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WEAP Analysis and HSDPT for Steel Piles for Transmission Line Project Across River Hooghly

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1 Introduction

High Strain Dynamic Pile Testing (HSDPT) is popular worldwide for more than four decades. HSDPT is primarily used to assess the capacity of pile foundation (Vaidya 2006). The testing is standardized by several codes worldwide (Beim and Likins 2008). Reliability of HSDPT has been rigorously investigated and its correlation with static load testing has been summarized by Likins and Rausche (2004).

The test can be used to evaluate various pile parameters, important of these are static capacity of the pile at the time of testing, simulated static load test curve, total skin friction and end bearing of the pile, skin friction variation along the length of the pile, stresses developed in the pile during driving, net and total displacement of the pile, pile integrity and hammer Performance.

HSDPT is now very common in India for bored piles, however its application for driven piles has been proved to be extremely beneficial to piling industry. The biggest advantage of HSDPT for driven piles is no separate test setup is required for the testing. With the pile driving hammer and regular operation only, pile testing can be performed while in case of static load testing especially in marine conditions, preparation of test setup is challenging and requires significant time.

Another powerful tool associated especially with driven piles is the WEAP software. The main objective of the software is to assess whether a pile can be driven to required penetration with the proposed hammer or not. The input includes hammer parameters, pile profile details and soil details either in terms of soil classification and SPT blow counts or in terms of layer wise unit skin friction and end bearing. The software then simulates the pile response to hammer impact forces. The input also requires careful selection of several other parameters such as gain/loss factors, damping and quake values etc.

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The following sections present a case study of a marine project for which WEAP and HSDPT was utilized successfully for driving of steel piles and resulted in significant cost and time savings for the project.

2 Project Information

A 400 kV Transmission tower was to be constructed across Hooghly River. For transmission towers, steel piles were chosen as preferred choice considering its ease of installation.

Each of the transmission towers was supported on four legs and for each of the legs 14 raker piles were designed. The center to center distance between adjacent legs was 55 m. The steel piles were open ended having diameter of 1219 mm of variable thickness and raked in 1:5. The High tide level was 9.5 m above mudline and maximum scour depth was 15 m. Four 12 m steel pipe segments were planned to be mobilized so as to achieve target penetration level of −42 m (Pile founding level). The thickness of steel pile section varied from 25 mm (bottommost segment) to 40 mm (topmost segment). Figure 1 presents the layout of foundation for the transmission tower.

