Assessment of pile failures due to excessive settlement during pile load test

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ABSTRACT

There are around 10 major bridges are being under construction in the Nagapattinam Tiruthuraipoondi B.G railway line. These bridges are supported by pile foundations with varying founding depths depending up on the soil stratum. Bored cast in suit piles were cast and pile load tests were conducted at five locations for the estimated pile capacity (capacity was estimated as per IS 2911). Almost in all the locations, the pile load test were failed, which means the pile settlement was beyond the specified settlement under the test load. The failure was assessed and reported in this paper. The estimated pile capacity (design load) and test load (working pile load test) was 278MT and 417MT respectively. The pile has got yielded (settled) beyond 12mm, when the test loads of 220MT (which is 80% of the working load) in progress. The pile got settled around 25mm when the working load was in progress and finally reached to 38mm after 12hrs. After unloading, the pile has got rebound only 3mm, which motivate us to do the complete re-assessment of the soil strata in the study area. The forensic investigation on this failure has clearly evident that the failure had happen due to inadequate geotechnical investigation and improper pile installation. The cause will be discussed in this paper.

Keywords: pile load test, settlement, pile failure, bridge

1 INTRODUCTION

In the literature study, extensive research has been carried out on assessment of pile failure under static pile load test (Charles et al. 2001; Gonzalez-Nicieza et al. 2007; Lopez Gayarre et al. 2009; Hussein et al. 2012; Opeyemi, 2009; Zhang et al. 2010; Kozubal et al. 2014 and Fan et al. 2014). In general, Failure is defined as the event that the displacements exceed the corresponding tolerable displacements (Fan et al. 2014). According to ASCE Technical Council on Forensic Engineering, “An unacceptable difference between expected and observed performance” is said to be a failure. Whereas, Collapse is gross movement of major members or a significant portion of the structural system, that renders them incapable of supporting the intended loading. Failure does not imply collapse, but collapse is viewed as a structural failure.

Static pile load test is a widely accepted test method for authoritative assessment of deep foundation (IS 2911 and ASTM D 1143). Testing is typically performed once and the results are considered the definitive answer regarding the pile’s load bearing capacity. However, there are technical and operation reasons that may cause misleading results (Hussein et al. 2012). Uncertainties are common phenomena in engineering (Opeyemi 2009). The lesson learnt from various literature collection is that failure assessment of pile under static load test are due to various factor like variability of geological conditions, weathered geomaterials, artificially lowering the groundwater table, geometry and spacing of pile group and process of settlement and consolidation (Zhang et al. 2010; Charles et al. 2001; Lopez Gayarre et al. 2009; Comodromos et al. 2003 and Gonzalez-Nicieza et al. 2007). There are many experimental studies that have been carried out by many other researchers to assess the pile failure under static load test.

A new B.G railway line between Nagapattinam and Tiruthuraipoondi is being under construction. The B.G line is about 34km length starting from Nagapattinam which is located in the east coast of Tamilnadu, India. In the railway alignment there are 10 major bridges are being under construction. The smallest bridge is typically a 2 span of each 12.19m and longest one is 8 span of each 12.19m. Each pier is supported by 2 x 2 pile groups and each abutment is supported by 12 piles of 3x4 pile groups. Out of these 10 bridges, 6 bridges were subjected to pile load test. The location and name of the bridges is shown in Fig.1.
2 DETAILS OF THE TEST PILES

All the piles are bored cast in-situ piles of 1.0m diameter. The grade of concrete of all the piles is M35. The pile depth and the depth of liner varies with location to locations. All the tests are routine pile load test. The test pile details along with design and test load is presented in Table-1.

