ASSESSMENT OF PILE VERTICALITY AND PILE PROFILE USING SHAPE (Shaft Area Profile Evaluator)

Brent Robinson
Vice President, Pile Dynamics, Inc., Cleveland, OH-44139
E-mail: brobinson@pile.com

Ravikiran Vaidya

Principal Engineer, Geo Dynamics, Vadodara-390023
E-mail: ravikiran@geodynamics.net

Sujan Kulkarni
General Manager, Geo Dynamics, Vadodara-390023
E-mail: sujan@geodynamics.net

ABSTRACT: Concrete bored piles or drilled shafts are usually designed with a uniform cross-section and assume they are vertical. Due to their inherent nature of installation, there are uncertainties in excavated pile profile and verticality, and specifications worldwide allow certain tolerances for verticality. The paper describes a tool available in the market to measure shaft verticality and profile and provides an insight into the measurements' theory, its applications, limitations and acceptance criterion based on IS:2911 and some of the other codes worldwide. Two case studies in India indicate capabilities and future potential of the measurements. A third case study from the United States describes the results of measurements on a shaft, compared with other measurements of pile integrity.

Keywords: *Pile Profile, Verticality, SHAPE, Bored Pile, Drilled Shafts, Quality Assurance*

INTRODUCTION

Reinforced Concrete bored piles, or drilled shafts, are common deep foundation elements in India and the rest of the world. With cutting-edge technologies, contemporary equipment, and construction industry improvements, larger diameter bored piles with drilled more deeply are becoming more popular. These foundations are built to withstand massive loads. The design assumes that the pile diameter is uniform throughout the length and that the pile is vertical. However, due to various reasons associated with installation practice, this may not be always true. In practice, the pile may have bulges or defects due to type of soil or construction techniques. Piles may also skew because of bent Kelly bars, allowable tolerances in long piles, improper alignment of drilling rig, and slippage of drilling tool due to hard stratum. If the pile verticality is out of tolerance, minimum cover requirements for the cage may be not met, and eccentric loading on the top of the pile may occur, resulting in additional lateral forces on the pile and potential damage in extreme conditions.

Various methods have been attempted to measure shaft verticality using levels, ultrasonics, caliper logs, or inclinometers mounted on augers. The paper describes the findings of an ultrasonic method to evaluate excavation geometry and verticality using Shaft Area Profile Evaluator (SHAPE). This method works in wet or dry bores and the test is conducted after excavation and prior to lowering of the pile cage. The current paper describes three case studies with verticality measurements to determine pile verticality, a 3D view of the pile profile and its application with respect to IS:2911- 2010(Part 1/Sec 2).

THEORY, APPLICATIONS AND LIMITATIONS

The SHAPE device measures the distances to the sidewall in bored pile excavations, which are installed using drilling fluid such as water, bentonite or polymer slurry. The equipment sends ultrasonic pulses through the fluid support medium and measures the time taken by the pulses to reflect back from the sidewall. The system calculates the distance between sensors and sidewall based on a wave speed measured for each depth using the formula: distance = wave speed x time. A higher measured wave speed yields longer distances. The deployment, data collection, and data evaluation is desidgned to minimize the time between boring completion and concreting. The equipment can either be connected to a Kelly bar or lowered with an independent winch system. To collect data, the equipment is lowered into the borehole at a speed of approximately 30 cm/sec. Figure 1 shows the downhole device.

FIGURE 1 SHAPE Equipment

The equipment consists of eight ultrasonic transmitters and one ultrasonic receiver to measure distances to the sidewall [2]. Additionally, in-built calibration sensors are used to directly measure the wavespeed of the medium. This measured wavespeed is further used to calculate the sidewall distance. Two pressure transducers mounted on the equipment estimate the depth of the equipment for each measurement. A gyroscope finds magnetic north and tracks the rotation of the device. A high resolution sidewall profile is obtained without any stopping at set depths or restricting the rotation of the equipment. The SHAPE connects wirelessly via Bluetooth with a windows based tablet. This minimizes the risk of loss of data due to cable damage. Figure 2 presents typical ultrasonic signals from a specific test depth. The top eight rows present the received signals from eight ultrasonic transmitters. The bottom signal is obtained by a calibration pulse indicating the measured wavespeed of the drilling fluid as 1533 m/s. All eight signals have similar first arrival time (FAT) indicating the device is equidistant from the side walls. The centered device is also evident from the plan view of excavation at the recorded depth presented to the right of the figure.

