Quality Assurance of Large Diameter Base Grouted Bored Piles for a Railway Bridge in Bangladesh

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***Abstract*—Base-grouted piles of 1500 to 2500 mm diameter bored cast-in-situ piles were installed for a railway bridge over River Rupsa in Bangladesh. To ensure that the piles are safe to support the design loads, a comprehensive quality assurance program was implemented. This included conducting high-strain dynamic load tests and ultrasonic cross-hole sonic logging. The paper presents use of these tests to ensure that the piles are of acceptable quality and can support the loads safely. Typical results of selected tests are presented demonstrate the reliability of the tests conducted.**

***Keywords*—base-grouted bored piles, static pile load test, quality assurance of piles, high-strain dynamic pile load test, cross-hole sonic logging**

I. INTRODUCTION

Large diameter bored piles are increasingly being used for construction of bridges across rivers. Piles are replacing well foundations as a preferred foundation system and are an economical and more reliable option. On major projects, these piles may carry design loads well in excess of 600-1000 Tonnes.

Since static load test for such high loads is prohibitively expensive, only a limited number of such tests are usually done. Therefore, quality assurance of the large diameter piles is essential to ensure that the piles are safe to carry such large loads. High strain dynamic load tests (HSDLT) and cross-hole sonic logging (CSL) are commonly used to verify safe pile capacities and to confirm that the pile does not have any major defects.

The paper presents a case study of a major bridge across a river in Bangladesh (see vicinity map on Fig.1) where HDSLT and CSL were used to confirm pile quality and safe load carrying capacity. The tests could effectively eliminate the uncertainties in construction of large diameter piles and enhance the reliability of construction.

Fig. 1. Map of Bangladesh showing project area

II. PROJECT DETAILS

As part of the Khulna-Mongla railway link in Bangladesh, a 5.13 km long railway bridge across River Rupsa is under construction. RCC bored cast-in-situ piles of 1500 mm diameter and 52 m long were installed for the viaduct and 2500 mm diameter 70 m long piles were installed for the main bridge. To ensure development of end bearing, the piles were base grouted.

The bridge has 69 spans 32.45 m long on the Khulna side approach, 7 spans 102.4 m long for the main bridge in the river portion and 67 spans 32.45 m long on the Mongla side approach. Fig. 2 presents a satellite image showing the alignment of the bridge.

The main bridge is an open web through type steel girder structure (780 MT steel per span) and has 2500 mm diameter bored cast-in-situ RCC piles of 70 m length. The approach bridge on either side has steel composite girder deck slab (90 MT steel per span) and has 1500 mm diameter 52 m long bored cast-in-situ RCC piles. Fig. 3 presents a schematic sketch of a typical approach-bridge span.

Fig. 2. Alignment of bridge across River Rupsa

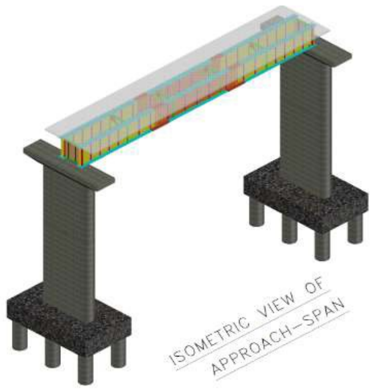


Fig. 3. A view of a typical approach-span (model)

III. Geology of the Area

The coastal belt of Bangladesh forms a low-lying landmass. It is part of the world's largest delta called the Bengal Delta or Ganga-Brahmaputra Delta with a 710-km long coastline. The Tidal Delta in the southwestern coastal belt and parts of Satkhira district belong to the inactive Ganga delta. Khulna district has both active and inactive delta deposits of the Ganga.

Most of Bangladesh is on the delta formed by three major rivers, the Ganga, Brahmaputra and Meghna (Bangapedia, 2015[1]). Originating from beyond the country's boundary, these rivers and other minor rivers in the area form the Ganga-Brahmaputra-Meghna River System.

