Lecture Notes in Civil Engineering

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Ground Characterization and Foundations

Proceedings of Indian Geotechnical Conference 2020 Volume 1

Springer

Instrumented Pile Load Tests in Southern India

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1 Introduction

A conventional vertical static load test on a pile provides limited information as one monitors load and displacement only at pile top. Such testing does not provide any quantitative information on the load-transfer mechanism (magnitude of the toe resistance and the distribution of shaft resistance). Similarly, conventional lateral load test only provides the load–deflection curve for the top of the pile and pile deflection along the length as well as point of fixity is unknown. Yet, this information is what the consultant often needs in order to verify his design. Therefore, more and more frequently, the conventional test arrangement is expanded to include instrumentation to obtain the required information.

This paper presents a case study for the instrumented tests performed in Kochi for a Test pile at Kochi Metro Rail Project. Geo Dynamics in association with Kochi Metro Rail Corporation (KMRL) performed state-of-the-art instrumentation studies during vertical as well as lateral load tests. Embedment-type strain gages were installed in the pile during pile casting to perform instrumentation study. An inclinometer casing was also installed in order to monitor the deflection of pile along the length during lateral load test. The pile was a test pile (mono pile) with diameter of 2 m and length of 50 m. A crosshole sonic logging test was also performed before the load tests, and it was concluded that the pile has major defect from 44 m to pile toe.

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C. N. V. Satyanarayana Reddy et al. (eds.), *Ground Characterization and Foundations*, Lecture Notes in Civil Engineering 167,
https://doi.org/10.1007/978-981-16-3383-6_68

2 Subsurface Conditions

During boring for the pile, samples at every meter were collected. Those samples were used for visual classification and presented as Table 1.

Table 1 Subsurface conditions

Sample depth (m)	Classification	Soil type
0–6	No samples collected (fill?)	Fill
6–12	Dark gray marine clay/plastic silt	CH/MH
12–17	Olive gray marine clay/plastic silt	
18	Olive gray silt (less plastic)	ML
19	Reddish yellow gray mix sandy silt	
20–22	Reddish brown spotted brownish yellow mix, sandy silt, some clay	
22	Reddish brown mix with yellow gray sandy clay/clayey sand	SC/CL
23	Brownish yellow mix with reddish brown plastic silt with some sand	MH
24	Dark gray clay with some organics	CL
25	Dark gray clay with some more organics	
26–28	Yellowish gray fat clay	CH
28	Brownish yellow sandy silt	ML
29	Brownish yellow reddish gray sandy silt	
30	Yellowish gray/brownish yellow clayey sand	SC
31	Medium to coarse brown sand	SP-SM
32	White sand trace clay	
33	Brownish gray clayey sand	SC
34	Gray medium sand	SP-SM
35	Plastic silt olive gray	MH
36	Brownish gray medium sand	SP-SM
37	Light gray sand	
38	Gray sandy clay	CL
39	Gray sand with trace clay	SP-SC
40–42	Dark gray clay trace organic	CL
42	Gray sand with trace clay	SP-CL
43	Dark gray peat	PT
44–46	Dark gray clay trace peat	CL
46	Brownish gray sandy clay	
47	Dark brown clayey sand	SC
48–50	Brownish gray silt	ML

3 Vertical Load Test

A cyclic load test was planned and the design load on the pile was 850 tons while the test load was 1275 tons. Combination of anchor piles and kentledge was used to provide reaction during testing. The instrumentation consisted of 56 embedment type vibrating wire strain gages. It was planned to install gages at every stratigraphy change (however not greater than 3 m). The strain gages were installed in sets of 2 and 4 alternatively. Whenever two gages were installed they were at 180° and whenever four strain gages were installed they were located at 90°. Photograph of the strain gage installation is presented below as Fig. 1.