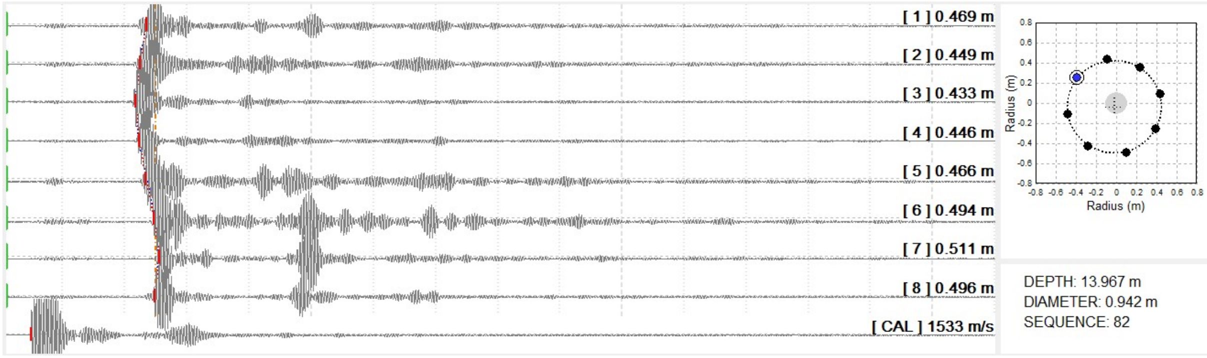

FIGURE 2 Ultrasonic Signals from eight radial transmitters and calibration pulse

Similar scans are collected every second as the device is lowered to the pile bottom. Eight scans are presented as radius versus depth in two dimensions after data is processed. Based on the collected data, the verticality of the pile is calculated as the relative offset of the circles' centroids at two defined depths divided by the vertical distance.

It is preferred to lower the device as close to the center of the pile as possible. If the device is lowered with Kelly bar then verticality of Kelly bar shall be ensured before lowering the equipment. These requirements will ensure that the device is away from the sidewalls at all times and data analysis for such cases becomes more reliable.

Each method has limitations. Thus a winch deployed system cannot be used for raker piles. To obtain verticality and pile profile in fluids with high viscosity typically beyond 150seconds or when sand content is more than 8% can be difficult and challenging.

ACCEPTANCE CRITERION WORLDWIDE

Several codes and specifications worldwide highlight the importance of the verticality of the borehole before the bored pile is cast. However, its actual measurement has been limited till now and rarely performed in India. Most specifications or codes worldwide allow a tolerance of 1%-2%. [3]. FHWA suggested specifications allow verticality within 1.5% in soil and 2% in rock [4]. ICE specification for Piling and Embedded Walls specified allowable verticality within 1.33% for bored piles [5]. The Eurocode and Australian standards allow 2% and 1% tolerances respectively [6, 7].

IS : 2911-2010 (Part 1/Sec 2) [8] allows a deviation along length up to 1.5% for vertical piles and up to 4% for raker piles. ASTM D8232-2018[9] outlines procedures for measuring the inclination of deep foundations.

INDIA CASE STUDIES

India Case 1

For a railway project of national repute, SHAPE was used for the first time in India as a demonstration case study to determine pile verticality. The test location was near Vadodara, Gujarat. The pile diameter was 1.8m and depth was 31.1m. The subsurface conditions consisted mainly of clayey soil and the piles were expected to terminate in hard clay.