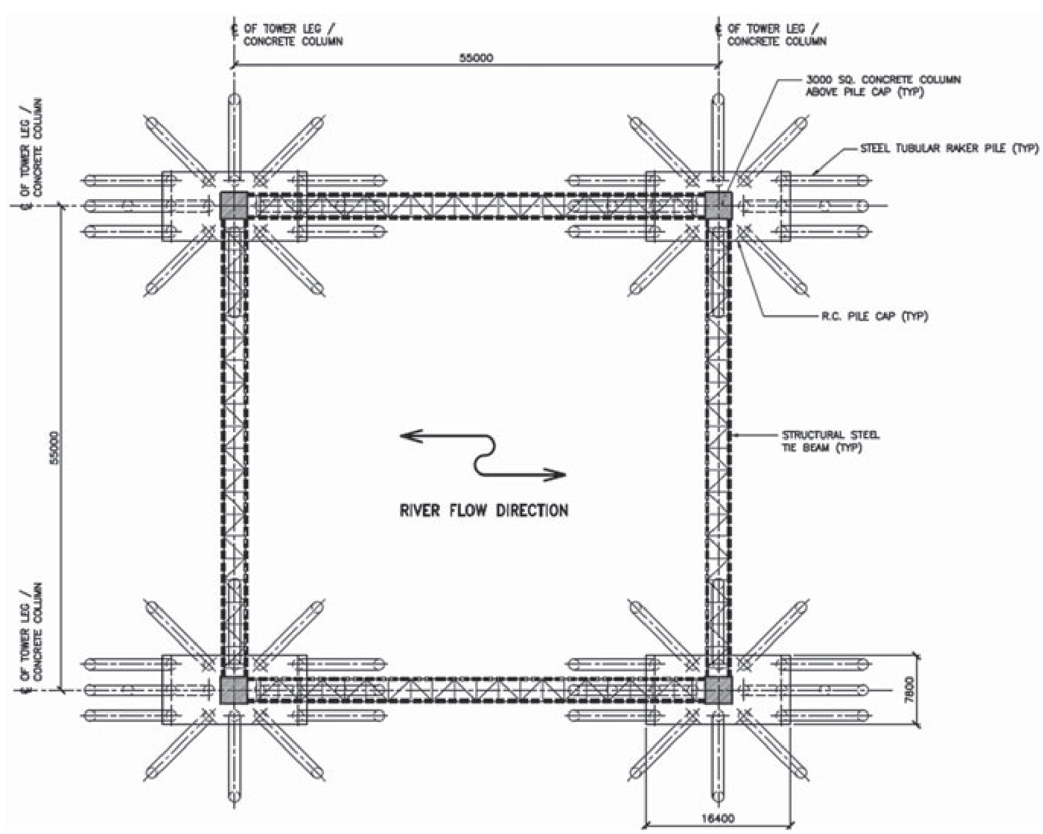

Fig. 1 Layout of foundation for transmission tower

3 Subsurface Conditions

Five boreholes were drilled up to depth of 55 m in order to assess the subsurface conditions at the site. Two boreholes (BH-3 and BH-4) were drilled on either side of river banks and three boreholes (BH-1, BH-2 and BH-5) were drilled in the river bed. Figure 2 presents the subsurface exploration in progress in river bed.

Typical subsurface conditions were consist of loose to medium dense silty sand, underlain by soft to stiff silt and silty clay. Medium dense to very dense silty sand was encountered below the silt layer underlain by very stiff to hard silty clay layer. Bottommost layer was again medium dense to very dense silty sand. The subsurface profile was highly variable for each boring and typically found to be layered profile of silts, sands and clays. Figure 3 presents the SPT blowcount for all five boreholes along the depth which indicates the consistency of each soil layer encountered in all boreholes along with the variation in subsurface condition across site.

Fig. 2 Subsurface exploration in progress

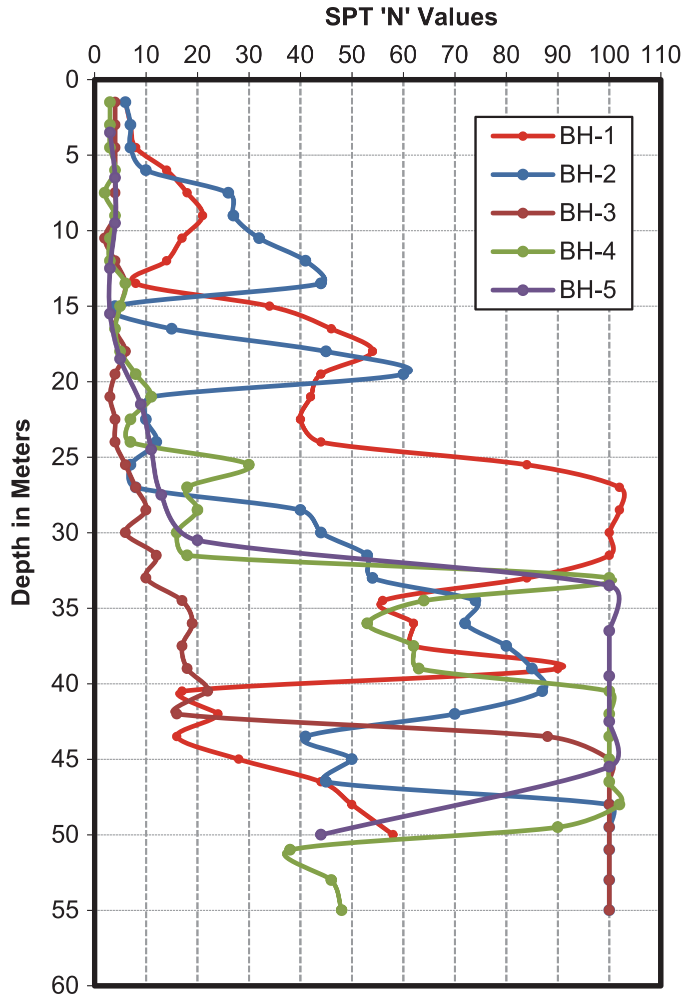

Fig. 3 SPT (N) blowcount versus depth

4 Weap Analysis

Based on information obtained from subsurface investigation program, detailed design study was undertaken and it was proposed to install driven steel piles as foundation for towers. Delmag D100-13 hammer was available with the client and hence it was the preferred choice for driving the piles. However, before mobilizing hammer to the site, it was necessary to confirm that the hammer is suitable to drive the piles to required penetration. Hence WEAP analysis was performed for two borehole locations (BH-1 and BH-3).

