the points depict hyperbolic. The ultimate capacity is determined by the hyperbola. In practice, the ultimate capacity by Chin's method is often 10 to 20% more than that by others (Davission).

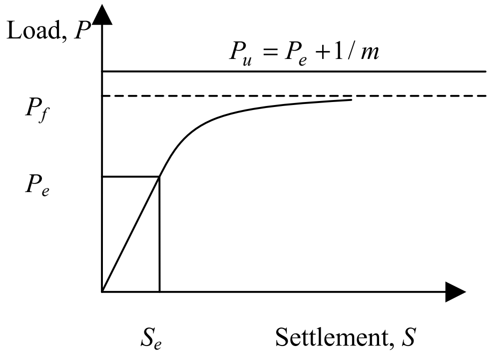

Fig. 6 Load vs. Settlement Curve Assumption

In the hyperbola based on the method by Duan (1997), a P-S curve is considered as two curves: a line and a hyperbola (Fig. 6). Two equations, therefore, is given by:

$$P = kS,\ 0 \le P \le P_e \tag{1}$$

$$S_1 / P_1 = mS_1 + c,\ 0 \le P_1 \le P_u \tag{2}$$

where $P_1 = P - P_e, S_1 = S - S_e, P_u = P_e + 1/m$, P_e and S_e are defined as linear limit load and corresponding settlement on the P-S curve. P_u is the ultimate capacity.

Because the capacity by Chin is often greater than that by the others, a reduction coefficient, R, is introduced and defined as:

$$R = \frac{P_f}{P_u} \tag{3}$$

where P_f is considered as the actual ultimate load. This empirical parameter depends on pile type, soil properties and other factors. It is taken as 0.85 in this paper.

Tables 3 and 4 illustrate the capacity calculation for Pile #1: In Table 3, the linear limits (P_e and S_e) were determined by correlation coefficients. For example, while the first two points were used, the correlation coefficient was 1. As the chosen points increased, the correlation coefficients decreased. At the fifth line, the coefficient was 0.8995. Thus, the linear limit was approximately 72 KN and corresponding settlement was 5.47mm. As soon as P_e and S_e were known, P_1 and S_1/P_1 were calculated and listed in Table 4. It can be seen that the correlation among the points beyond the linear limit was good. The parameter-m might be obtained by linear regression method. By Equation (2), the ultimate capacity was given in Table 4. In Table 5, the final capacities of all test piles are given by Equation (3). In Table 5, the results are compared with those by the Code-" Zhejiang Foundation Design Building Code on Soft Soils (in Chinese)". They are close.

Table 3. Linear Limits of Pile #1

Load (KN)	Settlement (mm)	Correlation Coefficient	P_e *(KN)*	S_e *(mm)*
0	0.00			
48	3.15	1.0000		
72	5.47	0.9947		
96	8.59	0.9858	72	5.47
120	19.8	0.8955		
144	67.02	0.7745		
158	109.89	0.8033		

Table 4. Ultimate Capacity of Pile #1

P (KN)	S_1	$\frac{S_1}{P_1}$	Correlation Coefficient	m	*Ultimate Capacity* (KN)
0					
48					
72	0.00	0.00			
96	3.12	0.13	1.0000		
120	14.33	0.3	0.9712		
144	61.55	0.85	0.9916		
158	104.42	1.21	0.9915	0.01131	160

Table 5. Comparison of Actual Ultimate Capacity by Duan (1997) and by the Code (" Zhejiang Foundation Design Building Code in Soft Clay (in Chinese)".)

Pile No.	P_e (KN)	P_u (KN)	P_f by the presented (KN)	Pf by Code * (KN)
#1	72	160	136	144**
#2	72	243	206	192
#3	190	312	265	240

** The Ultimate Capacity is taken the previous load before the damage load based on the Code. The damage load is defined in the section- " procedure of static load test."

