# Review of Load Test Performance of Base Grouted Concrete Piles

**D. Nagarajan, K. Raja Rajan, and T. Vijayakumar**

**Abstract** Bangladesh is a low-lying country crisscrossed by many rivers. Large diameter bored piles are replacing caisson foundation in Bangladesh. Bored cast in situ pile is a popular choice for heavy loaded structures due to the ability to adjust the pile length suitably in case of any variation found in the actual geological strata. Geological strata are predominantly silt in nature and N-value in this region is less than 5 up to 15 m depth. Pile design is based on field N-values and laboratory test results. Pile capacities estimated through static formula are in co-relation of N-value and laboratory test results. Two 1.5 m diameter bored cast in situ piles without base grout and two 1.5 m diameter bored cast in situ piles with base grout were casted, and initial load test was performed on these piles to finalize the pile length. This paper presents the vertical load performance of 1.5 m diameter base grouted concrete piles in comparison with ungrouted bored piles.

**Keywords** Angle of internal friction · Base grouting · End bearing · Initial pile load test · N-value · Settlement

## 1 Introduction

A railway bridge of length 700 m is planned across the Rupsa river with approach viaduct running length of 2.2 km on both sides. Super structure is of steel girder in approach viaduct, and steel truss in main bridge portion has been planned. Substructure of approach viaduct portion comprises 1.5 m diameter bored cast in situ pile of 800 nos. approximately and main bridge is of 2.5 m diameter of 48 nos. bored cast

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**Table 1** Project location details

| Type | Details |
|---|---|
| Terrain type | Alluvial-cum piedmont plain |
| Hottest month | April–May |
| Coldest month | December–January |
| Annual average temperature | 11.3° (in winter) |
| | 34.5° (in summer) |
| Rainfall season | June–September |
| Annual average rainfall | 1842 mm |

in situ pile. Pile designed during tender stages with the available soil reports carried out in initial stages. Pile capacity is estimated through static formula based on co-relation of N-value and laboratory results. To verify the pile capacities predicted during tender stage, detail soil investigation and pile load tests were planned. Every pier as one borehole each with depth of 15 m below the pile termination level is ordered to evaluate the soil parameters for every change of layers. Every pile group in each pier as one initial pile load test to ensure the given pile length is sufficient to take the estimate safe working load.

## *1.1 Location*

The southwestern coastal belt of Bangladesh, especially the Khulna-Satkhira coastal belt, is endowed with multi-layer prolific aquifers composed of deltaic sediments—a complex mixture of sand silt and clay. Hydrogeologically, the southwestern coastal belt of Bangladesh belongs to the Holocene Coastal Plains (Zone-V) (Table 1).

## *1.2 Soil Profile*

Geotechnical investigations were carried up to 60 m depth at every pier location to ascertain the actual soil strata. Subsoil profile of the particular stretch is dominated by silt content, and the N-value in this region is less than 5 in top 10 m soil strata. Generally, top 10 m is of sandy silt with soft layer, followed by 15 m of poorly graded sand with loose to medium dense and then followed by silty sand till the termination of bore hole. Standard penetration tests were conducted at every 1.5 m up to 15 m depth and 3.0 m interval beyond 15 m depth up to exploration depth. Disturbed and undisturbed samples were taken from boreholes for testing soil parameters. Angle of internal friction was co-related based on SPT N-values, and laboratory values are used in order to perform pile capacity calculations. Subsoil profile encountered in the proximity of test pile location is presented in Fig. 1.