A 4.5 m long temporary liner of 1.83 m diameter was installed during boring to prevent collapse of upper soil into the drilled borehole. Polymer was added to the drilling fluid to stabilize the sidewalls. The fluid level was 2.1 m from the pile top. A sand content of 0.75% was measured by onsite fluid control personnel. The SHAPE was centrally positioned over the borehole once drilling was completed. Figure 3 presents the initial position over the borehole, centered by a pulley. Once unit was properly positioned, it was armed for data collection from a tablet computer and the equipment was deployed by a winch capable of lowering at the rate of approximately 300 mm/sec. Figure 4 shows the data collection in progress, when the equipment is immersed in the drilling fluid. Data was collected during the descent and retrieval of the device.

Figure 5 presents the typical SHAPE results. The pile profile was vertical and uniform. The average diameter measured by SHAPE was 1.82m. The SHAPE demonstrated that the verticality of the pile complied to IS: 2911-2010 (Part 1/Section:2). Figure 6 presents the rendering of the data in 3D, indicating a very uniform excavation throughout the depth. Because the results were within tolerance, further piling was continued in similar manner.

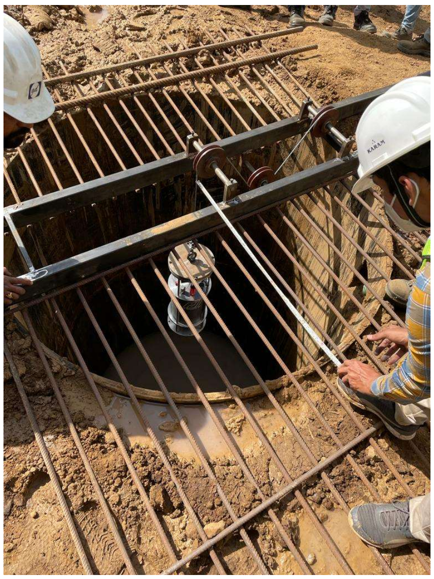

FIGURE 3 Centering

FIGURE 4 Data Collection

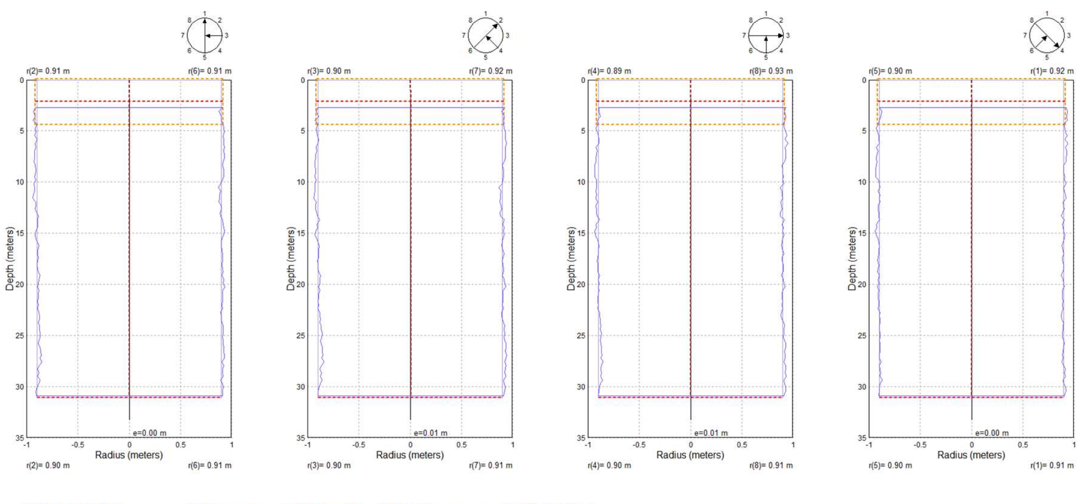

FIGURE 5 Measurement Results

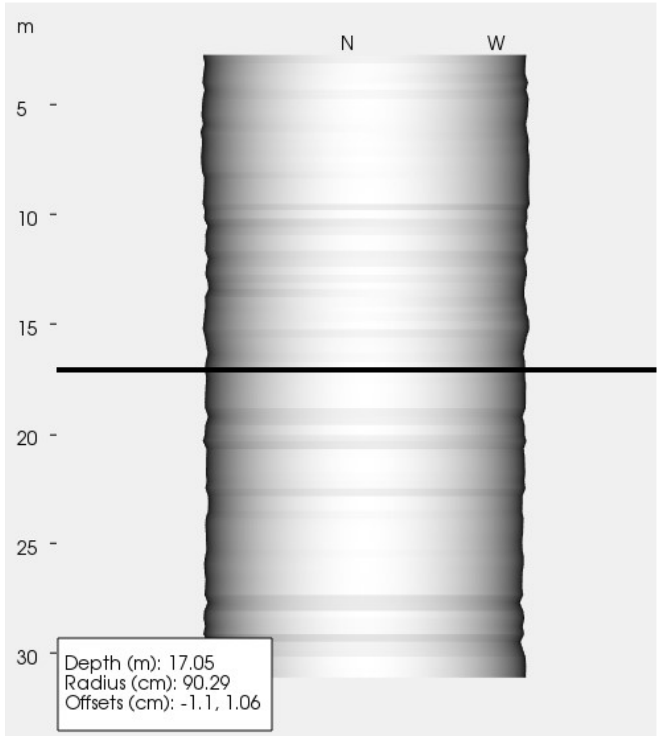

FIGURE 6 3D Rendering

India Case 2

A metro project in Ahmedabad, Gujarat, required assessment of verticality and sidewall profile. This was a demonstration case study before the contractor considers the utility of this verticality method for his projects in India. The pile diameter was 980mm and depth was 28m. The subsurface conditions consisted mainly of sandy clay and silty sand soils to the boring termination level and the pile was terminated in a sandy layer.

