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Bearing capacity of precast nodular piles in Tianjin soft clayey soil

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ABSTRACT: Static loading tests of five nodular piles and four non-nodular piles were performed in Tianjin soft clayey soil in which measurements of axial force and movements were made. Distribution of shaft resistance and load-movement curves for pile head and pile toe are presented in this paper. The applicability of modular piles to soft soil and their effectiveness are also discussed. Based on the comparison, it is concluded that nodular piles have an advantage over non-nodular piles mainly in contributing to shaft resistance. Dynamic testing was also conducted through R.P.T. for evaluating the service load of tested piles.

1 INTRODUCTION

The precast nodular pile is a kind of centrifugaly spun reinforced concrete pipe piles with corrugated configration along its shaft, the space between the shaft and the surrounding soil is filled with gravel during pile-driving, thus as shown in Fig.1, a combination of driven pile and gravel aleeve is formed which can effectively dissipate the excess of pore water pressure and mitigate or prevent soil liquefaction during the earthquake, therefore, the nodular pile has an advantage over other non-nodular piles especially in earthquake region.

The bearing capacity of nodular pile has been studied and the mechanism of frictional resistance of nodular pile has been also clarified by scaled model test which shows that the lowest nodule part of a pile works in the same way as the pile toe and a cylindric slip surface with diameter larger than the nodule is formed around the pile in large settlement (Ogura et al 1987).

Based on full-scale test result, it is also concluded that the toe bearing capacity of a nodular pile is about 70 per cent of the toe capacity of a non-nodular pile and the shaft capacity of nodular pile is about 5 times as that of a non-nodular pile (Ogura et al 1985).

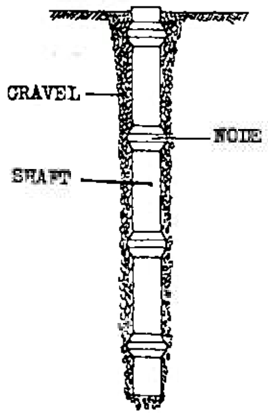

Figure 1. Precast nodular pile with gravel sleeve

However, the study on bearing capac ty of nodular pile is still unsufficient, few full-scale tests were made on nodular piles and only in loose fine sand.

In order to understand the load-settlement behavior of nodular piles driven in the soft clayey soil, nine piles of different types, including five nodular piles have been tested on the construction site in Tianjin City of China. Some of the test results are presented and discussed in this paper.

2 SOIL CONDITIONS

Pile test was conducted on the construction site of Tianjin 1st Central Hospital. Prior to the test, subsurface conditions were investigated by borings, 25 m deep, and were checked up by three additional bore-holes.

A representative soil boring log and SPT results are shown in the Fig.2. The soil strata consist of top fill layer followed by a thin layer of clay and two sublayers of loam, mucky loam stratum is encountered at depth of about 7 m, and then two sublayers of loam underlain by sandy loam layer extended to the end of borings, water table is at about -2 m from the ground surface.

Z (m)	LAYER	w	r	e_o	I_p	I_L	LOG	N-VALUE 10 20
0	FILL							
	CLAY	29.5	1.89	0.89	20.0	0.34		
5	LOAM	27.7	19.3	0.80	13.4	0.74		
		30.7	1.89	0.89	13.6	0.98		
	MUCK	38.4	1.82	1.44	15.9	1.74		
10	LOAM	20.1	1.98	0.74	13.2	0.69		
15		24.5	1.99	0.69	12.5	0.62		
20	SANDY LOAM	24.8	1.94	0.14	9.50	0.80		
	LOAM	22.3	2.03	0.63	12.3	0.47		
25								

Figure 2. Soil condition of the construction site

The typical characteristics of soil samples obtained from laboratory tests for each layer are also given in Fig. 2.

3 TESTED PILES

Nine piles were tested in-situ, among which, four piles (Pile No. 1 to No. 4) were 9 m long, others (Pile No. 5 to No. 9) were 21 m long. All piles, except square piles were equipped with 4 strain gages at each measured section as shown in Fig. 3. All piles were driven by a 45-kN diesel hammer.