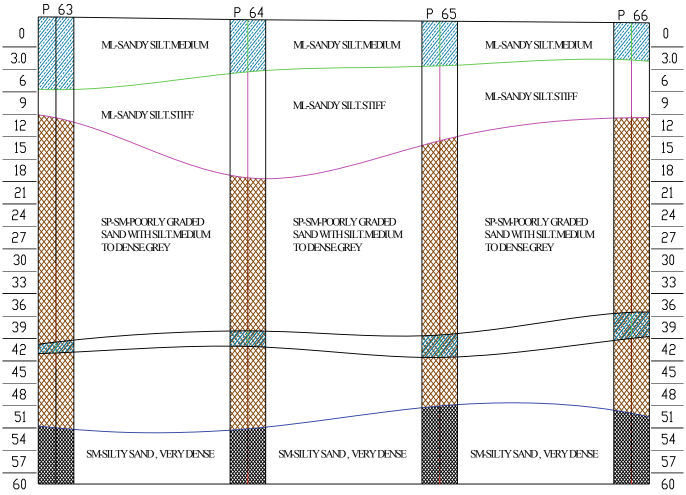


**Fig. 1** Soil profile in the proximity of P63 to P66

## 2 Test Pile Arrangement

Kentledge system is designed to perform the initial pile load test. Water table is at the ground level during the initial pile load testing time, so ground improvement will not be effective to support the kentledge, so steel liner was used to support the kentledge load. Concrete blocks were stacked over steel girders in order to take reaction to test pile. Two hydraulic jacks of 1000 MT are used along with grillage beam to transfer the load to the pile. Four dial gauges were placed using supporting block in order to measure the settlement of the pile (Fig. 2).

### *2.1 Measurement of Load and Displacement*

The jack, pressure gauge and power pack were checked and calibrated prior to commencement of test. Pressure developed in pressure gauge was monitored and the corresponding load was read from calibration certificate. The pile head movement was measured by using four dial gauges against independent reference beams. The supports are sufficiently embedded into the ground at distance more than 3D clear between support and test pile. Kentledge arrangement for test pile (TP-01) is shown in Fig. 3.

The readings were recorded in all the dial gauges, the load cell and the pressure gauge for the jack at 1-min intervals on the time-settlement data sheet. The loading pattern to the pile is 50, 100, 125, 150, 175, 200 and 250% of SWL and the settlement of the pile is monitored in both loading and unloading cycle at defined interval time.

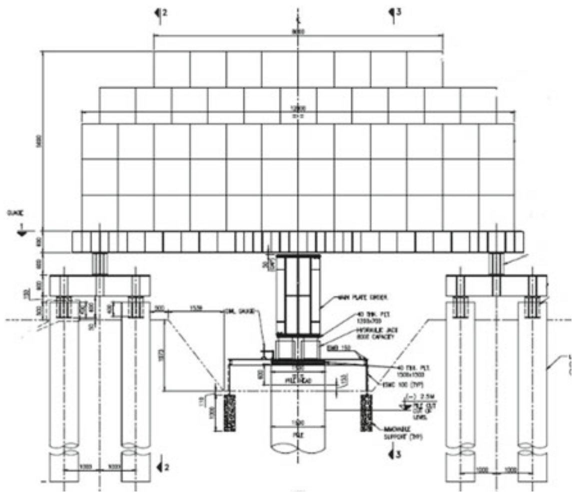

**Fig. 2** Test pile arrangement using kentledge method

**Fig. 3** Test pile arrangement—site photo

## 3 Test Pile TP-01 Details

Pile design carried out as per IS 2911 method and design is normally based on field test such as standard penetration test N-values and lab results. Coefficient of earth pressure taken as 1 and angle of wall friction between pile and soil was taken the same as angle of internal friction of soil. Overburden pressure was limited to 20 times the diameter of pile. By using the above said method and above assumptions, it has been estimated that 1.5 m diameter and 40 m length of pile would be sufficient to take safe working load of 570 MT.

**Table 2** Details of test pile-01

| Details | Test pile (TP-01) |
|---|---|
| Type of pile | Bored cast in situ pile |
| Diameter (m) | 1.5 m |
| Termination depth | 40 m |
| Design load | 570 MT |
| Test load | 1425 MT |
| Method of installation | Hydraulic rotary method under bentonite slurry |
| Drilling equipment | Hydraulic rig BG-25C |

In order to validate the design, initial pile load test was planned. Details of pile load test are tabled in Table 2.

Test pile is constructed in a manner similar to that to be used for construction of working pile, and by the use of similar equipment and material. Permanent steel liner is installed and boring is done by hydraulic drilling rig under bentonite slurry. Concrete is mixed in batching plant and poured through tremie pipe. During drilling soil strata were checked and all the relevant data recorded. Pile head was trimmed and prepared before testing.

### *3.1 Results of Test Pile TP-01*

The results were interpreted through load-settlement curves by applying various methods for determining the allowable load bearing capacity of the pile. Pile load test is terminated after reaching 777 MT load since the settlement exceeds 10% of pile diameter, that is, 150 mm. Load-settlement curve for test pile 01 is presented in Fig. 4.

## 4 Detailed Soil Investigation

Owing to unpredictable behavior of pile, consultant and contractor jointly proposed for detailed soil investigation, that is, borehole under each pier. A total of 144 boreholes has been planned to drill in the proximity of bridge pier alignment. Tests, like direct shear test, UCC, tri-axial test, grain size distribution and so on, to be performed at which depth were predetermined. Typical graph between SPT N-value and depth for P65 and P66 is shown in Fig. 5. Relative density range between loose and very dense increases with increase in depth (Fig. 5).

