A Case Study in Which a 50cm-Diameter CFA Pile Showed Low Capacity in the Dynamic Load Test

Daniel Kina Murakami
Benaton Specialist, São Paulo, Brazil, daniel.murakami@benaton.com.br

Jean Felix Cabette
Benaton Specialist, São Paulo, Brazil, jeancabette@benaton.com.br

ABSTRACT: The Dynamic Load Test (DLT) has been used worldwide due to speed and economy. Many authors have shown good correlations between static and dynamic tests. Moreover, dynamic data collected by the Pile Driving Analyzer (PDA) may be further analyzed by the signal-matching method to evaluate the soil resistance distribution, toe resistance, quakes, and damping. The CAPWAP is a software commonly used to perform the signal-matching method. In this case study, the piles were designed to support 280kN, and 50cm-diameter CFA piles were installed between 4.9m and 7.0m in depth. In addition, the soil profile indicated sandy clay soil, followed by clayey silt soil. Although it was not mandatory according to the Brazilian specifications (NBR 6122:2022), the contractor requested to test four piles through the DLT, and the final sets were between 5.0mm and 8.0mm, which indicates that the piles reached the ultimate load. The CAPWAP analysis showed that the pile E01 (4.9m depth) obtained only 246kN, lower than the design load. However, piles E12 (5.1m depth) and E25 (5.1m depth) reached 680kN and 643kN, respectively. The longest pile (E35, 7.0m depth) obtained 553kN. This paper shows the need for quality assurance of the deep foundations, even in small project sites.

KEYWORDS: Dynamic Increasing Energy Test, CFA Piles, Low Capacity, Quality Assurance, Deep Foundations, Small Project Sites

1 Introduction

The High Strain Dynamic Pile Testing (HSDPT) or the Dynamic Load Test (DLT) (ASTM D4945; ABNT NBR 13208) aims to evaluate the mobilized load at the pile-soil system. Based on the measurements from strain or force, and acceleration, velocity, or displacement transducers, the dynamic test obtains the force and velocity induced in a pile during an axial impact event. The Engineer may analyze the acquired data using engineering principles and judgment to evaluate the pile's integrity, the impact system's performance, and the maximum compressive and tensile stresses occurring in a pile.

The signals from the transducers shall be transmitted during the impact event to an apparatus for recording, processing, and displaying the data. The Pile Driving Analyzer (PDA) is a commonly used device to collect pile data (Pile Dynamics, Inc., 2009).

Further, the pile data collected are analyzed through a Signal-Matching Method. The CAPWAP (Case Pile Wave Analysis Program) is a software used to perform Signal-Matching Analysis (Pile Dynamics, Inc., 2006).

Since the 1980s, numerous authors have shown good correlations between dynamic and static load tests (Likins et al., 1982; Fellenius et al., 1989; Niyama and Aoki, 1991; Likins et al., 1996; Murakami, 2015; Murakami et al., 2016, 2018, 2019, 2020). Data quality is a necessity for a well-adjusted correlation between the tests. The High Strain Dynamic Pile Testing has been used for decades for quality assurance of deep foundations, presenting some advantages compared to the traditional Static Load Test (ASTM D1143M-07; ABNT NBR 16903).

The Brazilian Standard of Deep Foundations NBR 6122:2022 establishes that static load tests (SLT) are mandatory in some specific cases. In the case of Continuous Flight Auger (CFA) Piles, for example, when the number of piles in the foundation design exceeds 100 units or the allowable stress of the piles exceeds 5.0 MPa, it is mandatory to carry out static load tests. The Brazilian Standard allows the replacement of SLT by dynamic load tests (DLT) when the number of piles is between 100 and 200 units.

2 Objectives

This paper aims to present a case study in which a 50cm-diameter CFA pile showed low capacity in the dynamic load test. The piles were designed to support a load of 280kN. Furthermore, one of the piles (E01) reached an ultimate load of 246kN, resulting in a load lower than the design load. Although it was not mandatory according to the Brazilian specifications (NBR 6122:2022), the contractor requested dynamic tests in four piles.

3 Methodology

The CFA piles were installed between 4.90m and 7.00m depth, and four piles were tested by the Dynamic Increasing Energy Test (DIET), proposed by Aoki (1989 and 1997). Furthermore, the collected data on force and velocity were analyzed by the CAPWAP. The RMX vs. DMX curves of the tested piles clearly show that the mobilized loads were almost the same, with the increased applied energy to the pile top for piles E01, E12, and E35.