A cyclic load test was performed on the test pile in order to evaluate the load–settlement behavior of the pile. The load test was directed and carried out by DMRC as per their method statement. Four jacks, each having 500 tons capacity, were used for loading. The pile was loaded to an initial load of 170 tons (first cycle) and was unloaded to zero load. The next load cycles were 339.1 tons, 508.6 tons, 678.4 tons, 848 tons, 1017.4 tons, 1186.9 tons, and 1277.4 tons. After each load increment, corresponding settlements were measured and pile was unloaded to zero load. The pile was then again loaded to 1277.4 tons and the same load was maintained for 24 h after which the testing was terminated. The failure criterion was considered to be settlement of 12 mm. Load–settlement plot of the pile is presented as Fig. 2.

The maximum settlement was observed to be 12.08 mm when the test load of 1277.4 tons was maintained for 24 h. Once the pile was unloaded to zero load then the net settlement of the pile was observed to be 5.6 mm. The elastic recovery was

Fig. 1 Strain gage installation in progress

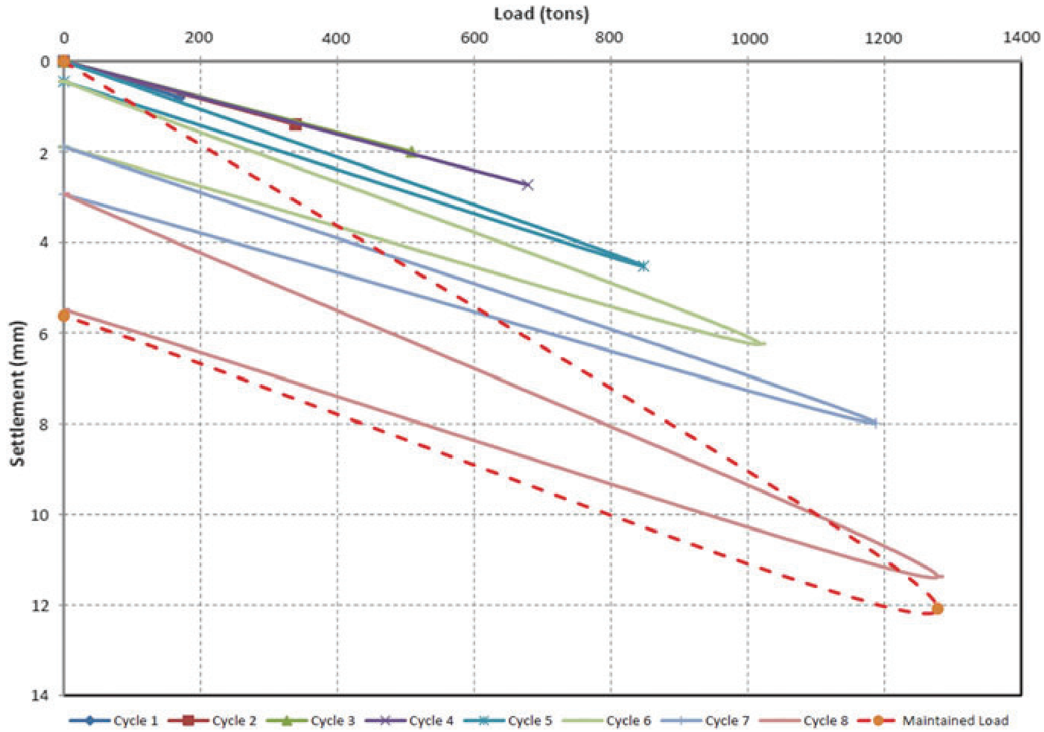

Fig. 2 Load–settlement plot—vertical load test

around 6.5 mm. Since pile had major defect from 44 m to pile toe, the load carried by the pile was due to frictional resistance only.

As stated above, 56 vibrating wire strain gages were installed in the pile. At the time of testing 9 gages were not functional. It is possible that while cage lowering operations or during concreting these gages and/or cables might have damaged. However, other gages provided reasonable data for the analyses and interpretation. Strain gages located below 44 m indicated unusual readings due to presence of defect. Other strain gages provided consistent readings implying that the pile shaft is under compression. Photograph shows the data collection in progress (Fig. 3).