A temporary liner with a diameter of 1.1 m and length of 3.5 m was installed during drilling. Similar to Case Study 1, polymer was added to the drilling fluid to stabilize the excavation. The polymer level was 3m from the top of pile. The sand content was not available at the site. A sand content beyond 6% may obscure the signals and render the data uninterpretable, and several codes and specifications do provide a limit on the allowable sand content for concrete bored piles. After drilling was completed, the device was centrally positioned over the borehole as presented in Figure 7 and was lowered using a winch at the rate of 300mm/sec. Figure 8 shows the data collection in progress. Data was collected during both the descending and ascending run. The runs were repeated several times to check repeatability of results.

Figure 9 and Figure 10 presents the results of the measurement. The geometry of the drilled borehole was found to be uniform and the average measured diameter was around 1 m. However, it was observed that pile was not plumb and eccentricity was evident in both north-south and east-west directions. In one direction eccentricity was 30 mm while in the other perpendicular direction eccentricity was 120 mm. The maximum eccentricity was 0.45% and was within acceptable limits. After further investigation, the main reason for the eccentricity was attributed to telescopic boom of the piling rig. The telescopic boom itself had some bending issues which was identified after the measurement and corrected before resuming further piling work. Figure 11 presents the 3D SHAPE rendering indicating an otherwise uniform pile shaft throughout the depth.