Table-1 Test Pile details

| Bridge Name        | Pile length from cut-off level (m) | Depth of liner from cut-off level (m) | Pile design load (MT) | Pile test load (MT) |
|--------------------|-----------------------------------|-------------------------------------|-----------------------|---------------------|
| Kaduviyar River    | 40.430                            | 5.0                                 | 259                   | 518                 |
| Ch. 9534.69        |                                   |                                     |                       |                     |
| Selliyar River     | 40.390                            | 5.0                                 | 259                   | 388                 |
| Ch. 15437          |                                   |                                     |                       |                     |
| Pandaviyar River   | 38.652                            | 10.0                                | 184                   | 276                 |
| Ch. 16424          |                                   |                                     |                       |                     |
| Vellaiyar River    | 32.397                            | 9.0                                 | 274                   | 422                 |
| Ch. 17545.54       |                                   |                                     |                       |                     |
| Harichandra River  | 31.01                             | 3.563                               | 274                   | 422                 |
| Ch. 26926.99       |                                   |                                     |                       |                     |
| Adappar River      | 26.990                            | 6.54                                | 278                   | 417                 |
| Ch. 34554.53       |                                   |                                     |                       |                     |

3 LOADING PROCEDURE / LOADING SEQUENCE

The Vertical compression load test of pile foundation was carried out with below mentioned loading stages. The loading sequence adopted in the test is in accordance with IS 2911 Part-4. The load was applied generally as per project specifications as shown below.

Maintained Load Method is adapted in the present test. In this method application of increment of test load and taking of measurement or displacement in each stage of loading is maintained till rate of displacement of the pile top is either 0.1 mm in first 30 minutes or 0.2 mm in first one hour or till 2 h whichever occur first.

In the test, the load is applied in increment 20% of the working load until 150% of working load. After this stage, the load is released/ reduced to 50% of working load and then brought to “no load” condition.

Each load step is maintained as mentioned above. The foundation movement readings are taken at 0, 15 and 30 minutes after each load step. To determine the vertical displacement at working load, the criteria suggested by IS 2911 Part-4 is adapted i.e. the routine test shall be carried for a test load of at least one and half times the working load; the maximum settlement of test loading in position being not exceeding 12 mm.

4 PILE LOAD TEST RESULTS

The first pile load test was conducted on Adappar River (Ch. 34554.53) bridge pile where the pile depth is 26.99m below cut off level and the liner was extended up to 6.54m below the cut off level. The design load of the pile is 278 MT. and test load is 417 MT. While doing the pile load test, the pile has reached a maximum settlement of 37.4mm load at 332MT.

When the working load of 277MT is in progress, the pile has reached a settlement of 24.135mm which clearly says that the pile has failed under static loading of the estimated theoretical load based on the soil design parameter as per the Geotechnical investigation report. Subsequently, the pile load tests were done at Pandaviyar River (Ch. 16424) and Vellaiyar River (Ch. 17545.54) bridge piles. The pile load test results of these two locations have also shown failure. The results of pile load test of these three locations are presented in Fig.2 and Table-2.

The actual capacity of the pile was calculated from the pile load test results as per De Beer (1968) producer for failure load. According to De Beer, the load settlement curve is plotted in log-log plot and the point of intersection of the two straight lines thus obtained the failure load.

Accordingly, the pile load test results were plotted in log-log scale (Fig. 3) and the failure load was obtained. The failure loads of 200MT, 210MT and 110MT for Adappar, Pandaviyar and Vellaiyar River bridge piles respectively were estimated. The safe load
### Table-2 Pile load test results

| Bridge name          | Pandaviyar River Ch. 16424 | Vellaiyar River Ch. 17545.54 | Adappar River Ch. 34554.53 |
|----------------------|----------------------------|-----------------------------|----------------------------|
| Pile length from cut-off level (m) | 38.652                     | 32.397                      | 26.99                      |
| Depth of linear from cut-off level (m) | 10                          | 9                           | 6.54                       |
| Pile design load (MT) | 184                        | 274                         | 278                        |
| Pile test load (MT)   | 276                        | 422                         | 417                        |
| Total Settlement (mm) | 17.09                      | 18.773                      | 37.4                       |
| Pile load test status | Failed Settlement reached more than 12mm at 165MT load | Failed Settlement reached more than 12mm at 275MT load | Failed Settlement reached more than 12mm at 332MT load |

has been taken as 2/3 of the failure load as per IS recommendation. Accordingly, the compression capacity of the piles was estimated as 130MT, 140MT and 73MT for Adappar, Pandaviyar and Vellaiyar bridge piles respectively which is very much lesser than the pile capacity (pile design load) presented in Table-2.