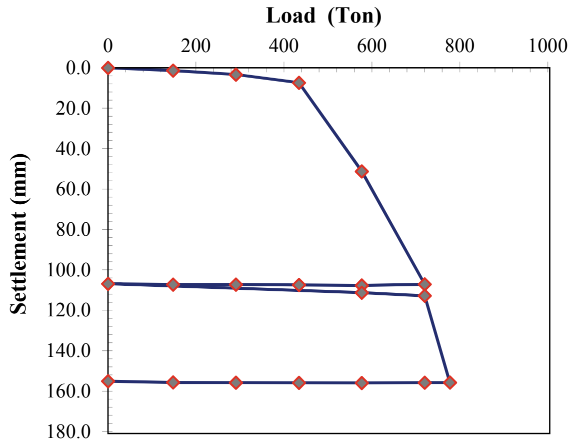


**Fig. 4** Load-settlement curve for test pile-01

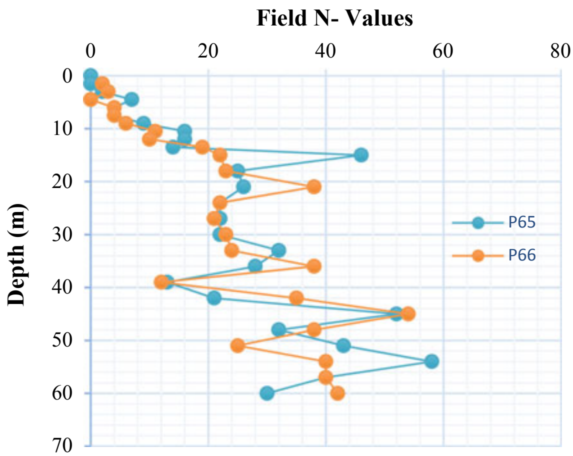


**Fig. 5** Field SPT N-values versus depth for P65 and P66

## 5 Redefining Geotechnical Parameters

With detailed investigation data, pile capacity has been re-evaluated for two pier locations P65 and P66. Based on particle size distribution and SPT-N values, pile-soil friction angle is revised. Based on particle size distribution, soil layer encountered is separated as per Table 3 and then redefined as per SPT-N values as tabulated in Table 4.

Based on the above redefined soil properties, test pile (TP-010) reveals the pile capacity of 390 tons which is already verified by load lest, so same redefined pile capacities were assumed for test pile (TP-02) design. Test pile (TP-02) of 1.5 m diameter pile is designed, pile capacity for 52 m length estimated as 450 MT and the same is presented in Fig. 6 (Table 5).

**Table 3** Soil layer as per PSD requirement

| Prefix | PSD requirement |
|---|---|
| 1A | Clay + Silt >= 50% |
| 1B | 20% = <Clay + Silt < 50% |
| 2 | Clay + Silt < 20% and Coarse Sand < 10% |
| 3 | Clay + Silt < 20% and Coarse Sand >= 10% |

**Table 4** Soil layer as per SPT N-values

| Suffix | PSD requirement |
|---|---|
| a and b | N <= 10 |
| c | 10 < N <= 17 |
| d | 17 < N <= 32 |
| e | 32 < N <= 50 |
| f | N > 50 |

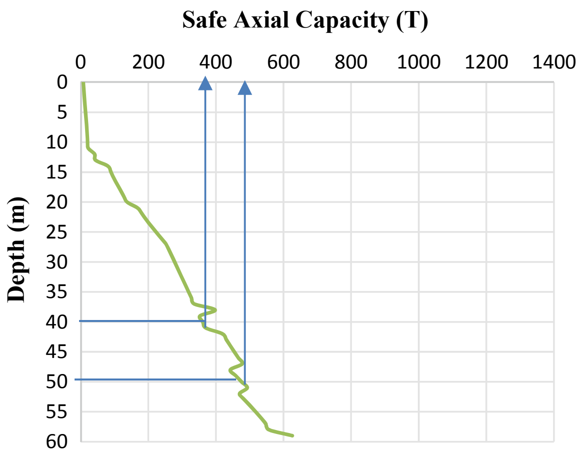


**Fig. 6** Estimation of pile capacity for TP-01 and 02

**Table 5** Design parameter for pile design

| Soil type | Unit weight (kN/m$^3$) | Friction angle (Φ) | Soil-pile friction angle (δ) |
|---|---|---|---|
| Unit 1a and 1b | 16 | – | – |
| Unit 2a, 2b and 2c | 17 | 25 | 22 |
| Unit 2d and 2e | 18 | 28 | 25 |
| Unit 2f | 19 | 30 | 27 |
| Unit 3e | 19 | 30 | 27 |
| Unit 3e | 19 | 32 | 28 |