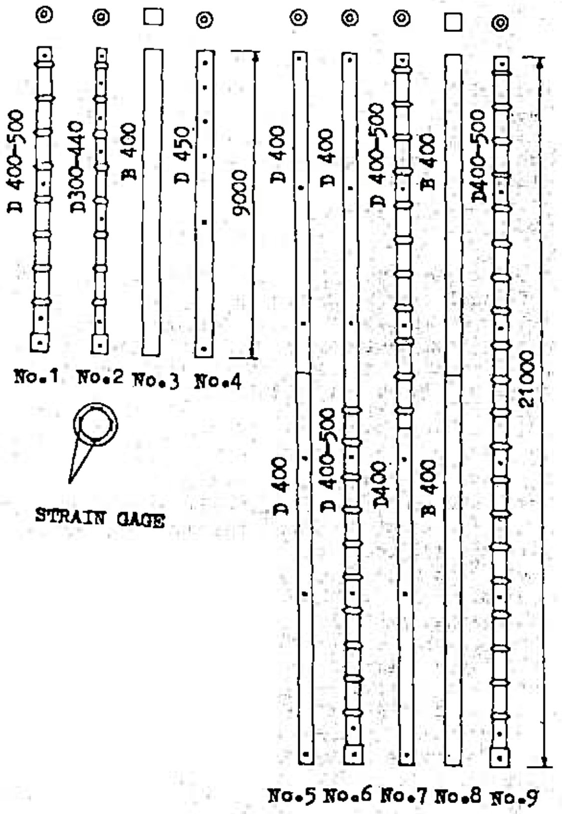

Figure 3. Tested piles and measured section equipped with strain gages

4 STATIC LOADING TESTS

The static loading tests were conducted according to the standared of JSSMFE and cycles of loading and unloading were applied. Load increment of each cycle was 100 kN for 9m long piles, except pile No. 1, and 400 kN for 21 m long piles. The schematic diagram for static loading test is shown in Fig. 4.

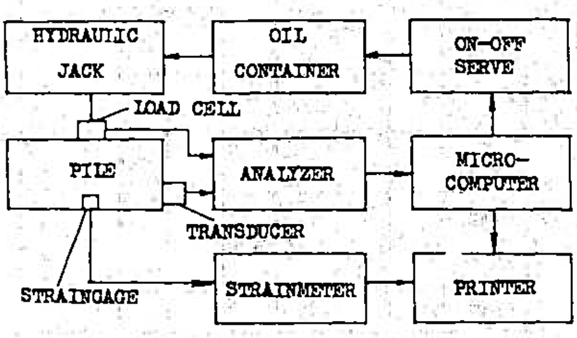

Figure 4. Key diagram for static loading test

5 DYNAMIC TESTING

Dynamic testing of piles followed the working instruction of Resonant Pile Test (R. P. T.). The vibrating force applied to the pile head and the response of the pile were monitored by transducers and then recorded and printed. Thus, the dynamic stiffness K of pile-soil system can be calculated. The schematic diagram for dynamic testing is shown in Fig. 5.

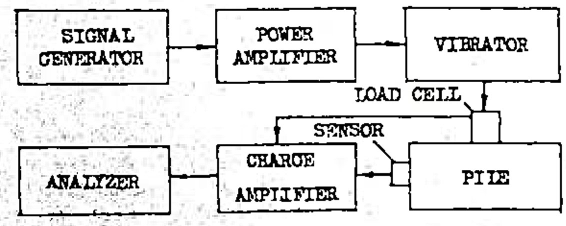

Figure 5. Key diagram for measuring system of R.P.T.

6 TEST RESULTS

The load-movement curves of pile head for all tested piles are given in Fig. 6 and 7. The load-movement curves of pile toe for all tested piles are given in Fig. 8 and 9.