The failure of these three pile load test have motivate us to do the complete re-assessment of the soil strata in the study area. In the meanwhile piling of all other bridges has stopped. A detailed forensic investigation was undertaken to understand the pile load test failures in different aspects.

The reassessment of the soil strata in the Adappar River Bridge location (Fig.4) clearly shows the inadequate and improper investigation which has lead to fix the termination depth of the piles. Based on the original investigation, a layer of cemented sand was reported depth from 24m onwards with SPT N value more than 100 up to 30m. The investigation was terminated at 30m depth. Based on this the pile termination depth of 27.0m has been estimated for the required pile capacity. However, the reassessment of soil strata at the same location shows very clearly the cemented sand layer is encountered depth beyond 30m and the layer is extended up to the depth of investigation i.e. 40m with SPT N value consistency more than 100. The soil at the original pile termination depth of 26.99m (27.0m) is silty sand (SM) group with SPT N value 45, which clearly shows the soil in only dense state and corresponding soil design parameters are very much less than that of the estimated parameters in the first investigation. It is also noticed that the silty sand at 27.0m depth is having very significant amount of fine content. The laboratory investigation on the silty sand shows around 20 to 30% strength reduction under remolded state and also low to medium swelling potential. These aspects were not considered in the pile capacity estimation. The top 8 to 10m depth of soil in all the locations were unconsolidated soft marine clay or soft marine silt strata and this layer often has more organic content, which leads to have negative friction in the piles. The effect of negative friction was not considered in the original pile capacity estimation.

Based on the reassessed soil strata, the theoretical corresponding characteristics were studied in all the bridge locations. A typical comparison of soil strata encountered in the first investigation (original investigation based on that the theoretical pile capacities were estimated) and the reassessment investigation (confirmation borehole) at Adappar River Bridge location is shown in Fig. 4.

7 RE-ASSESSMENT OF SOIL STRATA

Since the pile load tests at three locations have got failed, a detailed reassessment of soil strata and its
pile capacity was estimated as per IS 2911 method by using both soil design parameters (estimated in the laboratory) and SPT N values. The estimated theoretical capacity is very much comparable with the actual pile capacity obtained from the pile load test results (as per De Beers method), which gives a clear idea about the pile capacity mobilization in this region. Finally these three bridges have completed with additional piles in order to attain the required capacity of the pile group since piles were already installed in these locations. Based on the reassessment of soil strata, the founding depth of the additional piles was arrived and the pile load test was conducted on the newly installed piles (with increase in pile depth). The pile load test results are presented in Table-3.

The piles with revised depth of founding were passed the pile load test at all three locations. Therefore, the reassessment of soil strata was done for all other locations and accordingly the pile founding depth was arrived. The pile load test of all other locations were passed, which is presented in Table-4.

5 CONCLUSIONS

The approach to any design should ultimately be governed by whether the pile settlements at working loads are within acceptable limits for the supported structure. Failures must fundamentally guarantee an adequate factor against failure, not just the overall ability to carry the load, and this represents the true limiting factor in design. In order to attain the above we need to do on-site data collection, on and off-site testing and analysis as well as documentation are common components of geotechnical investigation. In the geotechnical investigation, the materials characterization should be explained such as the fine soils sensitivity, activity and expansiveness. The investigation should be more specific about the type of piles and method of installation, pile termination depth, casing requirements and its depth, pile spacing and group interaction effect. The very important aspect is, pile execution work. The piles should be done as per the design. The soil disturbance induced by the boring rig may be a concern in case of sensitive soils which has to be accounted in the pile capacity estimation. The borehole should be properly backwashed before concreting and also time gap between boring and concreting should be reduced. Most of the time failures have occurred due to the lake of interaction between the piling contractor and consultant. After taking care of all the above issues, the piles were successfully installed and passed the pile load test at all the locations in the railway B.G. line.

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