**Table 6** Details of test pile-02

| Details | Test pile (TP-02) |
|---|---|
| Type of pile | Bored cast in situ pile |
| Diameter (m) | 1.5 m |
| Termination depth | 52 m |
| Revised design load | 450 MT |
| Test load | 1140 MT |
| Method of installation | Hydraulic rotary method under bentonite slurry |
| Drilling equipment | Hydraulic rig BG-25C |

## 6 Test Pile TP-02 Details

Test pile of depth 52.0 m is casted nearby location in the proximity of piers P65 and P66 to evaluate the pile capacity as per redefined soil parameters. Details of pile load test are tabled in Table 6.

### *6.1 Results of Test Pile TP-02*

Test pile (TP-02) is carried out as per maintained load method. Test was terminated as pile reaches the settlement of 150 mm as it exceeds the 10% diameter of pile, and the corresponding load measured was 1212 MT. Load at 18 mm settlement was 690 MT and safe load was 460 MT obtained from test pile (TP-02) which validates the design assumption to estimate pile capacity. Load-settlement curve for test pile TP-02 is presented in Fig. 7.

## 7 Comparison of Test Pile Results

Test pile TP-01 test load estimated as 1425 MT for 40 m pile length, but after conducting pile load test for 10% of pile diameter, that is, 150 mm settlement occurred for the applied load of 777 MT. Load at 18 mm settlement was 469 MT, that is, safe load of 312 MT only obtained which leads to redesign the pile as it could not be able to meet the requirement. Test pile TP-02 working load estimated as 1140 MT for 52 m length, after conducting pile load test for 10% of pile diameter, that is, 150 mm settlement occurred for the applied load of 1212 MT. Load at 18 mm was 690 MT, that is, safe load as 460 MT which was parallel to the estimated pile capacity as per redefined soil properties in alluvial deposit (Table 7).

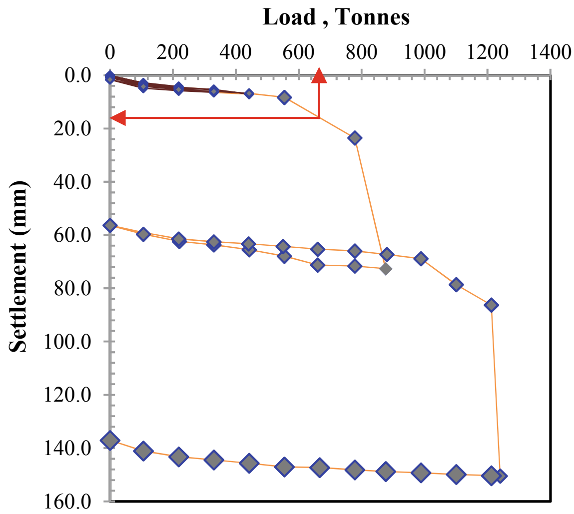


**Fig. 7** Load-settlement curve for test pile-02

**Table 7** Comparison of test pile results

| Test results | Test pile (TP-01) | Test pile (TP-02) |
|---|---|---|
| Max. applied load (Ton) | 777.6 | 1240.0 |
| Total settlement, mm | 155.7 | 150.4 |
| Net settlement, mm | 155.1 | 137.0 |
| Final load at 18 mm settlement | 469 MT | 690 MT |
| Safe load (2/3*Load at 18 mm) | 312 MT | 460 MT |

## 8 Base Grouting

Base grouting technique was introduced to increase the end bearing of the bored cast in situ pile. Base grouting techniques are widely used to increase the toe resistance of bored pile. Flat jack and tube-a-manchette method are generally employed and for this pile the latter one is selected. Access pipe and tube-a-manchette are shown in Fig. 10. Grout is prepared by mixing OPC and plain water with little bentonite. Grout pump model GI ET 2 of Soilmec SPA Italy was used for grout pumping.

The flowchart describes the activities involved in base grouting of pile in Fig. 8.

A pair of concrete-embedded strain gauge was placed near bottom of the pile to monitor load transfer behavior of the pile through the pile toe. The grouting technique carried out for test pile in order to increase the toe capacity and the details are presented in Table 8.