4 Case Study

The project site is located in Araras, SP, Brazil, and the deep foundations were designed to support loads from a Water Tank. The project foresaw 44 Continuous Flight Auger (CFA) piles with 50cm diameter to support compression loads of 280kN.

The soil profile indicated sandy clay up to 6.85m depth, followed by a clayey silt layer up to 8.60m depth. In addition, the Nspt values increased with depth, obtaining values between 16 and 27 in the last meters of the boreholes. The groundwater table was not found.

Table 1 shows the pile penetration and the days between the pile installation and the DIET (set-up). It is observed that three piles had a pile penetration close to 5m depth, while one pile had a pile penetration of 7m.

Table 1. Information on the tested piles

Pile	Diameter (m)	Set-up (days)	LP (m)
E01	0.50	25	4.90
E12	0.50	25	5.10
E35	0.50	21	7.00
E37	0.50	21	5.10

Where: LP = pile penetration

Figures 1 to 4 show the collected signals of Force, Velocity, and Wave-Up. All the collected signals indicate a negative Wave Up at the 2L/c time ("Negative Valley"), which is an indication of large toe quakes (Likins, 1983; Murakami and Cabette, 2014, 2022). The CAPWAP analysis confirmed the large toe quakes.

Furthermore, Figure 1 (Pile E01) shows a negative Wave-Up from the rise time to approximately 6L/c time. According to the procedure proposed by Murakami (2015), this fact indicates low shaft friction. Afterward, the Wave Up curve turns positive, which indicates the toe response but is delayed due to the large toe quake. However, the Wave-Up curve after the 6L/c time is low, indicating a low toe resistance. The CAPWAP analysis indicated a low capacity for pile E01, as shown in Table 2.

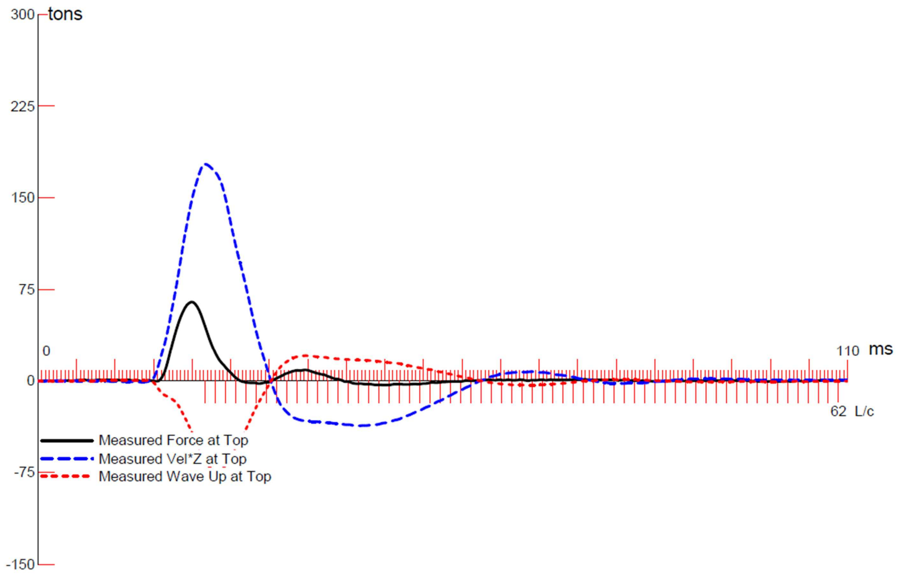

Figure 1. Collected signals of Force, Velocity, and Wave Up Curves (Pile E01)

Figures 2 to 4 (Piles E12, E35, and E37)) show a positive Wave Up from the rise time to 2L/c time. According to the procedure proposed by Murakami (2015), this fact is an indication of the shaft friction being mobilized, and it is expected that the shaft friction on those piles (E12, E35, and E37) would be higher than the pile E01, as shown in Table 2. Afterward, the Wave Up curve turns negative up to 6L/c time, which indicates the toe response but is delayed due to the large toe quake. However, the Wave Up curve after the 6L/c time turns positive, and the Maximum Wave Up is higher on those piles (E12, E35, and E37) than on pile E01, indicating a higher toe resistance. As expected, the CAPWAP analyses indicated higher toe resistance and total capacity for piles E12, E35, and E37, as shown in Table 2.

