The Benefits of Pile Driving Monitoring for Precast Concrete Piles

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ABSTRACT: Compression and tension stresses may occur along the pile shaft, and these values may not exceed the concrete strength, avoiding damage to the piles. This paper shows a case study in which pile driving monitoring was made using the Pile Driving Analyzer (PDA). 17 cm-square precast concrete piles for a workload of 30 tons were driven by a 2.8-ton free-fall hammer with a 30cm drop height. The PDA data collected during the pile driving indicated that the compressive and tension stresses were acceptable (23 MPa and 3.0 MPA, respectively). However, when the pile reached 5.0m depth, the pile refusal was 10mm/10 blows, and the pile capacity was lower than expected (55 tons). Therefore, the pile testing engineer decided to increase the drop height to 40cm, and the compression and tension stresses increased to 28MPa and 3.2MPa, respectively, and were acceptable. Moreover, the pile length increased to 5.5m with a pile refusal of 10mm/10 blows, and the pile reached the ultimate load of 62 tons. This case study shows the benefits of pile driving monitoring: install the piles to the design depth with a drop height that may not exceed the concrete strength, achieving the desired pile capacity.

KEYWORDS: Pile Driving Monitoring, Pile Driving Analyzer (PDA), Precast Concrete Piles, Pile Damage, High Strain Dynamic Pile Test (HSDPT).

1 Introduction

The High Strain Dynamic Pile Testing (HSDPT) or the Dynamic Load Test (DLT) (ASTM D4945, NBR 13208) intends to determine the pile capacity and the pile shaft integrity. In the field, measurements are done from strain or force and acceleration, velocity, or displacement transducers. Furthermore, the DLT collects the force and velocity induced in a pile during a centric impact load from a pair of sensors attached to the pile. The Pile Testing Engineer may use engineering principles and judgment to check out the captured data to inspect the impedance changes along the pile shaft, the efficiency of the hammer used to produce impact loads, and the peak tensile and compressive stresses appearing in a pile during the event.

The transducers' signals shall be transferred at the moment of the impact load to the device for recording, processing, and displaying the data. The Pile Driving Analyzer (PDA) is a commonly used device to collect dynamic data (Pile Dynamics, Inc., 2009).

Moreover, the dynamic data collected are analyzed through a signal-matching Method. The CAPWAP (Case Pile Wave Analysis Program) is a software commonly used for signal-matching analysis (Pile Dynamics, Inc, 2006).

Typically, the HSDPT is performed during the restrike once this procedure may provide a better correlation with the Static Load Test due to the set-up effect. Notwithstanding, the PDA may also be used to monitor the pile installation, select the ideal drop height, and avoid excessive compression and tension stresses along the pile driving (Murakami and Cabette, 2014, 2022).

2 Objectives

Initially, the test pile was driven through the usual drop height of 30cm for a 17-cm square precast concrete pile with a 2.8-ton free-fall drop hammer. However, at the pile refusal, this usual drop height of 30cm was not sufficient to provide the desired pile capacity. Once the test pile was installed through the pile driving monitoring with the PDA, it was possible to increase the drop height to 40cm safely, avoiding excessive compression and tension stresses and obtaining the desired pile capacity. This case study shows the benefits of pile driving monitoring: install the piles to the design depth with a drop height that may not exceed the concrete strength, achieving the workload with the minimal factor of safety.

3 Methodology

It is shown in this paper the results of the pile driving monitoring that include the variation of these parameters along the pile installation: RMX (Maximum Static Resistance), DMX (Maximum Dynamic Displacement), CSX (Average Compression Stress), CSI (Maximum Compression Stress), TSX (Average Tension Stress), and EMX (Energy Transferred to the pile top). Based on these parameters, a pile driving criteria was established (pile set), including the ideal drop height to achieve the workload with a minimal factor of safety.

4 Case Study

The project site is located in Itupeva, SP, Brazil, and the deep foundations were designed to support a workload of 30 tons. The project foresaw 17 cm-square precast concrete piles with lengths between 6m and 10m in depth. Initially, the deep foundations were driven by a 2.8-ton free-fall hammer with a 30cm drop height.