Since the early 1970s wave equation analysis of pile driving (WEAP) has become a standard tool for the preparation of pile installations by impact driving. The original concept had been developed by E.A.L. Smith of Raymond International. Basically, the analysis simulates what is happening in hammer, pile and soil during and immediately after the ram impact. It does this by replacing the system's components with masses, springs and dashpots and calculating the displacements and velocities of the masses and the forces in the springs. Stresses are determined from forces divided by cross sectional area at points that are roughly 1 m apart. This method of calculating the pile movements and stresses is an accurate solution of the wave equation (a differential equation).

Based on available information, WEAP was performed to determine whether Delmag D100-13 diesel hammer is capable to drive open ended pipe piles of 1219 mm diameter to a tip elevation of −42.0 m. The pile was proposed to be driven 37 m into mudline at BH-1 location and 44 m at BH-3 location.

Static analysis was performed by contractor which was used as input into WEAP to define soil parameters. Friction angle for sandy soil was varying from 30° to 35° in case of BH-1 and 36°–37° in case of BH-3. Cohesion for silts and clays were ranging from 3.5–20 ton/m^2 in case of BH-1 and 2.1–9 ton/m^2 in case of BH-3. The setup factor was considered as 1.2 for sands and 2.5 for silty clays. In order to model the SRD, i.e. the static resistance to driving based on the above setup factors, analysis was performed with shaft Gain/Loss Factor of 0.4 (full loss of resistance) and 1.0 (no loss of shaft resistance, i.e., full long term resistance or restrike situation). It was considered that there will be no change in End Bearing with time and hence a toe Gain/Loss Factor of 1.0 was used for the analyses.

A shaft damping factor of 0.65 s/m for clays and 0.16 for sands were used and a toe damping factor of 0.5 s/m have been considered based on the soil type, GRLWEAP recommendations and some conservatism. Shaft quakes were set to 2.5 mm which are standard assumptions for open ended pipe piles. It was expected that such large diameter piles will be driven unplugged and hence toe quakes were also set to 2.5 mm.

For each of the analysis of BH-1, two cases of hammer performance were evaluated; the lowest fuel setting of the hammer for an efficiency of 80% and 3rd fuel setting of hammer for an efficiency of 60%. For each of the analysis of BH-3, similar two cases of hammer performance were evaluated; the 2nd fuel setting of the hammer for an efficiency of 80% and highest fuel setting of hammer for an efficiency of 60%.

For BH-1 analysis, static analysis of piles ignored the upper 15 m soil resistance to account for scouring. However, during driving operations this soil was present and expected to offer some resistance to driving and hence was modeled accordingly. The ultimate static capacity ignoring the upper 15 m of soil was estimated to be around 837 tons. It was estimated that upper 15 m of soil will offer approximately 73 tons and the total ultimate capacity of the pile was expected to be 910 tons. Around 95% of resistance was expected to be contributed by skin friction. Although plugging at pile bottom was not anticipated, for conservatism as far as driveability is concerned, it was considered that friction inside the pile would be present and would offer resistance to driving. For BH-3 analysis, it was assumed that there will be 48 h interruption after driving two sections of the piles i.e. after 24 m (20.2 m into the ground). It was assumed that the piles will be driven continuously without any other significant interruptions like hammer breakdown or any other site related unforeseen issues.

WEAP analysis performed for both locations i.e. BH-1 and BH-3 indicated that, under the assumption of no plugging, the Delmag D100-13 hammer would successfully drive the piles to the required depth. It was expected that driving stresses would be within allowable limits as the estimated compressive stresses were around