The strain gage readings were used further to calculate the load transfer at each level (presented below as Fig. 4). The load transfer was estimated based on state-of-the-art published literature by renowned professor [1, 2]. For each load increment, load transfer up to 6.7 m was similar indicating not much resistance offered by the surfacial soil. However, after this level, there was significant decrease in load transfer indicating high amount of skin friction. Strain data obtained from the gages located beyond 44 m were not used for load transferred calculation due to their unusual behavior.

The skin friction provided by the soil is calculated as difference in load transferred to the pile and presented as Fig. 5.

For the maximum test load, the skin friction was estimated to be around 89% while end bearing was only 11%. Note that this 11% also includes skin friction from 41 m to pile toe.

Fig. 3 Instrumented vertical load test—data collection in progress

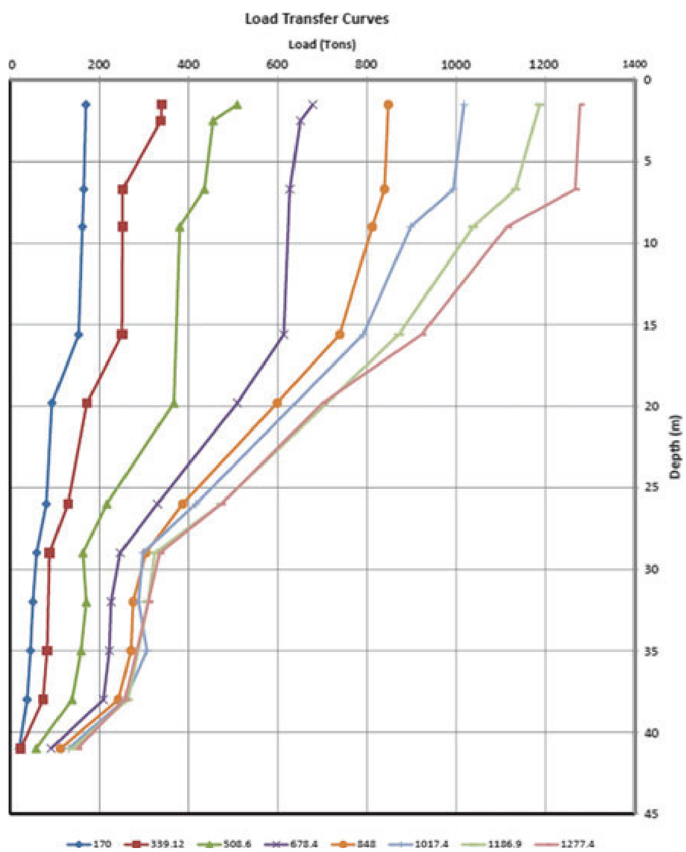

Fig. 4 Load-transfer curves for each loading cycle

4 Lateral Load Test

Upon completion vertical load test, an instrumented cyclic lateral load test was performed on the same pile. The design lateral load on the pile was 45 tons while the test load was 67.5 tons. Pile deflection along the length of the pile was measured