Grout controlling criteria based on the injected grout volume if it is lesser than 300 L and pressures achieves 3.0–6.0 MPa on second stage. Injection pressure is

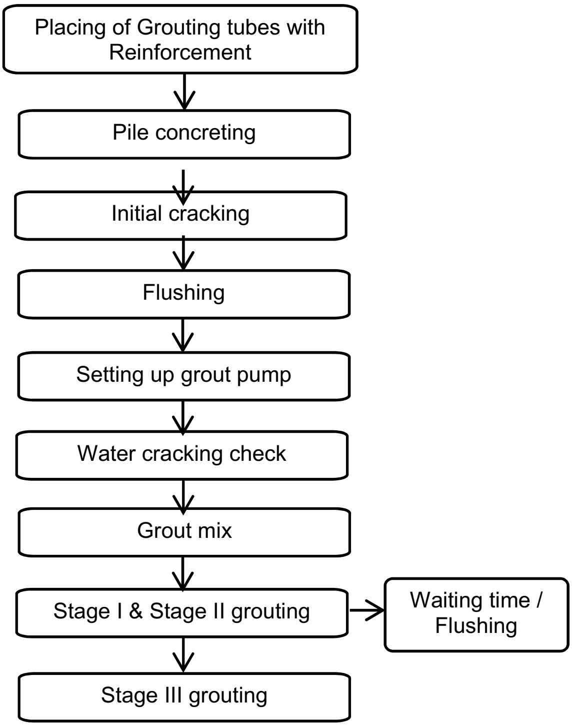


**Fig. 8** Flowchart of base grouting operation

**Table 8** Grouting technique details

| Activity | Details |
|---|---|
| Setting time | Pile concrete strength achieves at least 20 MPa |
| Water cracking check | Done separately for each circuit less than 12 h |
| Grout mix (for 1000 L) | Cement—1115.7 kg, water cement ratio—0.5, water—557.7 kg, admixture 1% of cement weight |
| Injection rate | 10 L/min for each separate circuit, then |
| Injection rate | 5 L/min maximum, |
| Maintaining pressure | 3.0–6.0 MPa maximum |

monitored at inlets and outlets. Tentative cement grout pumped in three stages for test pile and quantities is as follows (Figs. 9, 10, 11 and 12):

- 1st stage: 600 L
- 2nd stage: 750 L
- 3rd stage: 450 L

**Fig. 9** Site photo showing grout pipes on test pile

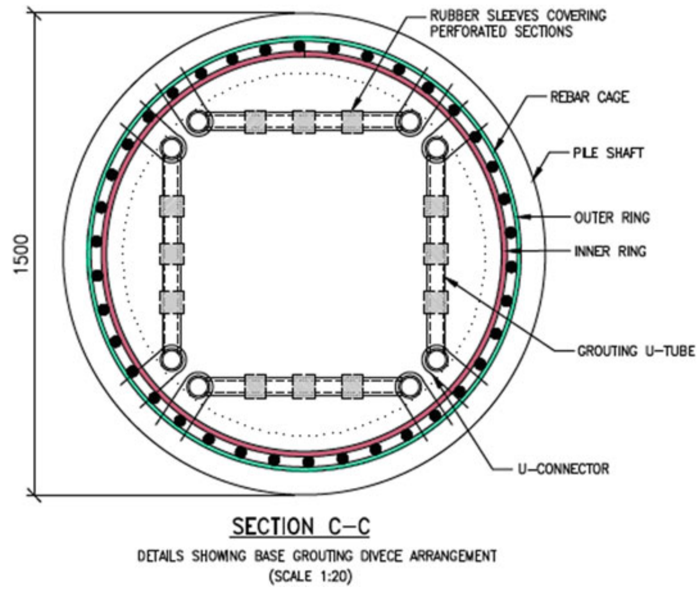


**Fig. 10** Plan of pile showing grouting pipes

## *8.1 Grout Mix*

Grout mix is a base parameter to achieve the desired capacity of pile. Cement, water, BASF and bentonite were the main ingredients for grout mix. As per specification, for 1000 L of grout volume the following are the mixing ratio: Cement 822 kg, water