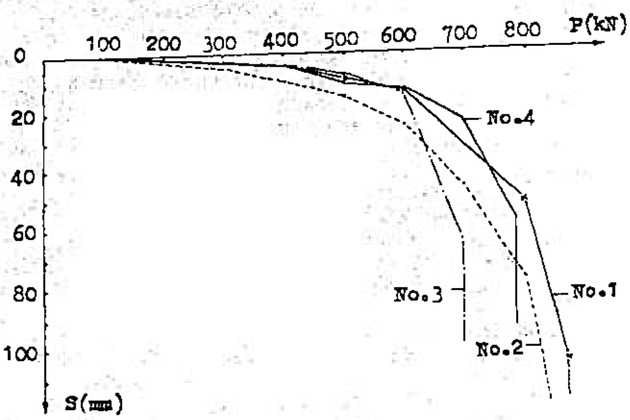

Figure 6. Load-movement curves of pile head for 9 m long piles

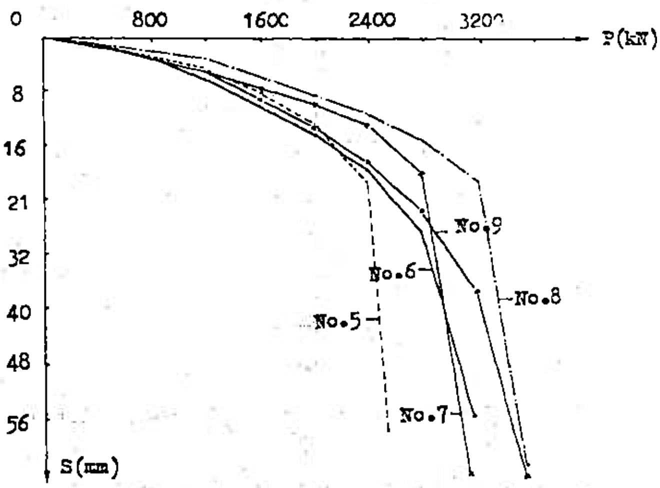

Figure 7. Load-movement curves of pile head for 21 m long piles

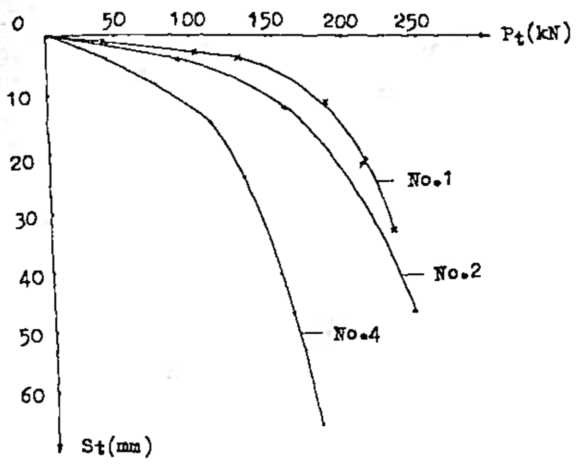

Figure 8. Load-movement curves of pile toe for 9 m long piles

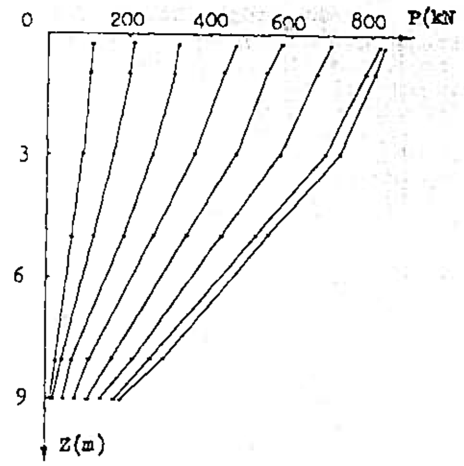

Figure 11. Axial force distribution of pile No.2

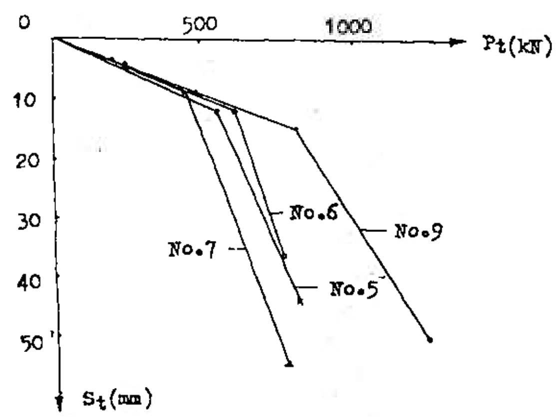

Figure 9. Load-movement curves of pile toe for 21 m long piles

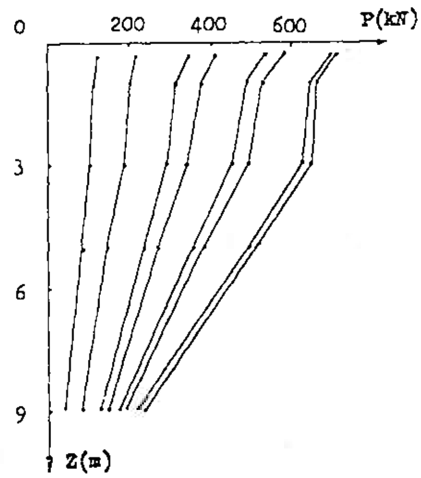

Figure 12. Axial force distribution of pile No. 4

The axial force distributions along the shaft of instrumented piles are shown in Fig. 10, 11, 12, 13, 14, 15, and 16, based on which the shaft resistance distributions can be obtained and presented in Fig 17 18, 19, 20, only for comparison.