The boreholes indicated a 2m-thick layer of landfill, followed by clayey sand up to 12.4m depth. In addition, the Nspt values increased in depth, with values higher than 20 blows/30cm below 6m depth.

Figure 1 shows the results of the pile driving monitoring that includes the variation of these parameters along the pile installation: RMX (Maximum Static Resistance), DMX (Maximum Dynamic Displacement), CSX (Average Compression Stress), CSI (Maximum Compression Stress), TSX (Average Tension Stress), and EMX (Energy Transferred to the pile top). It may be observed that the RMX, CSX, CSI, and TSX values increase in depth while the DMX values decrease in depth. At the beginning of the pile installation, it was placed about 2 cm of pile cushion.

The PDA data collected during the pile driving indicated that the compressive and tension stresses were acceptable along the pile installation (23 MPa and 3.0 MPA, respectively). However, when the pile reached 5.0m depth, the pile refusal was 10mm/10 blows, and the pile capacity was lower than expected (55 tons). Therefore, the pile testing engineer decided to raise the drop height to 40cm, increasing the thickness of the pile cushion to 4 cm, and the compression and tension stresses increased to 28MPa and 3.2MPa, respectively. These values of stresses were acceptable. Moreover, the pile length increased to 5.5m with a pile refusal of 10mm/10 blows, and the pile reached the ultimate load of 62 tons, achieving the workload with a minimal factor of safety.

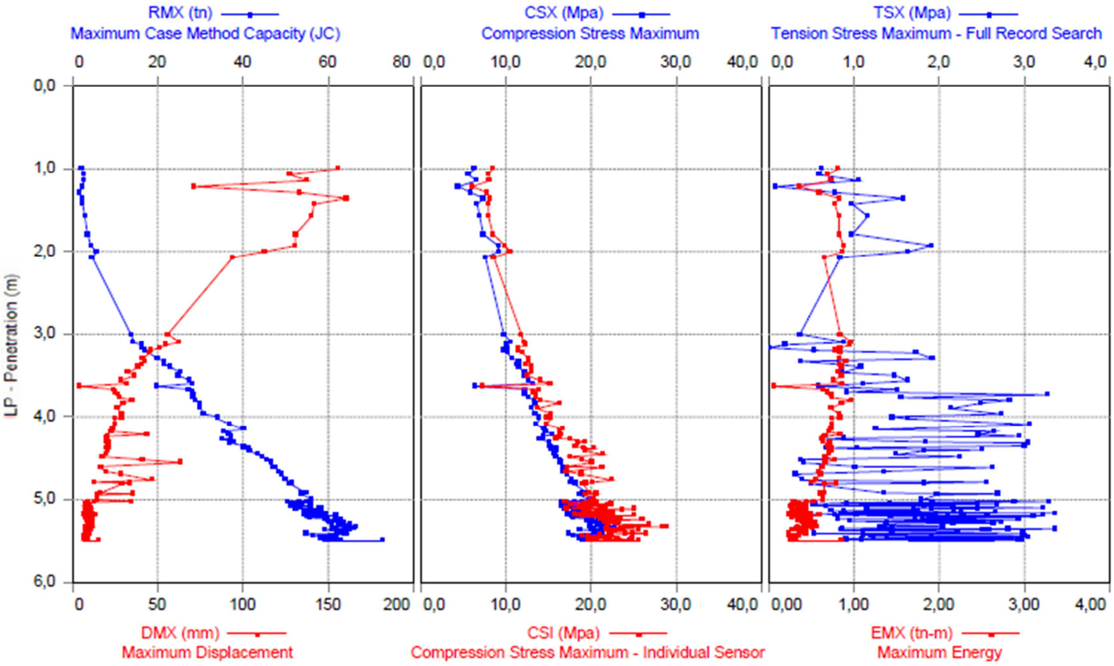

Figure 1. Graphs of the Pile Driving Monitoring

Figure 2 shows the collected force, velocity, wave up, and wave down when the pile penetration was 3m. It may be observed that the wave-up values are almost zero from the rise time to 1L/c time and negative from this time to 7L/c time, indicating low capacity (14 tons) at this depth according to the procedure proposed by Murakami (2015).