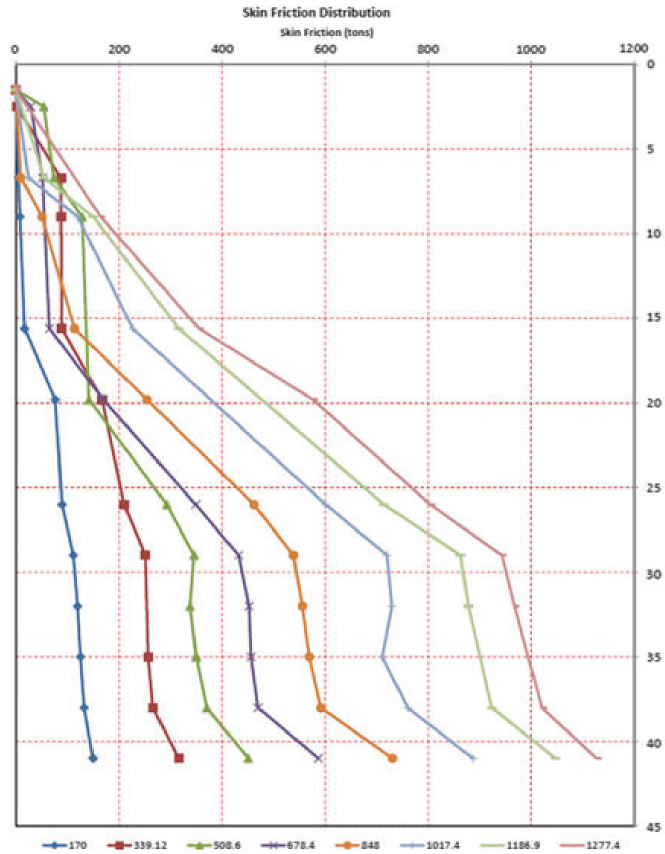

Fig. 5 Skin friction distribution for each loading cycle

by means of inclinometer. Inclinometer casing was installed during pile concreting. The depth of the inclinometer casing was 15 m which was determined based on theoretical point of fixity (12 m).

The pile was loaded to an initial load of 9.24 tons (first cycle) and was unloaded to zero load. The next load cycles were 18.48 tons, 27.72 tons, 36.96 tons, 46.2 tons, 55.44 tons, 64.68 tons, and 67.76 tons. After each load increment, corresponding displacements were measured and pile was unloaded to zero load. The pile was then again loaded to 67.76 tons and the same load was maintained for 24 h after which the testing was terminated. Before maintaining the load, all the dial gages were reset to zero. The failure criterion was considered to be displacement of 12 mm. Load displacement plot of the pile is presented below as Fig. 6.

The maximum settlement was observed by dial gages to be 8.54 mm when the load was maintained for 24 h. Once the pile was unloaded to zero load, then the net displacement of the pile was observed to be 3.6 mm. The elastic recovery was around 4.94 mm.

Inclinometer readings were taken after each loading cycle as shown in Fig. 7. A typical load deflection along the depth is also presented as Fig. 8. Generally good agreement was observed between dial gage readings and deflection at the top observed by inclinometer. Based on the data collected by inclinometer, it can be