FIGURE 7 SHAPE Centering

FIGURE 8 Data Collection

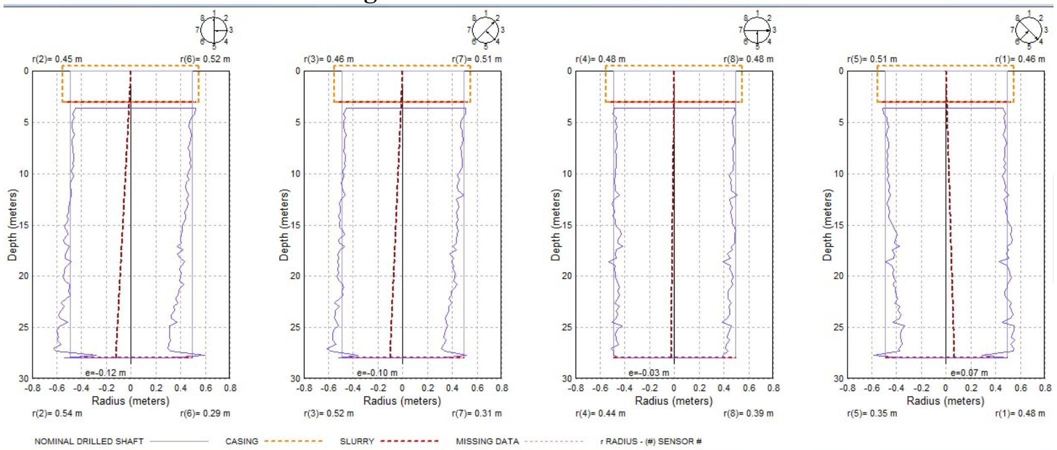

FIGURE 9 Results

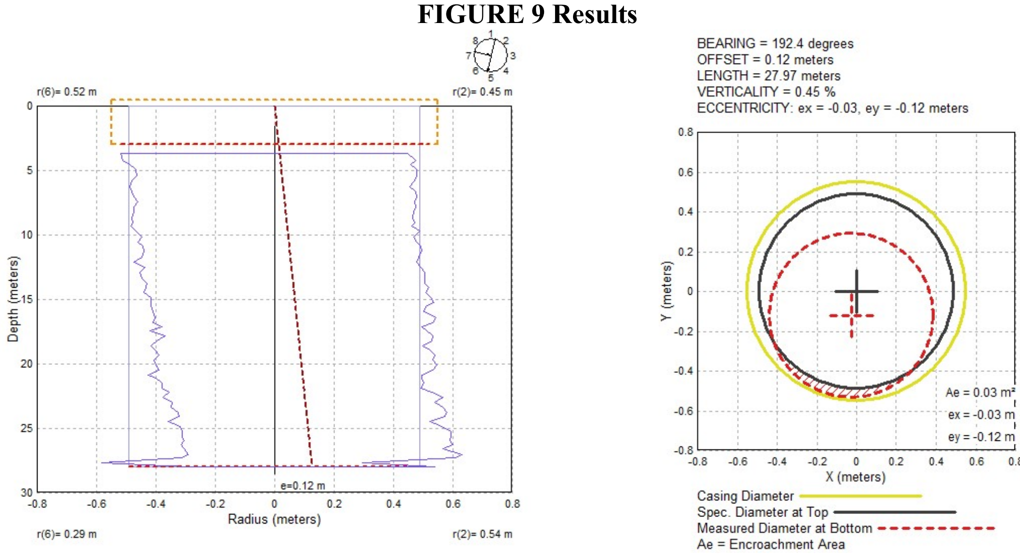

FIGURE 10 Verticality Results

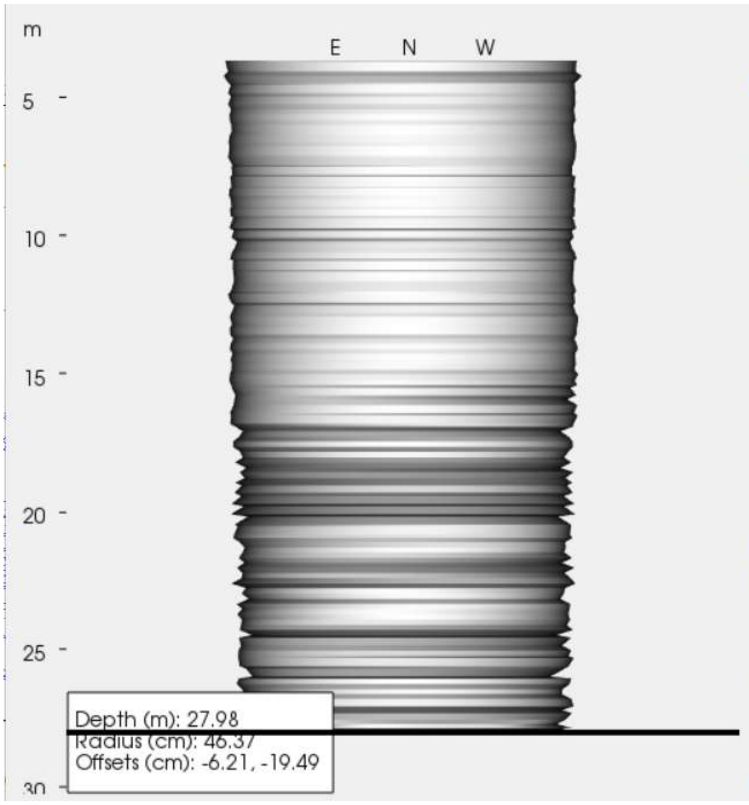

FIGURE 11 3D Rendering

UNITED STATES CASE STUDY

Quality control on a bridge foundation in the United States called for profiling and verticality of the excavation, as well as integrity testing of concrete after the shaft was poured. The shaft had a nominal diameter of 1.675 m. The 27.4 m long pile was drilled with a 3.65 m long temporary cased section at the surface. Soils were described as silty medium grain sand and sand with gravels to depths of 16 m, underlain by fine silty sands with gravel to the pile termination at 27 m.

A polymer slurry was selected to provide excavation support. After reaching the design excavation, the shaft's profile and verticality were measured. High sand content in the slurry at the excavation's bottom scattered the transmitted signal, so a full depth scan was not possible. Figure 12 shows an example of the signals received in a cleaner slurry at 8 m, compared to signals received in a slurry of high sand content and viscosity sampled at 27 m. The dashed vertical line indicates the expected time of a reflected pulse for a 1.675 m diameter shaft; the upper plot shows some very minor eccentricity of the excavation; the lower plot shows almost immediate signal reflections from the heavy concentration of sand particles at depth. Note the bottom calibration signal, over which travels a direct distance of approximately 200 mm, is only mildly affected by the sand content. The calculated wave speed in the contaminated slurry near the bottom averages 1550 m/s, with an initial arrival pulse and signal that has a lower amplitude than the slurry that allowed the wave to propagate (1503 m/s on average).