In Bangladesh, two distinct types of soil conditions are encountered. These are (i) the alternating seasonal wet-or-inundated and dry conditions, which is prevalent in most of the flood plain areas, and (ii) the intermittently wet-or-moist and dry conditions in the upland areas of hills and terraces.

The project site is in the active flood plains that occupy land within and adjacent to the main rivers where shifting channels deposit and erode new sediments during the annual floods. Newly deposited alluvium within this floodplain is stratified in different layers. Usually, silty and clay deposits are finely stratified, and sandy deposits, as well as mixed sandy and silty deposits are coarsely stratified.

IV. Site Stratigraphy

Geotechnical investigation for this major bridge included over 140 boreholes to 65-75 m depth. In general, the deposits at site are alluvial in nature. The soils to about 7-11 m depth consist of very loose silt with SPT values of 1 to 2. This is underlain by silty sand with intermediate lenses of low plastic silt. The soil is medium-dense with SPT values of 12 to 24 to 18 to 20 m depth, dense with N values of 32 to 50 to 47-50 m depth and very dense (N values of 55 to 77) below to the final explored depth of 65-70 m.

It may be highlighted here that the deltaic soils are very loose to 7-11 m depth and loose to about 14 m depth. The SPT values increase with depth. All piles were terminated in dense sand stratum with SPT value exceeding 40-60.

Fig. 4 presents a pictorial summary of typical boreholes on the Mongla side approach.

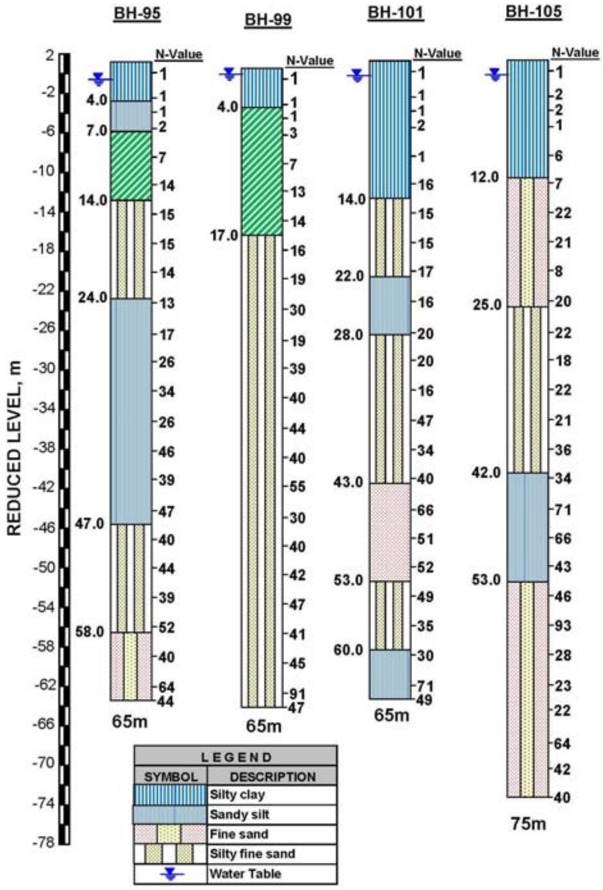


Fig. 4. Typical Borehole Data

V. Load Tests

Two vertical initial load tests (installed near Pier P-63) were performed on 1500-mm diameter piles, one of length 40 m and the second of length 52 m. The safe loads interpreted from the tests were 389 T for the 40 m long pile and 469 T for the 52-m long pile. Fig. 5 presents a photograph of a pile load test in progress.

Both piles fell short of the required safe loads with large displacement under the design load. The low capacity of the piles is probably due to poor end bearing, probably due to slush / muck at the bottom of the pile-bore. Safe capacity of long pile is less than the design capacity primarily due to insufficient bottom cleaning and presence bentonite slurry mud and soft material after caving. This was confirmed by low-strain pile integrity test that suggested a very poor toe response.