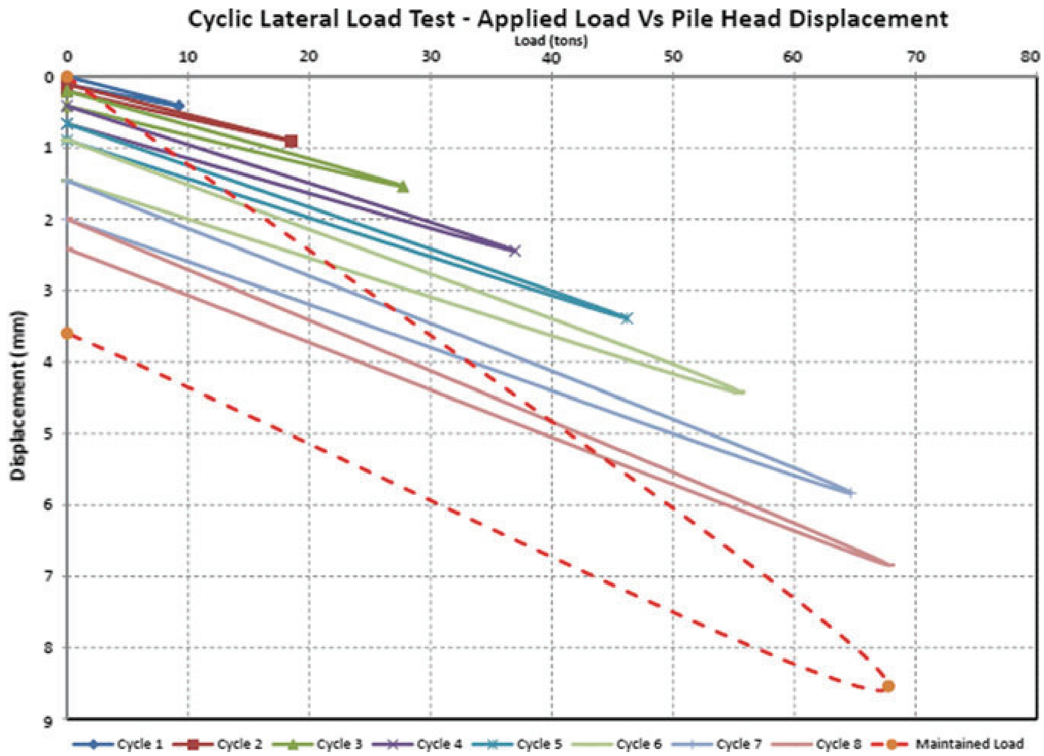

Fig. 6 Load–displacement plot—lateral load test

Fig. 7 Inclinometer reading being taken during lateral load test

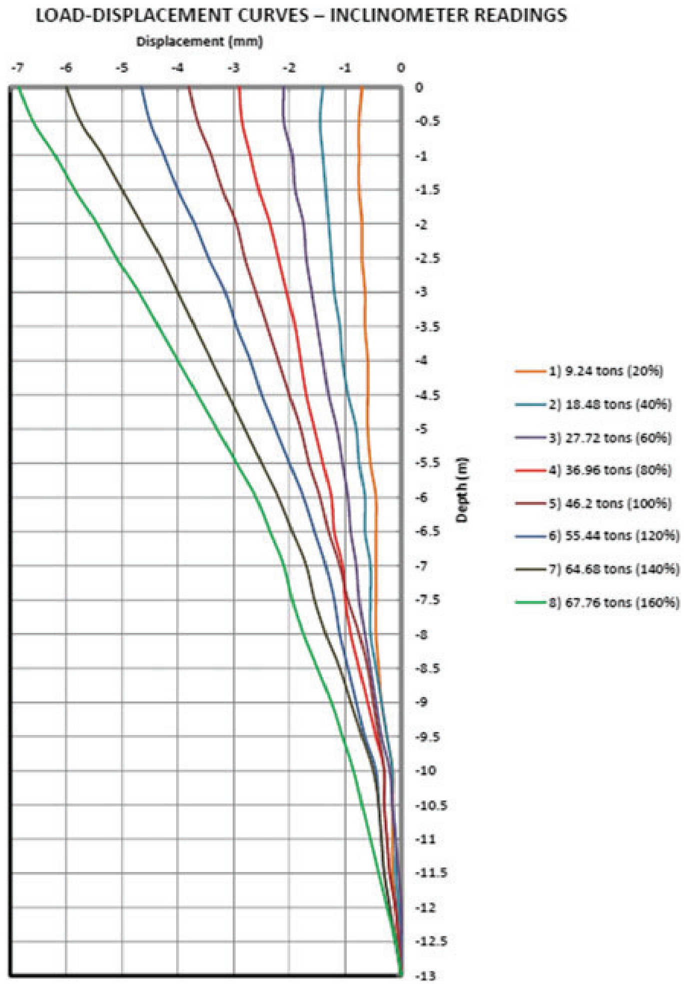

Fig. 8 Load deflection graph for each loading cycle

inferred that the pile undergone some deflection even at 12 m and below indicating that the actual point of fixity is somewhat lower than the theoretical calculations.

5 Conclusions

1. Based on CSL results, the pile has major defect form 44 m to pile toe, and this was verified by the strain gage readings at corresponding levels.
2. Strain gage readings were used to compute the skin friction distribution and amount end bearing mobilized. 89% of the load was resisted by skin friction (up to 41 m) while only 11% was resisted by end bearing (which also includes friction from 41 m to pile toe).
3. An instrumented lateral load test was performed on a test pile, and this report presents the results of the inclinometer readings. The pile was loaded to a maximum load of 67.76 tons and the maximum settlement was observed to be around 8.5 mm by inclinometer (8.54 mm as per dial gages).

4. Inclinometer readings were used to verify theoretical point of fixity, and based on the data, it can be concluded that the actual point of fixity is somewhat lower than the theoretical calculations.

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