**Fig. 11** Site photo showing reinforcement cage with grout pipes

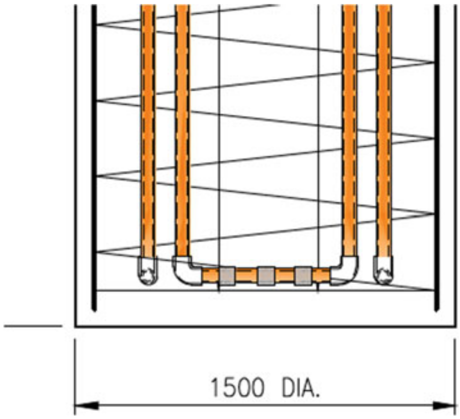


**Fig. 12** Grout tube arrangement at the bottom of pile

cement ratio is 0.6, water is 493.2 kg, BASF Master flow 150 is 1% of cement, that is, 8.22 kg, and bentonite is 3% of cement content, that is, 24.66 kg. In order to ensure the flow ability of grout mix, initial temperature of mix shall not exceed 30 °C (Fig. 13).

**Fig. 13** Grout mix preparation

## *8.2 Grouting Stages*

Grouting has been done in stages in order to achieve the grout strength. I-stage is referred to as permeation grouting, whereas II-stage is referred to as compaction grouting. Grout mix is kept ready as per the specification. Grout pressure and grout injection rate is also predefined as per the specification. Pressure of 3 MPa is to be applied during initial stage of grouting and 6 MPa to be achieved during final grouting stage. Target grout volume for each circuit is estimated as 145 L. Holding time shall be 2 h with same pressure after initial grouting is completed. Water flushing shall be carried out immediately after holding time. Arrangement of grout pile in pile head is shown in Fig. 14.

Dial gauges are fixed and monitored for uplift of pile. If any uplift occurs, grouting shall be stopped for holding time, and then the remaining volume shall be applied in the third stage of grouting (Fig. 15).

# 9 Test Pile TP-03 Details

Test pile of depth 45.0 m with base grouting is casted in the nearby location in the proximity of piers P65 and P66 to evaluate the pile capacity. Base grouting was carried out on stages with different grouting pressure in order to densify the soil at the bottom of the test pile (Table 9).

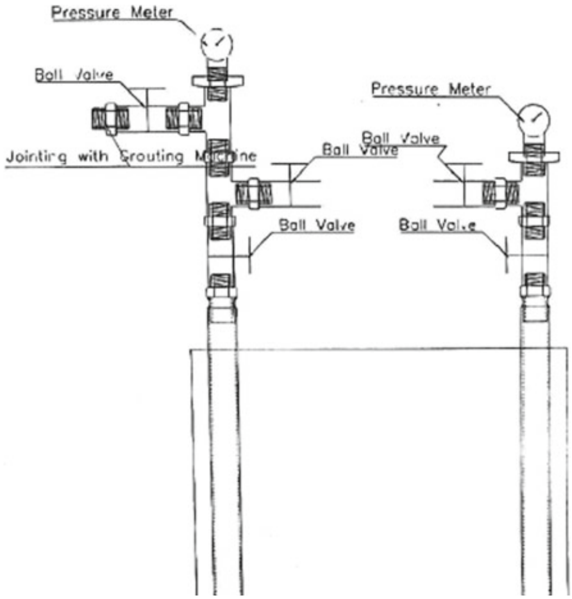


**Fig. 14** Arrangement of grout pipe at pile head

**Fig. 15** Arrangement of grout pipe at pile head

## *9.1 Results of Test Pile TP-03*

Test pile with base grouting (TP-03) is carried out as per maintained load method. Test was terminated as pile reaches the settlement of 74 mm and the corresponding load measured was 1098 MT. Load at 18 mm settlement was 890 MT only and marginally safe load obtained was 590 MT and it did not reach the test load of 1425

**Table 9** Details of test pile-03

| Details | Test pile (TP-03) |
|---|---|
| Type of pile | Bored cast in situ pile with base grouting |
| Diameter (m) | 1.5 m |
| Termination depth | 45 m |
| Revised design load | 570 MT |
| Test load | 1425 MT |
| Method of installation | Hydraulic rotary method under bentonite slurry |
| Drilling equipment | Hydraulic rig BG-25C |