Fig. 5. Static pile load test in progress

VI. Base Grouting of Pile

To enhance the end-bearing capacity of the pile, the owner decided to base grout the pile. Bottom cleaning is generally common problem for long piles. In such a situation, the pile capacity can be improved substantially by post-grouting the pile tip. Bagui and Das (2018) [2] state that greater increase in end bearing capacity from base grouting occurs for pile tip resting on cohesion less soil. Since the stratigraphy indicated sandy soil at the pile tip, base-grouting is a good option for this site. Bhattacharya [3] explains the value engineering benefits that is obtained by base grouting of the large diameter piles in such strata.

Subsequently, two 1500 mm diameter test piles were base-grouted and load tested. The test pile installed near P-63 was 45 m long; it had a safe load carrying capacity of 593 T. The second pile installed near P-67 was 52 m long; it had a safe load carrying capacity of 857 T. Four bidirectional static load tests [4] conducted on 2500 mm diameter piles (Piers P-69 to P-76) also confirmed substantial increase in pile capacities as a result of base grouting.

VII. Quality Assurance for Working Piles

Since routine load tests are expensive and time consuming, it was decided to perform high-strain dynamic load tests and cross-hole sonic logging was performed to verify the pile capacities as well as pile quality. Experience has shown that [4] these tests can effectively be used to evaluate the quality of the pile construction, identify any major defects and to develop the equivalent static load-settlement curve.

The piles for the approaches on the Khulna side and Mongla side were 1500 mm in diameter and 52 m below the cut-off level. The grade of concrete used was M40. The piles were designed for a safe load of 525 T.

A. *High Strain Dynamic Load Test (HSDLT)*

An 8.5 MT hammer was used to perform the test. Drop heights ranging from 0.5 to 2 m were used. A typical arrangement for the test is illustrated on Fig. 6.

The tests were performed on the 1500 mm diameter piles installed along the approaches on either side of the main bridge across the river.

Fig. 6. HSDLT test in progress

Four strain gauges and two accelerometers were attached to the pile just below the pile head. They were mounted on the opposite sides of the pile to cancel the bending effects during strike of the hammer.

A close-up of an accelerometer and strain gauge installed on the pile is illustrated on Plate 7.

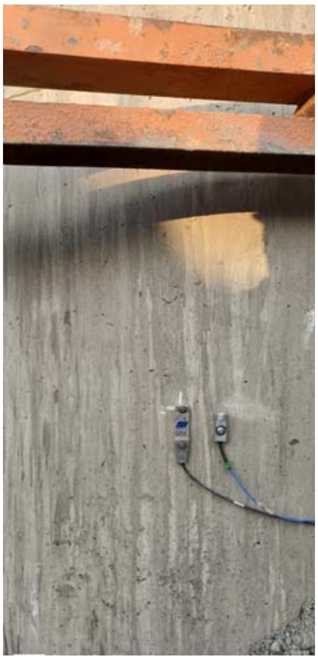


Fig. 7. Close-up view of accelerometer and strain gauge installed on a 1500 mm diameter pile

On each pier, one pile in the pile group (of 6-8 piles) were tested in accordance with ASTM D 4945-12 [6]. The signals of the strain and acceleration were processed by the PDA. Data acquisition using the Pile Driving Analyzer is shown on Fig. 8.

The PDA measures the total (static and dynamic) resistance acting on the pile. Selected PDA field records of force and velocity data for a blow delivered to the pile is analyzed using CAPWAP software. This involves applying the measured pile-top velocity-time record to the top of a lumped-mass and spring in a wave equation pile-model. After CAPWAP analysis is done, the complete pile and soil model is available for static analysis. This is analogous to a static load test and is referred to as a “simulated load test”.

Fig. 8. Data acquisition using PDA

CAPWAP analysis from one typical pile at Pier P-94 (pile dia 1500 mm, pile length 52.05 m, concrete grade M40) is presented on Fig. 9.