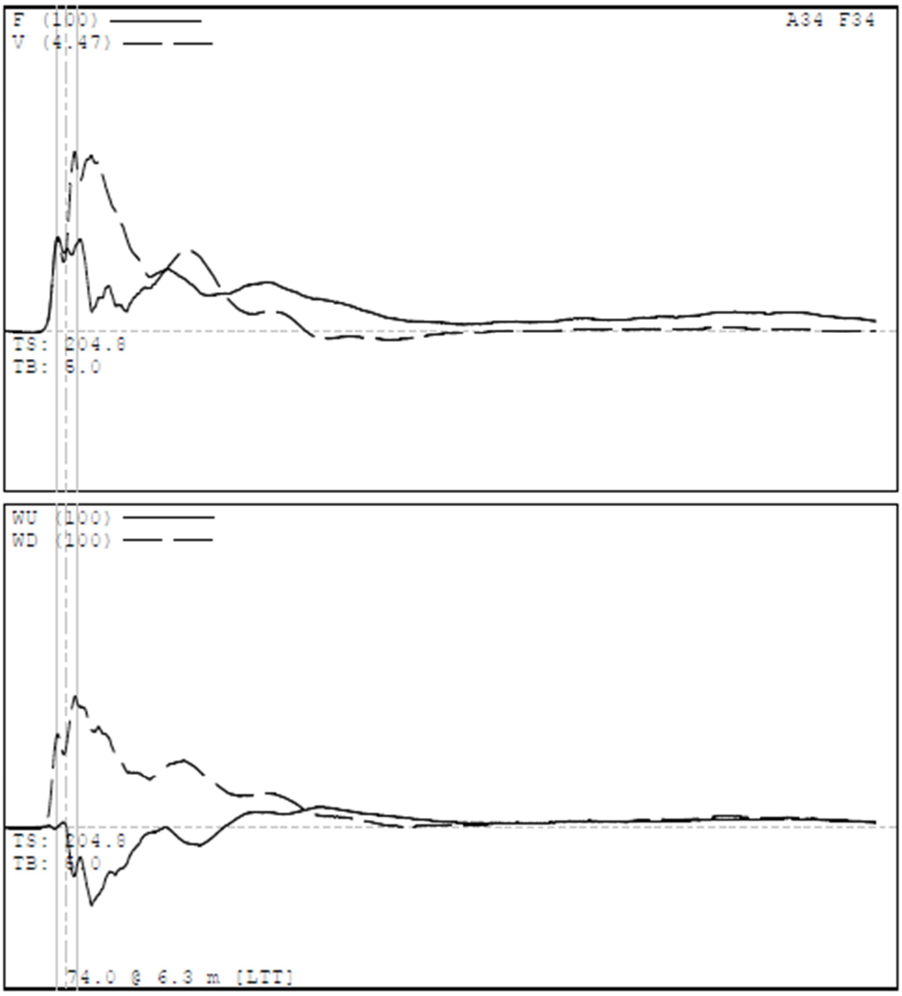

Figure 2. Force, Velocity, Wave Up, and Wave Down curves collected at 3.0 m depth

Figure 3 shows the collected force, velocity, wave-up, and wave-down when the pile penetration was 4m. It may be observed that the negative wave up values close to the 2L/c period were reduced compared to the collected data at 3m, which indicates that the pile capacity increased, according to the procedure proposed by Murakami (2015). The Case Method indicated an RMX of 39 tons.