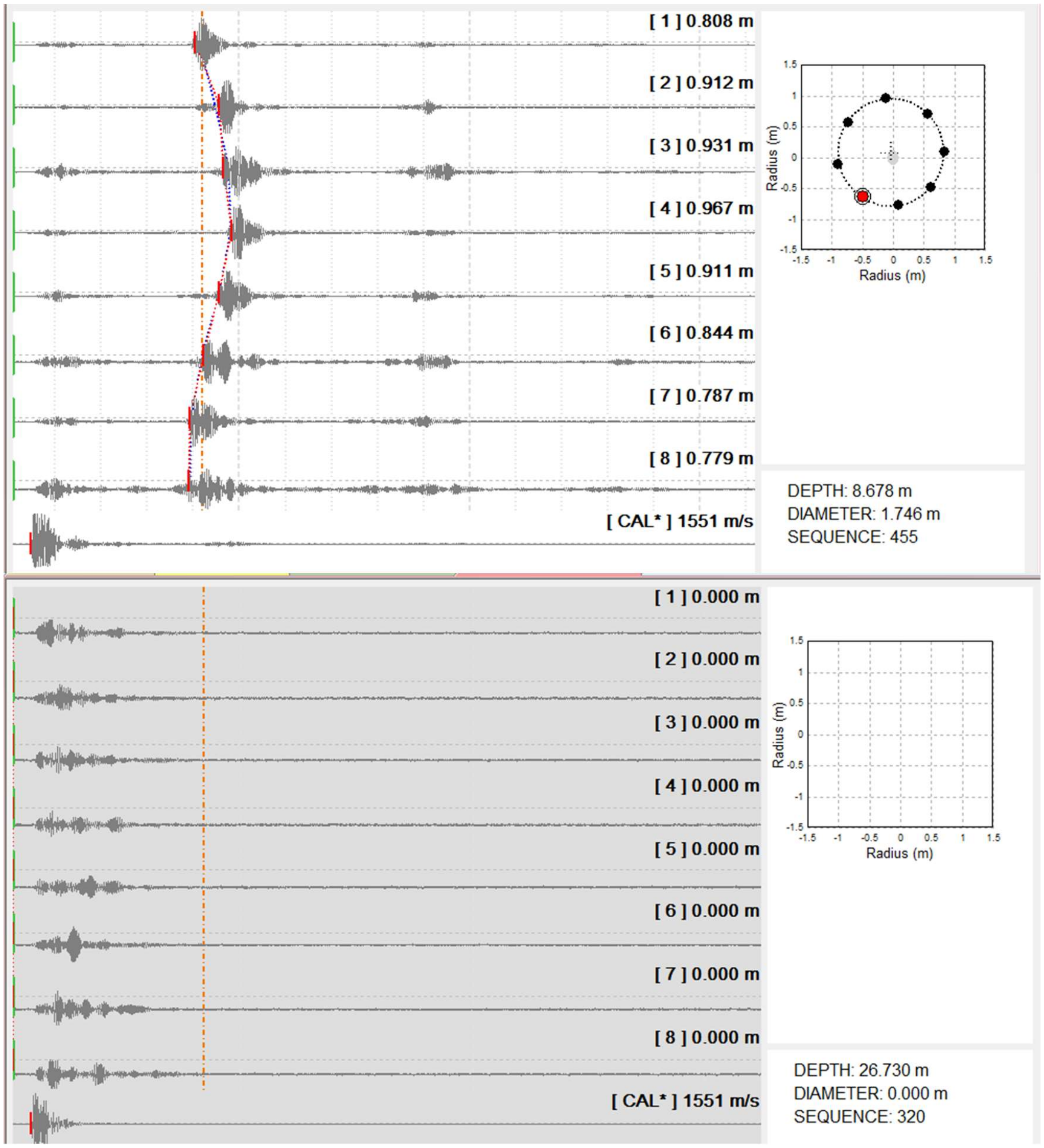

FIGURE 12. Comparison of ultrasonic results in clean (top) and contaminated slurry (bottom)

Figure 13 and 14 shows the results of the SHAPE excavation profile. The verticality was within tolerance, at less than 1%, but it was also noted two oversized zones just above and below 15 m. Below the temporary casing, some sandy soils sloughed off into the excavation. The maximum diameter of these oversized sections was approximately 2.4 m from the ultrasonic data.

The reinforcement cage was then lifted and set. Integrity testing by thermal methods was performed according to ASTM D7949-14 [10], using six Thermal Wire Cables® spaced evenly around the cage perimeter. The concrete was poured by tremie, and the thermal cables monitored the heat of hydration of the concrete. It found a generally uniform temperature profile, but for two zones of high temperature just above and below 15 m. When the reported concrete volume placed in the shaft was used for the thermal analysis, the shaft's diameter could be compared to the TIP results. SHAPE and TIP yielded similar diameter versus depth profiles, with maximum radii of 1.2 and 1.18 m, respectively.