** The crack was found on the pile top when the load was 144 KN.

Load transferred behaviors of Cement-soil Columns

(1) Single Pile

From here to the end, the ultimate capacity is referred to as P_f in Table 5. Figs 6 and 7 showed measured strain transfer curve along pile length for Pile #1 and #2, respectively. In Fig. 6, when the applied load was less than the linear limit-72 KN from Table 5, the maximum load was at the pile top. The strain near the tip was less than 3% of the first measured point.

The major deformation of the pile was in the range of 0 to 7m. Beyond 7 m, the strain was less than 10%.

If an effective length of cement-soil column is defined as the pile length beyond which the axial strain is 10% of the strain at the pile top, the effective length, l_c, for Pile #1 is approximately 7m, i.e. 14 *d*, where *d* is the diameter of the pile and is 500mm.

From Fig.6 as the load exceeded the linear limit, the second point along the depth was found greatly increasing and became the maximum. The reason needed to be studied further. The curves at 144 KN and 160 KN were close because the applied load approached the damage load. Thus, the ultimate capacity was estimated as 144 KN for this pile. It is also seen that the capacity by the presented method in Table 5 was close to this value.

The major deformation of the pile was from 0 to 7m, beyond which the strain was small. The measured strain near the tip was less than 3% of the first point. The increase of the load mainly affected the deformation in the 0 to l_c, but hardly beyond l_c.

Since the pile axial load is approximately proportional to the axial strain under the linear limit, the axial load behavior of the axial load is the same as that of the strain and calculated by Young's modulus multiplied by the measured strain. Young's modulus was back-calculated by an analytical method by Duan et al. (2000).

In Fig. 7, the similar transfer behavior to Pile #1 was observed for Pile # 1. The effective length was about 8.5 m, i.e., 17*d*. The major deformation of Pile #2 was from 0 to l_c. The measured strain at the tip was still less than 3%. The major deformation of the pile was in the range of zero to the effective length.

(2) Single Pile With Square Footing

Fig. 8 showed the measured strain along the pile length for Pile # 3 of a single pile with a square concrete cap. When the load is less than the linear limit-190 kN, the strain transfer behavior was similar for each load increment. The maximum strain was at the third point at 3.2m not at the first point. The reason was the interaction between the pile and the cap. The results by finite element method (Duan, 1993) showed that the maximum stress for single pile with a cap occurred at 0.5 to 1 diameter of the pile.

When the load was over the linear limit, the load transfer quickly increased within the depth of 8.8m. After 240 KN, the curves were very close. Therefore, the ultimate load was reached. This result was identical to that in Table 5.

The major deformation for pile #3 with a square cap was in the range of 0 to 8.8m, i.e., the effective length was 17.7*d*. After l_c, the strain was less than 10 % of the first measured

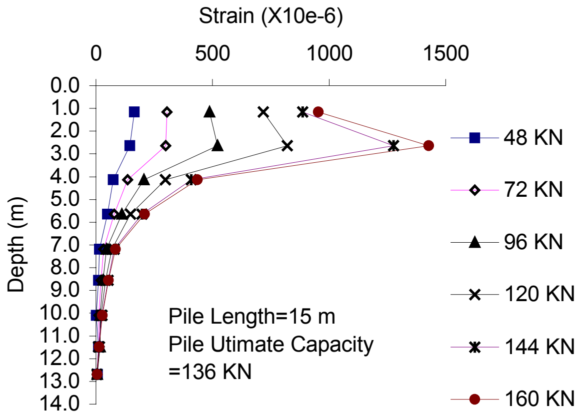

Fig. 6 Axial Strain Transfer Along Pile Length (Single Pile #1)