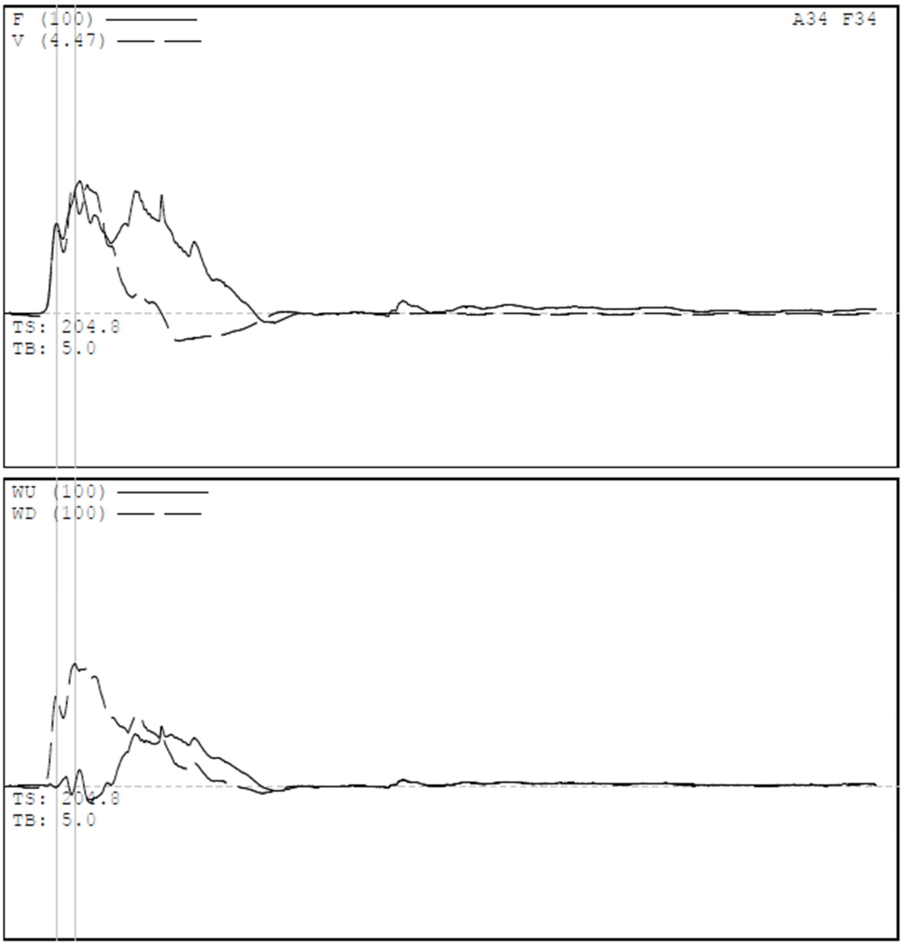

Figure 3. Force, Velocity, Wave-Up, and Wave-Down curves collected at 4.0 m depth

Figure 4 shows the collected force, velocity, wave-up, and wave-down when the pile penetration was 5m. It may be observed that the wave-up values are positive from the rise time to 12L/c time, indicating a higher pile capacity at this depth (55 tons) compared to the collected signals at 4m depth (39 tons), according to the procedure proposed by Murakami (2015).