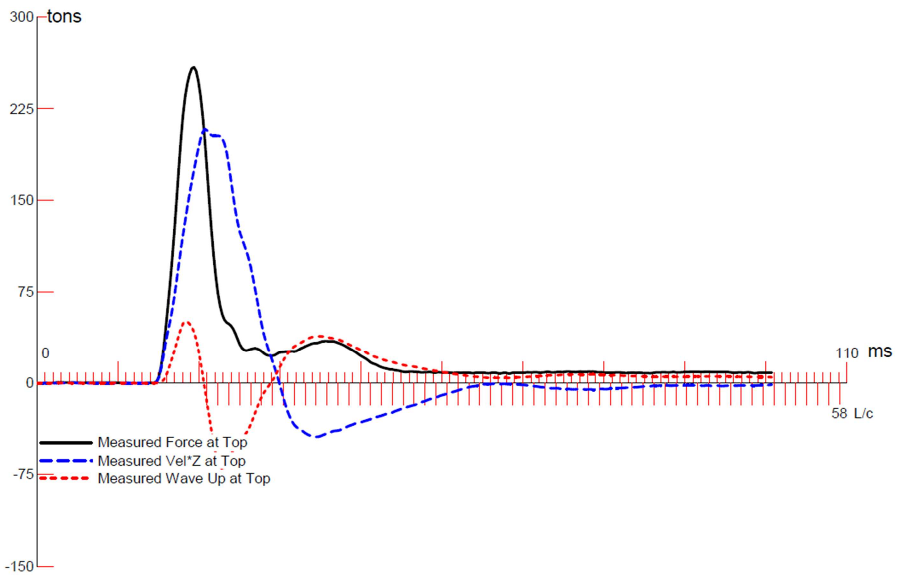

Figure 2. Collected signals of Force, Velocity, and Wave Up Curves (Pile E12)

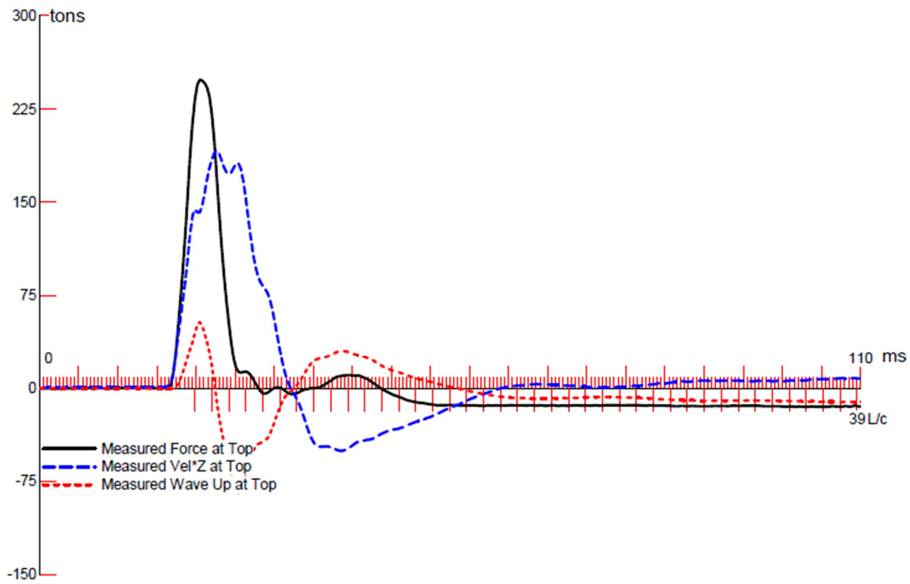

Figure 3. Collected signals of Force, Velocity, and Wave Up Curves (Pile E35)

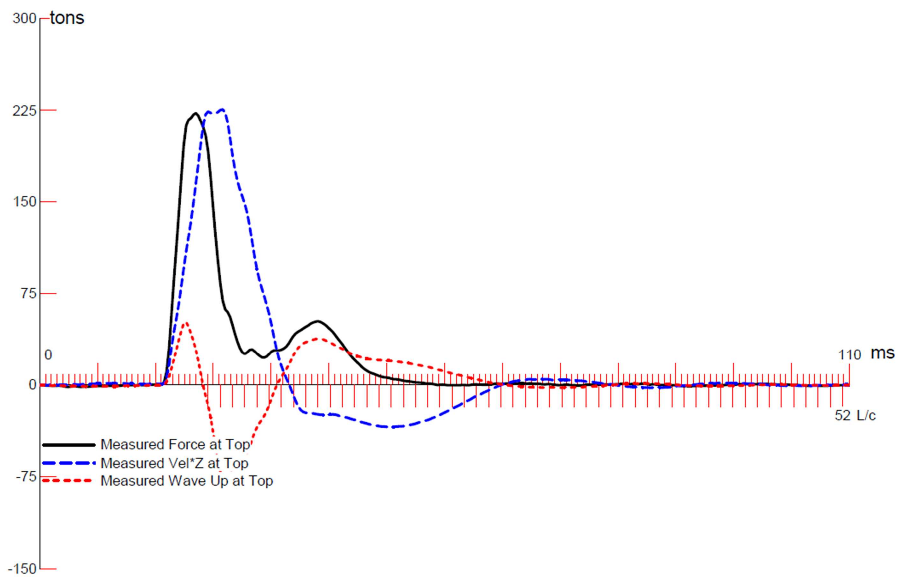

Figure 4. Collected signals of Force, Velocity, and Wave Up Curves (Pile E37)