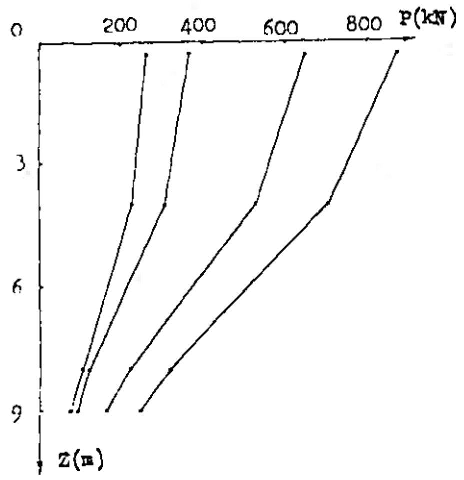

Figure 10. Axial force distribution of pile No. 1

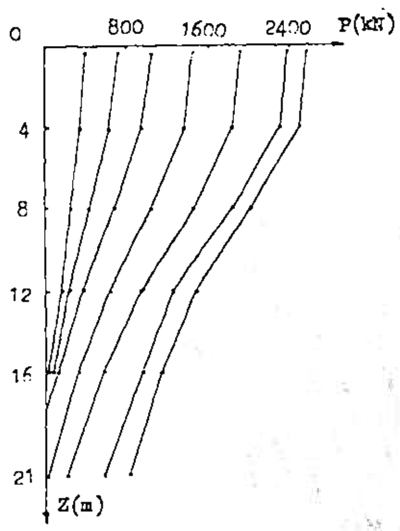

Figure 13. Axial force distribution of pile No. 5

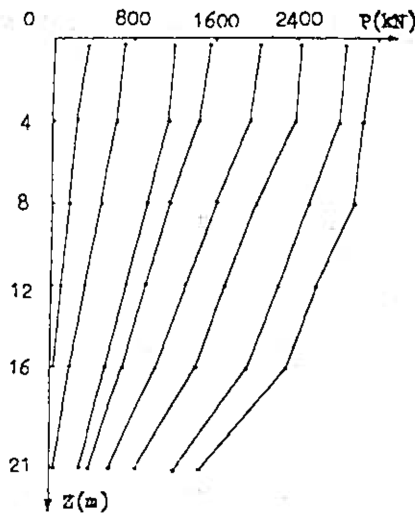

Figure 14. Axial force distribution of pile No. 6

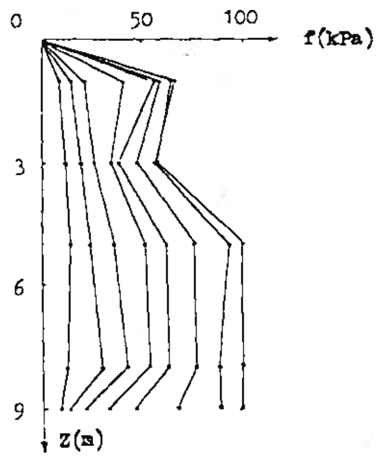

Figure 17. Shaft resistance distribution of pile No. 2

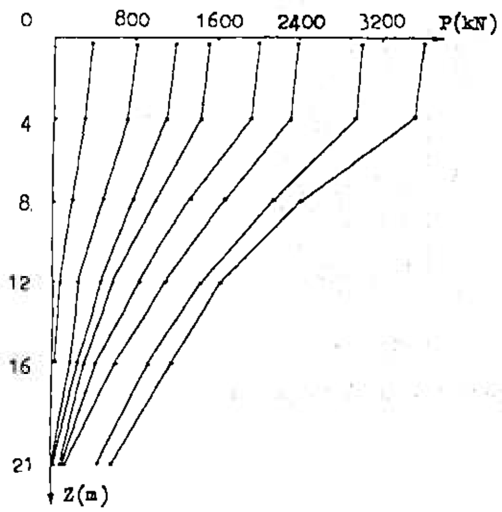

Figure 15. Axial force distribution of pile No. 7

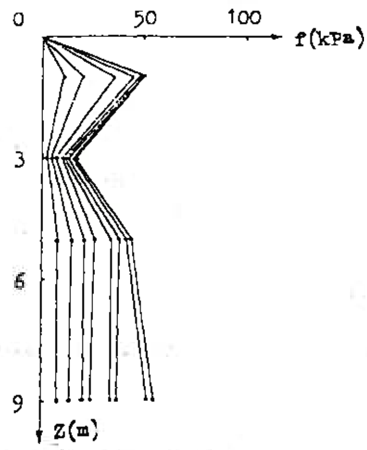

Figure 18. Shaft resistance distribution of pile No. 4

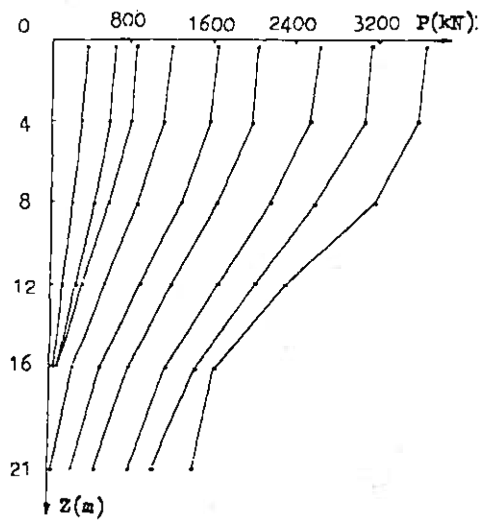

Figure 16. Axial force distribution of pile No. 9

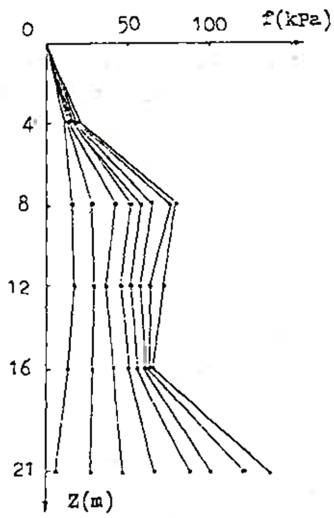

Figure 19. Shaft resistance distribution of pile No. 6

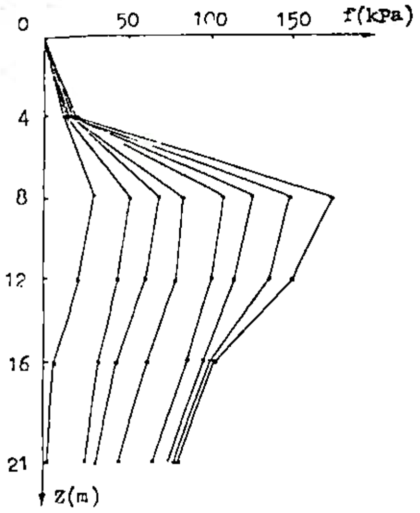

Figure 20. Shaft resistance distribution of pile No. 7

Synthesizing the obtained P-Scurves, log P-log S curves and S-log t curves we can determine the yielding load P_y and ultimate load P_u of tested piles as summarized in Table 1.

Table 1. Summary of in-situ pile-testing results

Pile	Static loading test			R.P.T.
No.	P_y (kN)	P_u (kN)	P_s (kN)	P_s (kN)
1	700	870	300	300
2	600	840	240	250
3	500	700	300	325
4	600	790	300	325
5	2000	2650	1000	1000
6	2800	3200	840	830
7	2600	3200	920	940
8	3200	3650	1300	1220
9	3200	3600	950	990

Based on the K value obtained from dynamic testing the service load for a certain settlement of pile can be evaluated as follows

$$P_s = B \cdot K \cdot (S)$$

where B is the correlation coefficient, (S) is allowable settlement, 2.5 mm for 9 m piles and 4 mm for 21 m piles.

The comparison between the P_s results from R.P.T. and those from static loading test under the same settlement is made as in Table 1.

7 DISCUSSION