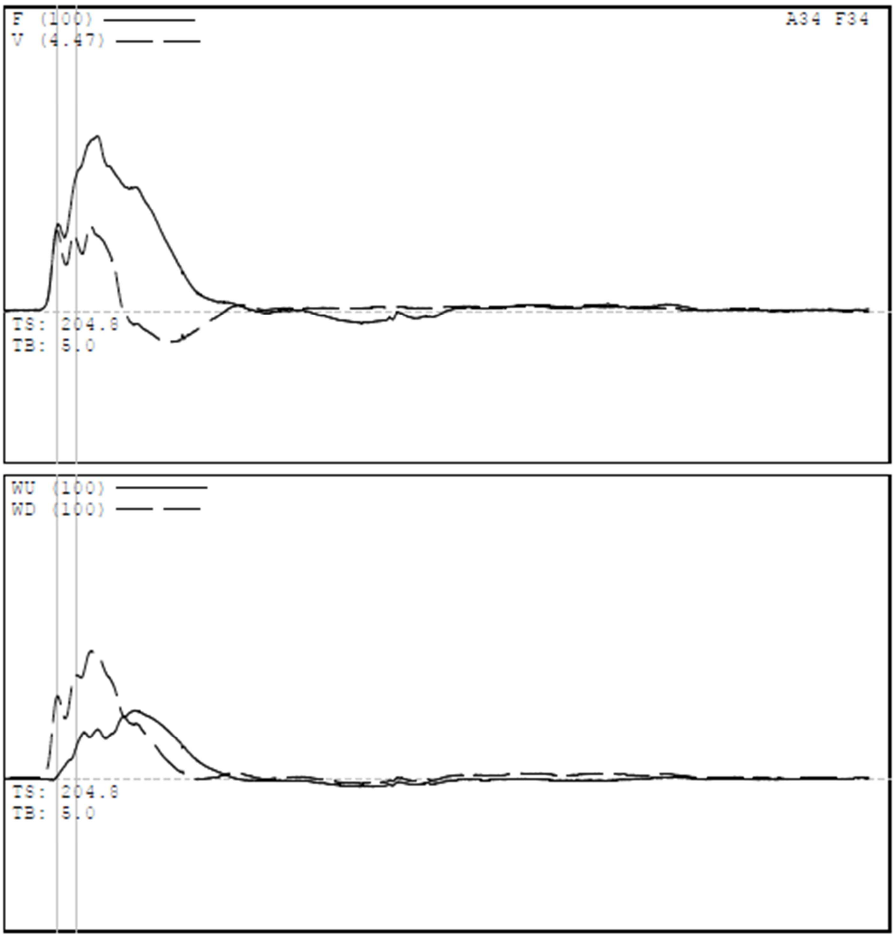

Figure 4. Force, Velocity, Wave Up, and Wave Down curves collected at 5.0 m depth

Figure 5 shows the collected force, velocity, wave up, and wave down when the pile penetration was 5.5m. It may be observed that the wave up values are positive from the rise time to 12L/c time in this depth and qualitatively are close to the signals at 4.0m depth. However, the PDA indicated a higher pile capacity at this depth (64 tons) than the collected signals at 4.0m depth (55 tons).