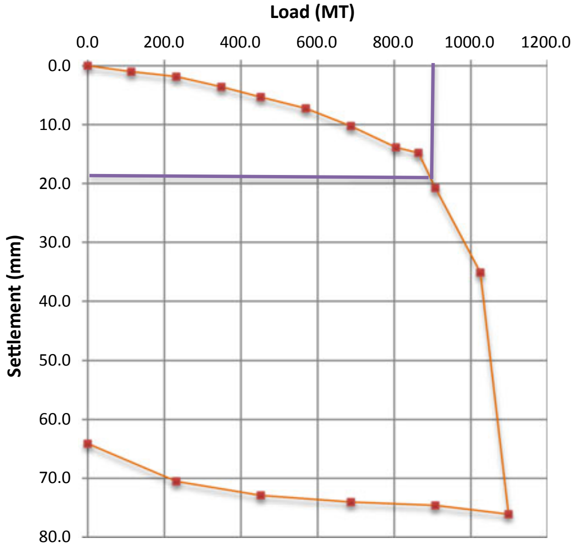


**Fig. 16** Load-settlement curve for test pile-03

MT. So it has been planned to cast test pile-04 with increased depth of 52.0 m to check the pile capacity increase. Load-settlement curve for test pile TP-03 is presented in Fig. 16.

## 10 Test Pile TP-04 Details

Test pile with increased depth 52.0 m with base grouting is casted in the nearby location in the proximity of piers P65 and P66 to evaluate the pile capacity. Similarly, as per TP-03, base grouting was carried out on stages with different grouting pressure in ordered to densify the soil at the bottom of the test pile (Table 10).

**Table 10** Details of test pile-TP-04

| Details | Test pile (TP-04) |
|---|---|
| Type of pile | Bored cast in situ pile with base grouting |
| Diameter (m) | 1.5 m |
| Termination depth | 52 m |
| Revised design load | 570 MT |
| Test load | 1425 MT |
| Method of installation | Hydraulic rotary method under bentonite slurry |
| Drilling equipment | Hydraulic rig BG-25C |

## *10.1 Results of Test Pile TP-04*

Test pile with base grouting (TP-04) is carried out as per maintained load method. Test was terminated as pile reaches the settlement of 24 mm, and the corresponding load measured was 1358 MT. Load at 18 mm settlement was 1300 MT and safe load was 866 MT obtained from test pile (TP-03) which satisfies the pile capacity requirement of superstructure. Load-settlement curve for test pile TP-04 is presented in Fig. 17.

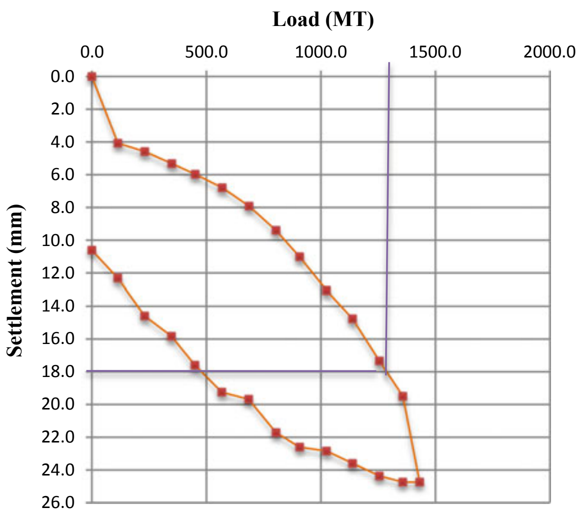


**Fig. 17** Load-settlement curve for test pile-03

## 11 Comparison of Test Pile Results

A total of four test piles has been carried out with different depths to finalize the pile capacity. Test pile (TP-01) of depth 40 m obtained safe load of 312 tons and test pile (TP-02) of 52 m depth obtained safe load of 460, which shows a 12.0 m increase in depth increases only 148 tons in pile capacity. Test pile (TP-03) with base grouting of depth of 45 m shows safe load capacity of 593 tons and test pile (TP-04) with base grouting of depth of 52 m shows safe load capacity of 866 tons, which shows an increase in pile capacity of 273 tons between base grouted piles. However, TP-02 and TP-04 with same depth of 52 m having base grout and without base grout piles show the increase in pile capacity of 406 tons which is 90% of safe load capacity. It shows base grouting considerably increase the pile capacity in alluvial deposits (Fig. 18).

In test pile TP-02 and TP-04, base grouting method improves the axial load-settlement performances by increasing the axial resistance of the pile and/or by improving the mobilization of shaft resistance. Potential benefits of postgrouting piles include reduced settlement under loading, decreased length of the shaft, better alignment of load transfer curves for end and side resistance and improved ground beneath the base of the pile. Test pile TP-01 without base grout and test pile TP-03 with base grouting of having depth difference of almost 7.0 m, however TP-03 of 45 m showing the higher safe load of 593 tons than the test pile TP-02 of 52 m, that is, 460 tons pile capacity. It clearly states that base grouting helps to reduce the pile depth with increase in base resistance (Table 11).