It is evident from the figures of distributuon of shaft resistance that nodular piles provide greater shaft resistance than the non-nodular piles do and make very little contribution to the toe resistance (see Fig. 8) which is mainly depending on the supporting area, soil condition and stress condition of bearing stratum.

The yielding load and ultimate load per unit section area of 9 m nodular pile (pile No.1) are about 2-2.5 times those of non-nodular piles, and even more if it had been tested with same load increment of 100 kN.

As for 21 m piles, the yielding or ultimate load of nodular piles is greater than that of non-nodular pipe pile (pile No. 5) but smaller than square pile (pile No.8) which was driven into bearing stratum 0.5 m deeper than other piles, but the yielding or ultimate load per unit section area of nodular pile is still 1.5-2 times that of square pile.

Comparing pile No.6 with pile NO.7 we can see that nodes in upper part of pile generate more shaft resistance than those in the lower part do, however the latter can make a little contribution to increase the toe resistance.

As compared to the results from static loading test resonant pile test give a satisfactory results in evaluating service load of nodular pile under a certain settlement condition.

8 CONCLUSION

Nodular piles are applicable to soft clayey soil both from technical and economic consideration.

Nodular piles have an advantage over non-nodular piles in increasing shaft resistance rather than toe resistance, so they are preferred to be used as friction piles.

Load-settlement behavior of nodular pile in soft clayey soil is a little different with that of nodular pile in loose sand.

R.P.T. can be served as a convenient medium to evaluate service load of nodular piles.

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