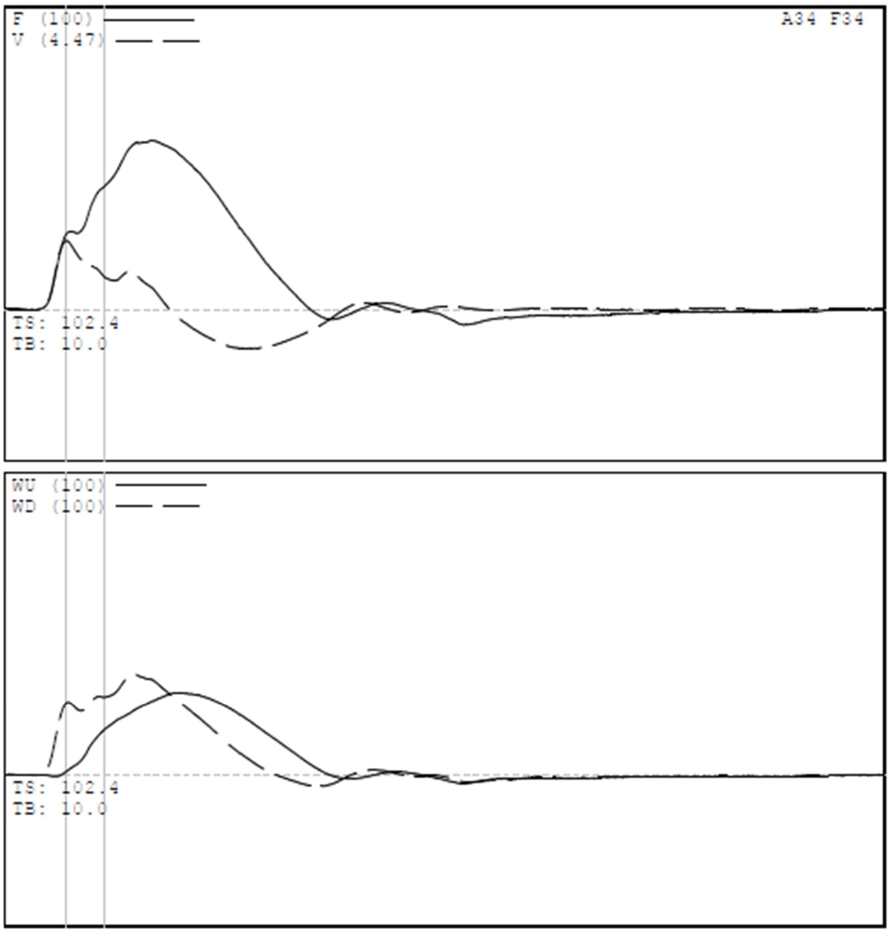

Figure 5. Force, Velocity, Wave Up, and Wave Down curves collected at 5.5 m depth

Table 1 compares the PDA parameters along the pile installation from 3.0m to 5.5m depth. It may be observed that the RMX values increased in depth, as shown in Figure 1.

Table 1. Comparison of the PDA parameters along the pile installation

Depth (m)	RMX (tons)	CSX (MPa)	CSI (MPa)	EMX (tons.m)	DMX (mm)	TSX (MPa)	FMX (tons)
3.0	14	9.8	11.8	0.84	56	0.4	29
4.0	39	14.6	16.7	0.74	24	1.3	43
5.0	55	19.6	19.9	0.65	16	1.4	58
5.5	59	19.0	19.7	0.27	7	1.7	56

Figures 6 and 7 show the CAPWAP results when the pile reached 5.5m depth for drop heights of 20 cm and 40 cm, respectively: measured force vs. computed force, measured force vs. measured velocity, simulated load vs. displacement, shaft resistance distribution, and axial force in depth. A good Match Quality was observed in both analyses, obtaining values of 1.85 (drop height of 20cm) and 2.03 (drop height of 40cm).

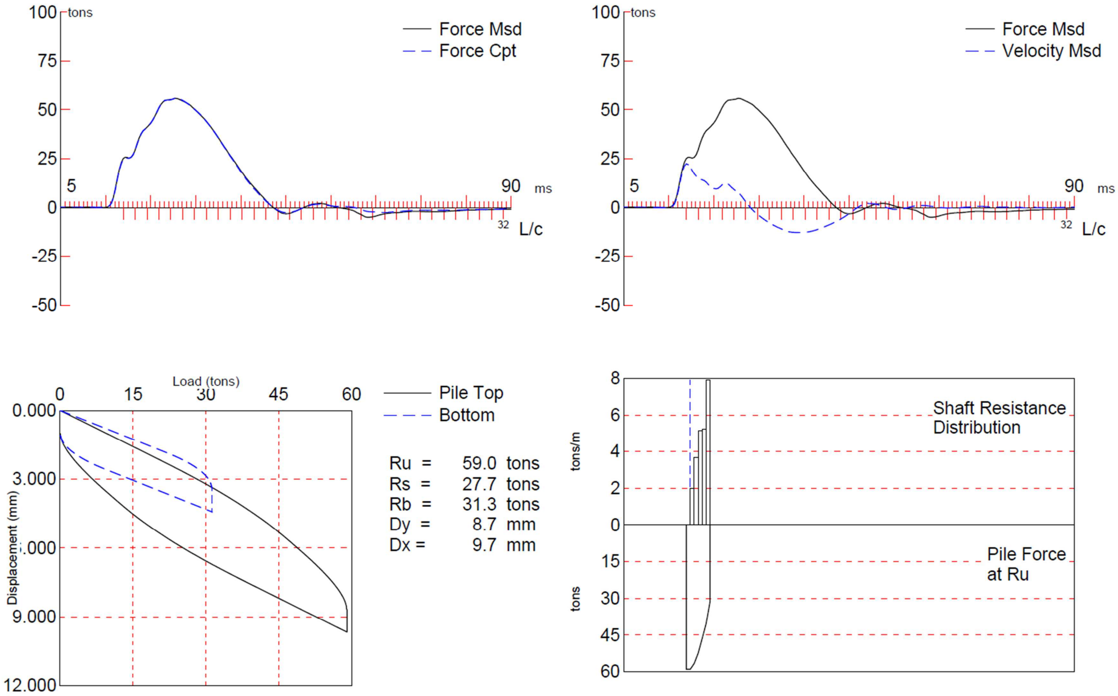

Figure 6. CAPWAP results for a drop height of 20 cm.