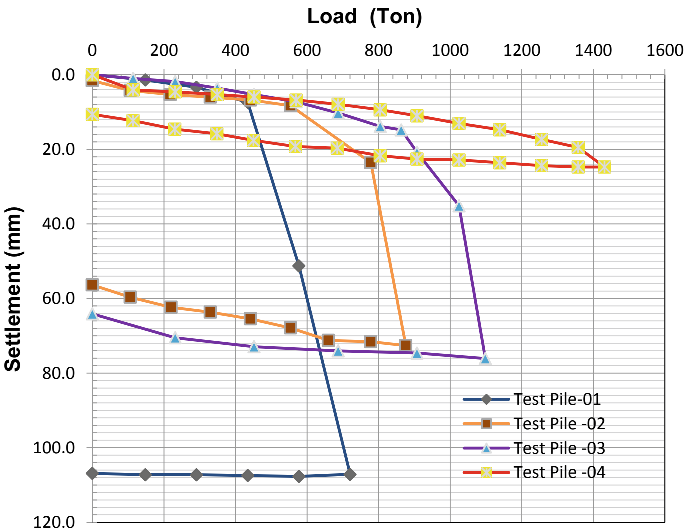


**Fig. 18** Comparison of load-settlement curve for all test piles

**Table 11** Comparison of test pile results

| Test pile | Pile depth (m) | Max. applied load (MT) | Max settlement (mm) | Load at 18 mm | Safe load (MT) |
|---|---|---|---|---|---|
| (TP-01) Without base grout | 40 | 777.6 | 155 | 469 | 312 |
| (TP-02) Without base grout | 52 | 1240 | 150 | 690 | 460 |
| (TP-03) With base grout | 45 | 1098 | 76 | 890 | 593 |
| (TP-04) With base grout | 52 | 1431 | 25 | 1300 | 866 |

## 12 Conclusion

Following are the conclusion made based on the test piles with and without base grouting with respect to pile capacity considered in substructure design:

(a) Test pile (TP-01) conducted for estimated theoretical capacity of 1.5 m diameter with pile length 40 m for the safe load of 570 T, whereas actual soil condition reveals only 50% of capacity achieved for estimated pile length.
(b) Increase in fine content of silty deposits reduces the angle of internal friction, which ultimately leads to reduced pile capacity.
(c) Detailed borelog investigation planned, that is, one borelog under each pier, so a total of 144 borelogs has been planned with some additional laboratory tests for determining shear strength parameters at predetermined depths.
(d) With redefined soil parameters pile capacity estimated and pile length increased to 52 m for pile load test (TP-02), which shows load-settlement curve close to theoretical pile capacity.
(e) Though increase in pile depth increases skin friction marginally, considering the limitation on piling rig increase in pile depth has restriction after some extent.
(f) With increase in pile length and adopting base grouting of piles found to be engineered economical solution.
(g) In order to percolate the grout to base, grouting is carried out with different grout pressure, which will increase the percolation of grout to the bottom of the pile.
(h) Test pile TP-03 and TP-04 conducted with 52 m length along with base grout shows satisfactory results of pile capacity.
(i) TP-04 shows 46% more pile capacity than the actual required capacity.
(j) Test pile settlement decreases with increase in pile capacity due to effective base grouting.

(k) Pile capacities based on static formulas were calculated by not considering base grout effect, but increase in pile capacities is due to base grout considered as additional advantage.
(l) However, time cycle decreased slightly due to base grout for each pile, but capacity increases rapidly.
(m) After review of the above load test, base grout pile was proposed with pile length of 52 m.
(n) All the piles in this project were revised to bored cast in situ piles with base grouting due to sufficient increase in vertical load capacity.
(o) Lateral load test were carried out after vertical load tests, and lateral load test shows the satisfying lateral load carrying capacity of piles.
(p) Time cycle of working piles with base grouting was increased, and it reduces by increase in the number of grouting pumps for base grouting.
(q) It has been planned to monitor the performance of base grouted piles to understand the long-term behavior by placing inclinometer and strain gauges to record the displacement of pile if any.

Base grouting is becoming more widely accepted in the drilled shaft industry as a means to improve end-bearing response to load. There are a limited number of full-scale field comparisons of test shafts. This full-scale static load test of test piles conducted on piles with and without base grouting clearly estimates the increase in pile capacity and decreases the settlement with respect to load.

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