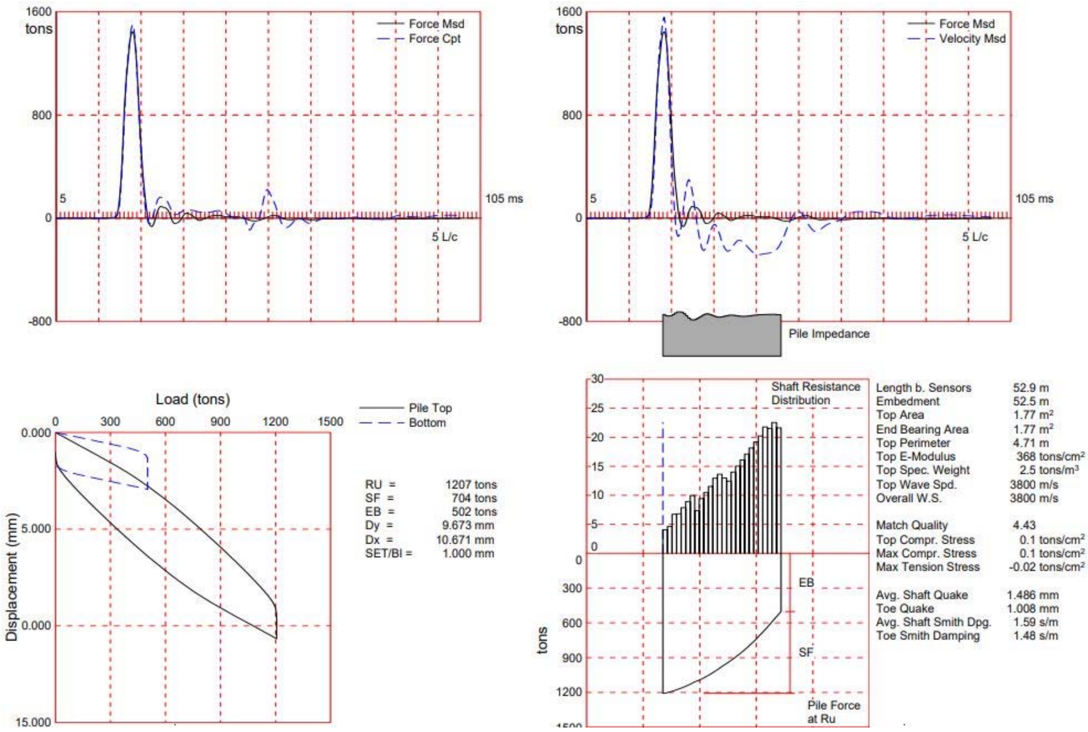


Fig. 9. Pile at Pier 94/3: CAPWAP analysis and equivalent static load-settlement curve

The analysis suggests that Pile 94/3 mobilized a capacity of 1207 T during the test with corresponding settlement of about 9.67 mm. At 787.5 T (1.5 times the design load of 525 T), the displacement is 4.9 mm. The pile is therefore safe for the design load of 525 T.

Table I below presents the safe capacities and the settlement assessed from CAPWAP analysis for a few selected piles.

TABLE I. PILE QUALITY AND CAPACITIES ASSESSED FROM HSDLT

Pier No. / Pile No.	Pile Length, m	Test Load (1.5 x Safe Capacity), T	Interpreted Settlement, at 1.5 x safe load, mm	Pile Integrity
P-94/3	52.05	787.5*	4.9*	Continuous and reasonably uniform. No anomalies
P-99/5	52.05	787.5*	5.5*	Continuous and reasonably uniform. No anomalies
P-105/4	52.05	787.5*	5.6*	Continuous and reasonably uniform. No anomalies
P-128/5	54.05	720†	4.5	Continuous and reasonably uniform. No anomalies
P-133/5	54.05	690‡	4.1	Continuous and reasonably uniform. No anomalies

* Design safe load = 525 T † Design safe load = 480 T
‡ Design safe load = 460 T

B. Cross-Hole Sonic Logging (CSL)

Cross-hole sonic logging or cross-hole ultrasonic monitoring of the piles involves sending ultrasonic pulses between parallel access tubes (cross-hole) installed in a pile. The information received is used to interpret the quality of concrete in the pile section between the tubes. The test is performed in accordance with ASTM D 6760-16 [7].