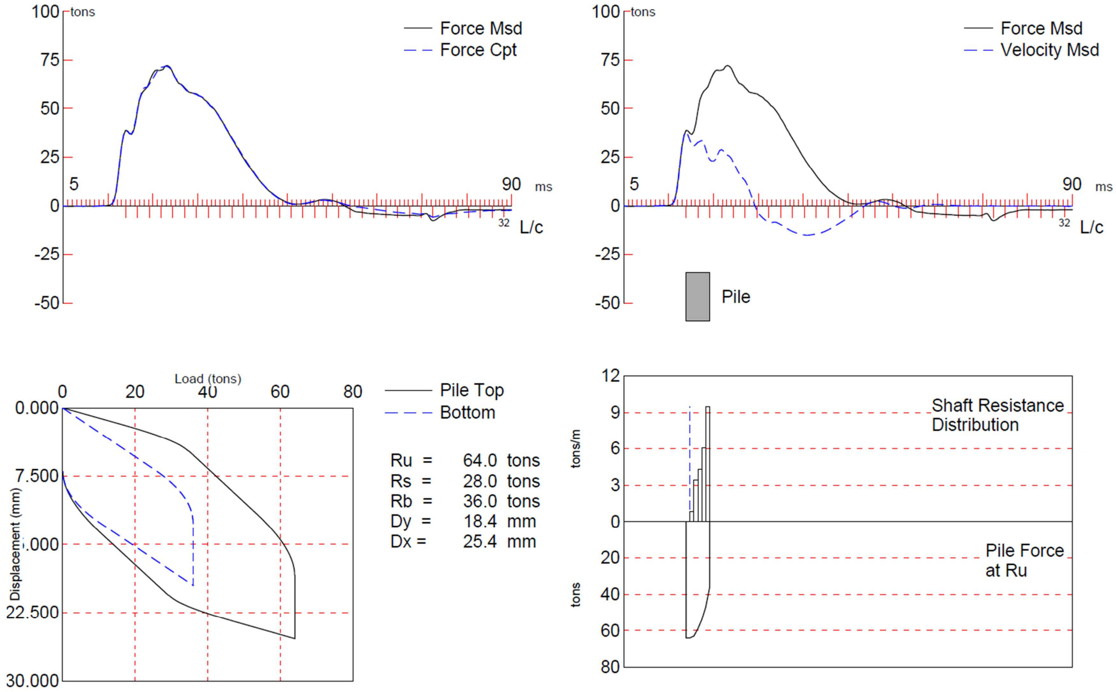

Figure 7. CAPWAP results for a drop height of 40 cm.

5 Conclusions

This case study shows the benefits of pile driving monitoring: install the piles to the design depth with a drop height that may not exceed the concrete strength, achieving the desired pile capacity.

It is shown in this paper the results of the pile driving monitoring that include the variation of these parameters along the pile installation: RMX (Maximum Static Resistance), DMX (Maximum Dynamic Displacement), CSX (Average Compression Stress), CSI (Maximum Compression Stress), TSX (Average Tension Stress), and EMX (Energy Transferred to the pile top). Based on these parameters, a pile driving criteria was established (pile set), including the ideal drop height of 40cm to achieve the workload with a minimal factor of safety, incrementing the thickness of the pile cushion from 2cm to 4cm to minimize the stresses along the pile driving.

Furthermore, the traditional procedure of installing the piles without Monitoring the Pile Installation would lead to a pile penetration of 5.0m (drop height of 30cm). However, at this depth, the pile capacity did not achieve the workload with the minimal factor of safety, and probably the piles would be restriked to reach a more extended pile penetration.

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