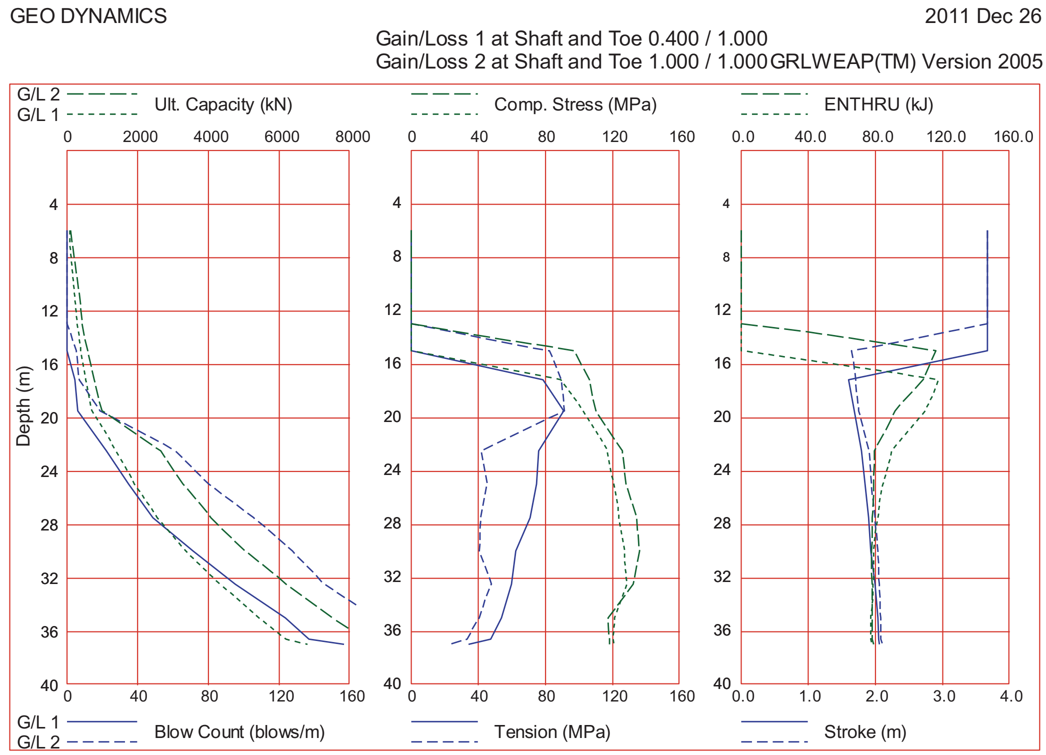

Fig. 4 WEAP output (BH-1) 80% efficiency with lowest fuel setting

135 MPa and allowable limit was 216 MPa. Figure 4 presents typical output obtained from WEAP analysis for BH-1 location which summarizes variation of blowcounts along the depth, expected compressive and tensile stresses, energy as well as predicted pile capacities along the depth.

5 HSDPT of Steel Piles

WEAP analysis confirmed that Delmag D100-13 hammer is capable to drive the steel piles to required penetration and hence hammer was mobilized to the site for pile driving operations. All the piles were driven successfully and no issues were encountered. Piles were not monitored during initial driving operations. However, few piles were selected and HSDPT was performed after wait period of few days (ranging from 5 days to 28 days) in order to assess pile capacities and to confirm that piles can carry the required test load.

Four piles were tested in marine condition after wait period ranging from 5 days to 11 days and one land pile was tested after wait period of 28 days. Marine piles were driven up to depth of around 33 mm and land pile was driven up to a depth of 46 m. The required test load was 454 tons for marine piles and 600 tons for land piles. Restrike tests were performed by providing 10 blows to the pile from a height of approximately 3.5 m (i.e. 4th fuel setting).

After performing HSDPTs set observed during HSDPT was in the range of 1–3 mm indicating the piles are not loaded till their ultimate capacities and piles have more capacities which were not needed to be mobilized. CAPWAP analysis was performed for selected blow for each of the HSDPT for evaluating the pile capacities. CAPWAP analysis indicated that all piles achieved much more capacities than required test load. For all piles estimated capacities were more than 800 tons. Skin friction component was 85% while the end bearing was 15% which matched fairly well with the static analysis results. Also the capacity estimated by static analysis proved to be conservative based on HSDPT results. Maximum measured compressive stresses were around 150 MPa which were close to the predicted compressive stress of 135 Mpa from WEAP. Small variations to the stresses as estimated by WEAP to the actual measurement can also be attributed to fuel setting which was 4 during actual restrike testing. Figure 5 presents results for typical CAPWAP analysis which summarizes skin friction distribution, simulated load settlement curve and force-velocity data.

6 Concluding Remarks

WEAP, HSDPT and CAPWAP are routinely used tools in piling industry and have resulted in tremendous assistance to entire fraternity. It is always riskier to mobilize pile driving hammer to the site before making sure its suitability to drive the piles. WEAP is powerful software addresses this issue and for a transmission tower project hammer was mobilized after confirming that Delmag D100-13 is suitable hammer to drive the open ended steel piles. Actual compressive stresses measured during restrike testing were nominally higher than predicted by WEAP but which is justified as the testing was performed with the 4th fuel setting. Static capacity from computation was a conservative estimate and actual measured capacities were higher than estimated although friction components as predicted from WEAP and actual measurements were within 10%. Thus assumptions of damping and quake and other parameters can be largely justified and can be said within acceptable range as the pile could be driven to the estimated depth at similar compressions stresses. Performing static load tests in marine conditions is always a crucial activity. A proper planning and check with wave equation analysis followed by HSDPT provided viable and reliable option for speedier completion of project.