The test involved casting four to six PVC pipes in the pile. For the 2500 mm diameter piles of the main bridge, six access pipes were cast in the piles. Two ultrasonic transducers of which one a transmitter and the other a receiver are lowered to the bottom of the water-filled tubes, leveled. The transducers are lifted in unison in their respective access tube(s) to test the pile shaft from bottom to top. The transmitter probe generates ultrasonic pulses at frequent and regular intervals as the probes move upward.

Fig. 10 illustrates pipes cast in the pile and probe being lowered into the pile for testing. Fig. 11 shows the data acquisition for cross-hole sonic logging in progress.

Fig. 10. Pipes cast in pile for CSL test

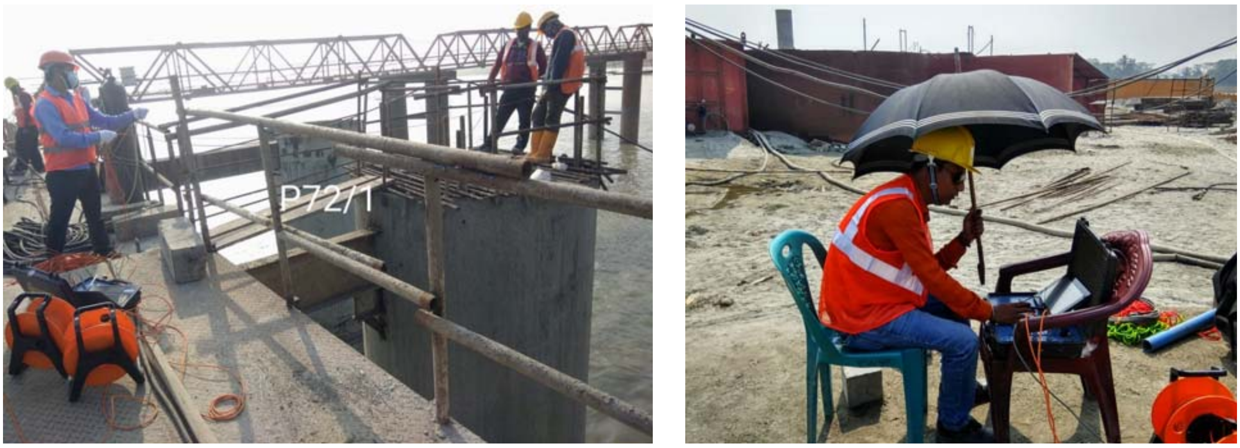


Fig. 11. Data Acquisition for CSL test

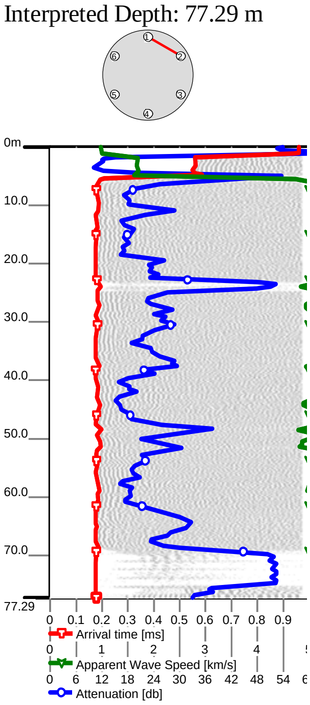
The CSL tests were performed on the 2500 mm diameter piles in the main bridge portion. About 3-6 piles on each pier were tested so as to generate confidence in the quality of data and to ensure that the piles are free of major defects.

Typical results of some selected piles are summarized in Table II. Fig. 12 presents typical output of cross-hole sonic logging from Pile 72/1 and the interpretations from the test results.