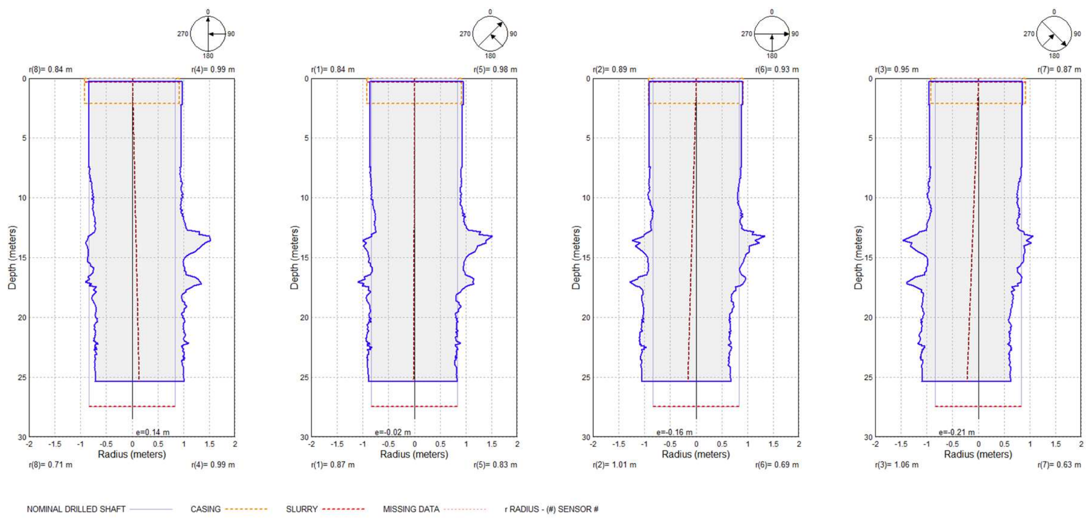

Figure 13. Excavation Profile Results

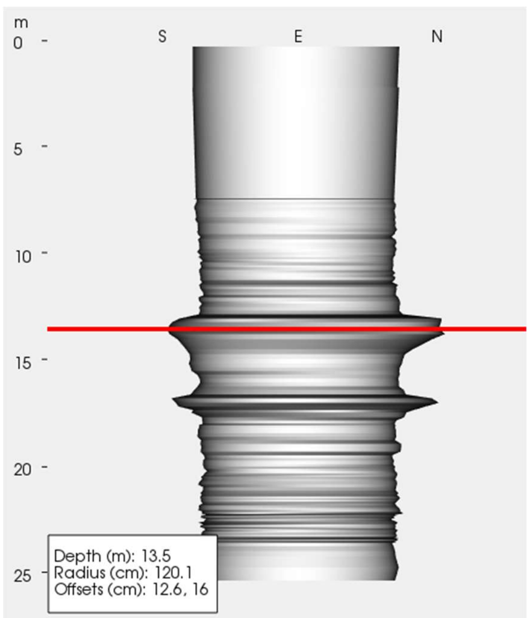

FIGURE 14. 3D Results

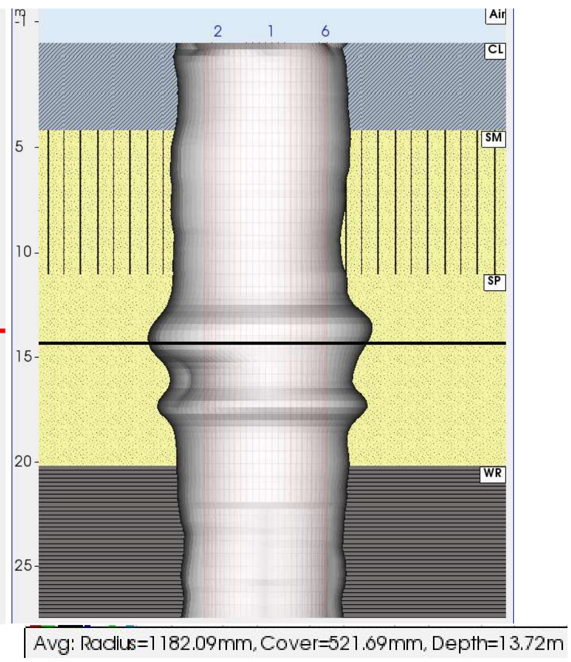

FIGURE 15. 3D Results from Integrity Test by Thermal Methods

CONCLUDING REMARKS

Large diameter reinforced concrete bored piles with high working loads and depths have seen increased use worldwide as well as in the Indian deep foundation industry. Such deep foundation construction requires that every aspect of installation of such large and deep foundations is verified. Low Strain Integrity testing, Crosshole Sonic Logging, Thermal Integrity Profiling and High strain and static load tests are well known tools for QA-QC of pile foundations and address pile integrity and capacity issues. However, in Indian practice, measurement of pile foundation verticality is not commonly done. If an installed pile is excessively out of plumb, then eccentric loads may result in damage to the pile from moments introduced due by that eccentricity. It is advisable to measure the pile verticality so verticality and unexpected hole geometry can be addressed prior to cage and concrete placement.

The current case studies demonstrate several measurements of pile verticality and geometry. The method now addresses the IS:2911 requirement was rarely implemented, as there were few readily available tools to make the measurement.

The entire process of data acquisition for all the excavation profile case studies took approximately 10-15 minutes and did not obstruct the piling process. Quantitative evaluation of the borehole diameter provides a useful tool to the structural and geotechnical engineers to compute moments, calculated unit shaft resistance, and accordingly adjust pile capacities. The method also has application when large diameter under-reamed required mapping of the extent of underream or the excavation support is insufficient to keep side walls from caving.

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