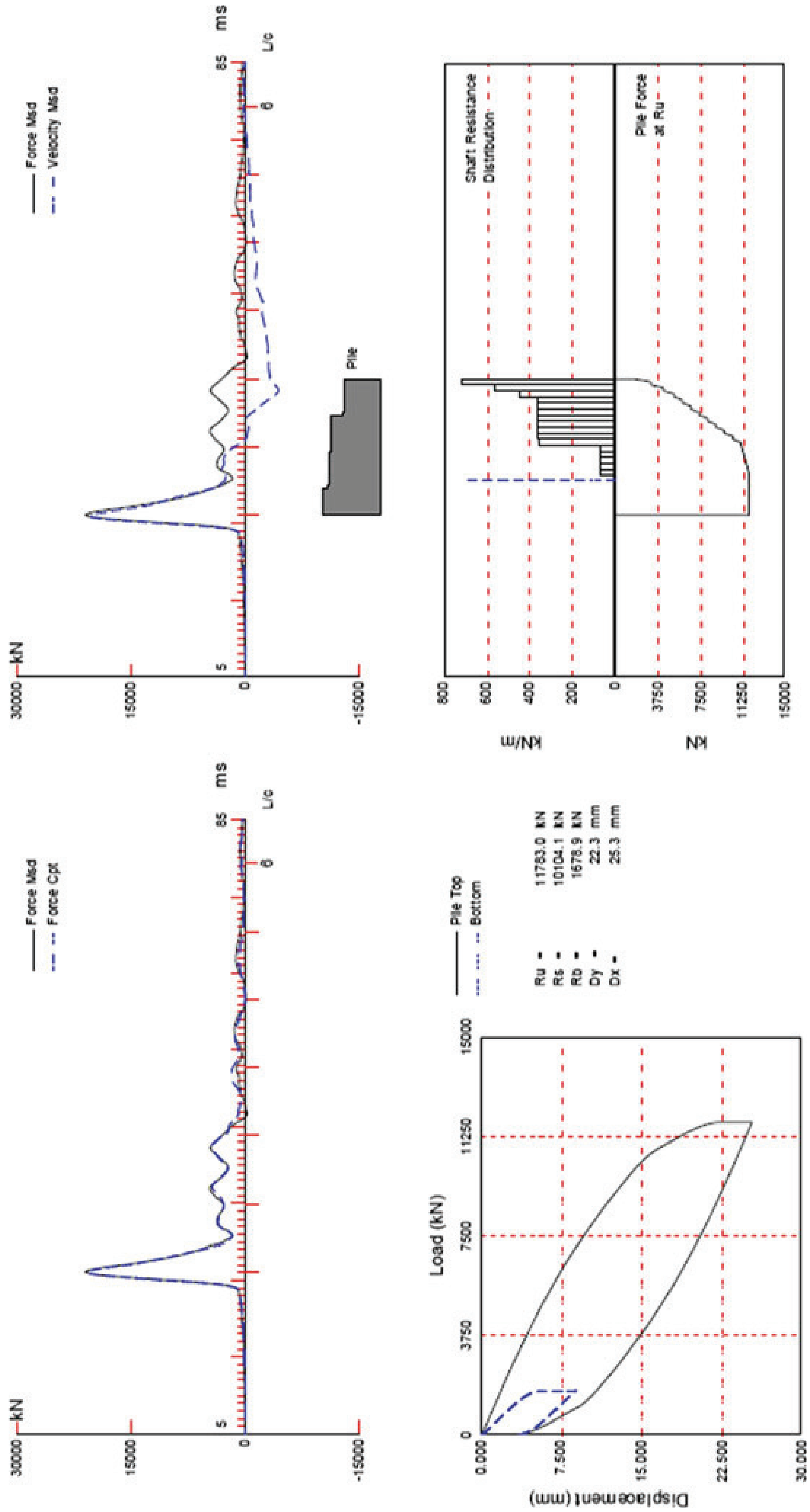

Fig. 5 Typical CAPWAP output

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