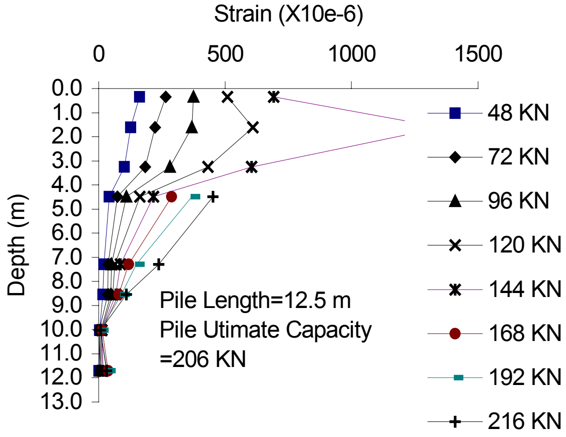

Fig.7 Axial Strain Transfer Along Pile Length (Single Pile #2)

point. The strain near the tip for Pile # 3 was less than 6%. Little transfer was evident below the effective length.

CONCLUSION

In this paper, the effective length of a pile, $l_{c,}$ is considered as the length beyond which the deformation of the pile is less than 10% of the pile top. According to the definition the effective lengths are 17*d* for Pile #1, 14*d* for Pile #2, and 17.7*d* for Pile #3 with a cap.

The major deformation of the pile is in the range of 0 to $l_{c.}$ Beyond $l_{c,}$ the strain is less than 10%. The strain at the tip was less than 3 % for a single pile and 6% for a single pile with a cap.

A method was presented to estimate the ultimate capacity of the pile. The results were in agreement with the test results and by the Code-“ Zhejiang Foundation Design Building Code on Soft Soils.”

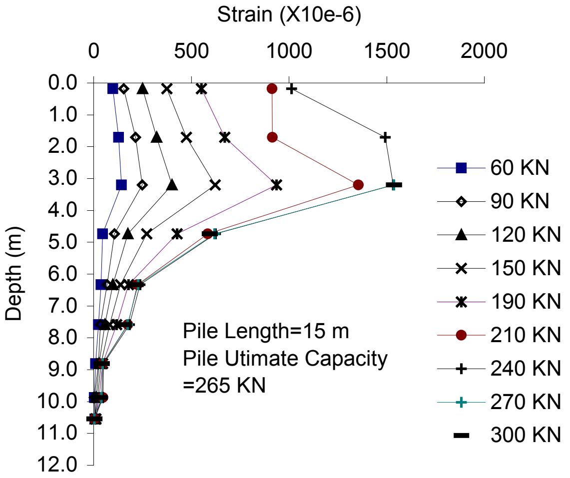

Fig.8 Axial Strain Transfer Along Pile Length (Pile #3-Single Pile with a Square Cap)

REFERENCES

Chin Fung Kee, [1970]. “Estimation of the ultimate load from tests not to failure”, Proc. 2nd Southeast Asain Conf. Soil Engineering, pp81-90.

Duan J. and Lee, P.K.K. [2002]. “Analysis of settlement for a single axially loaded soil-cement pile”, the 9th International Conference on Piling And Deep Foundation (DFI), pp483-489.

Duan J. [1997]. “ Estimation of pile capacity by load to settlement curve”, the 3rd Zhejiang Province Conference on Soil Mechanics and Foundation Engineering, Zhejiang, China, pp52-55 (in Chinese).

Duan J. [1996]. “Analysis of Deformation of Axially Load Flexible Single Pile”, Proceeding of the 2nd International Conference on Ground and Improvement Geosystem - Grouting and Deep Mixing, Japan, pp. 499-502.

Duan, J. [1993]. “Numerical Analysis of Axially Flexible Piles”, Ph.D. Dissertation, Zhejiang University, Hangzhou, Zhejiang, China (in Chinese).

Isenhower W. M., Arrellaga, J.A., Wang, S.T. and Johnson, J. O. [1998]. “ Experience with geojet piles in sandy clays”, Soil Improvement for Big Digs, Geotechnical Special Publication No. 81, pp72-82.

Lu, Y. and Zhou, G[1989]. “Three dimensional finite element analysis for cement-soil columns”, Chinese Journal of Geotechnical Engineering, Vol. 11, No.5, p86, (in Chinese).