TABLE II. PILE QUALITY AS ASSESSED FROM CSL

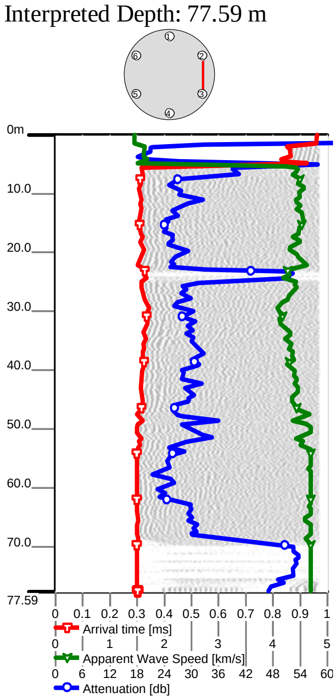
Pier No / Pile No.	Pile Length	Pile Integrity
P-69/2, 3, 4, 6	72 m (acceptable)	Continuous and reasonably uniform. No anomalies
P-70/3, 4, 5	72 m (acceptable)	Continuous and reasonably uniform. No anomalies
P-72/1, 2, 3, 4, 5, 6	72 m (acceptable)	Continuous and reasonably uniform. No anomalies
P-76/2, 5, 6	72 m (acceptable)	Continuous and reasonably uniform. No anomalies

P72/1 Data acquisition between Pipes: 1-2
Interpreted Depth: 77.29 m



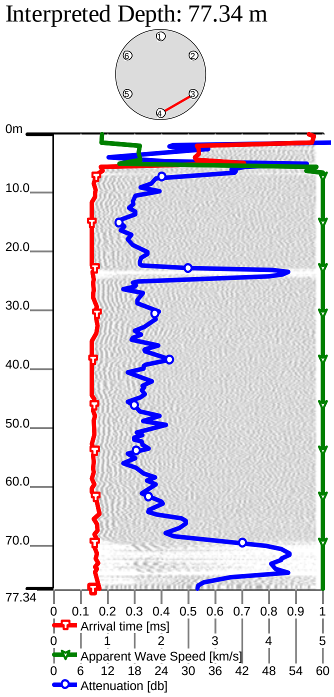
P72/1 Points1-2: Sound section below 5m. from top

P72/1 Data acquisition between Pipes: 2-3
Interpreted Depth: 77.59 m



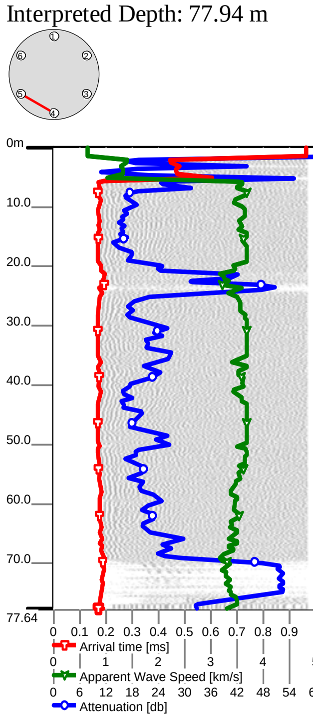
P72/1 Points 2-3: Sound section below 5m. from top

P72/1 Data acquisition between Pipes: 3-4
Interpreted Depth: 77.34 m



P72/1/3-4: Sound section below 5m. from top

P72/1 Data acquisition between Pipes: 1-6
Interpreted Depth: 77.94 m



P72/1/4-5: Sound section below 5m. from top

Fig. 12. Typical CSL output for Pile P72/1

VIII. Concluding Remarks

The quality assurance tests performed on the piles helped to develop the confidence that all piles installed for the project are adequate and safe for the design loads.

High strain dynamic load tests for the 1500 mm diameter piles confirmed that no major defects (necking or bulging of piles) are present. They also confirmed the continuity of the concrete. The equivalent static load-settlement curve generated from CAPWAP analysis confirmed that the piles are safe for the design loads.

The ultrasonic cross-hole ultrasonic logging for the 2500 mm diameter piles confirmed that the piles are of fairly uniform quality.

The authors emphasize on the importance of a well-planned and implemented quality assurance plan for large diameter piles to ensure uniform good quality piles. Static load tests for large diameter piles are not only expensive but also time consuming and involves a lot of preparation. For cost-effective quality assurance, low strain pile integrity tests, high strain dynamic load tests as well as cross-hole sonic logging can be done quickly with relatively less effort and preparation. For important bridge projects, testing at least one pile in each pile group can greatly enhance the reliability of the piling.

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