Table 2 shows the CAPWAP results of the piles tested by the dynamic increasing test. The pile E01, with the lowest pile penetration, had the lowest ultimate load (246kN), not reaching the design load of 280kN. Moreover, piles E12 and E37 reached the design load with the minimal factor of safety defined by the NBR 6122:2022. In contrast, pile E35 had a factor of safety close to the minimal factor of safety defined by the Brazilian Standard, but it was lower than 2. All the signal-matching analyses reached a good match quality with values between 1.82 and 2.91.

Although pile E35 had the longest pile penetration of 7.0m, the CAPWAP analysis indicated a lower RMX value than the other two piles with a shorter pile penetration of 5.10m (piles E12 and E37).

Table 2. CAPWAP results

Pile	Drop Height (m)	Set (mm/blow)	JC	Shaft (kN)	Toe (kN)	RU (kN)	Match Quality
E01	0.40	5.0	0.66	96	150	246	2.91
E12	0.60	7.0	0.24	270	410	680	2.09
E35	0.80	8.0	0.31	378	174	553	1.82
E37	0.50	8.0	0.42	241	401	643	2.57

Where: JC = Case Damping Factor; RU = CAPWAP Ultimate Load

Figure 5 illustrates the RMX vs. DMX curves of the tested piles, showing that the mobilized loads did not increase with the increased applied energy to the pile top for piles E01, E12, and E35. Pile E37 had the RMX values increasing with the applied energy to the pile top. However, the pile set was already high on the third blow (8.0mm/blow).

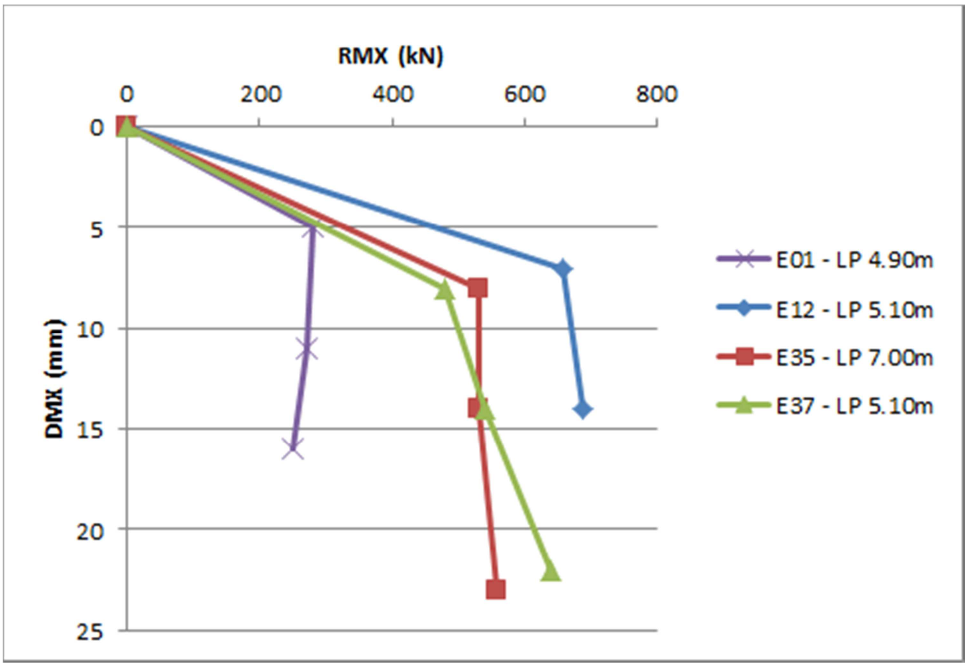

Figure 5. RMX vs. DMX curves

Figures 6 to 9 show the CAPWAP results for the four tested piles: measured force vs. computed force, measured force vs. measured velocity, simulated load vs. displacement, shaft resistance distribution, and axial force in depth. It is observed that the Davisson Offset is reached in all the piles tested by the dynamic tests at the maximum load in this project site.

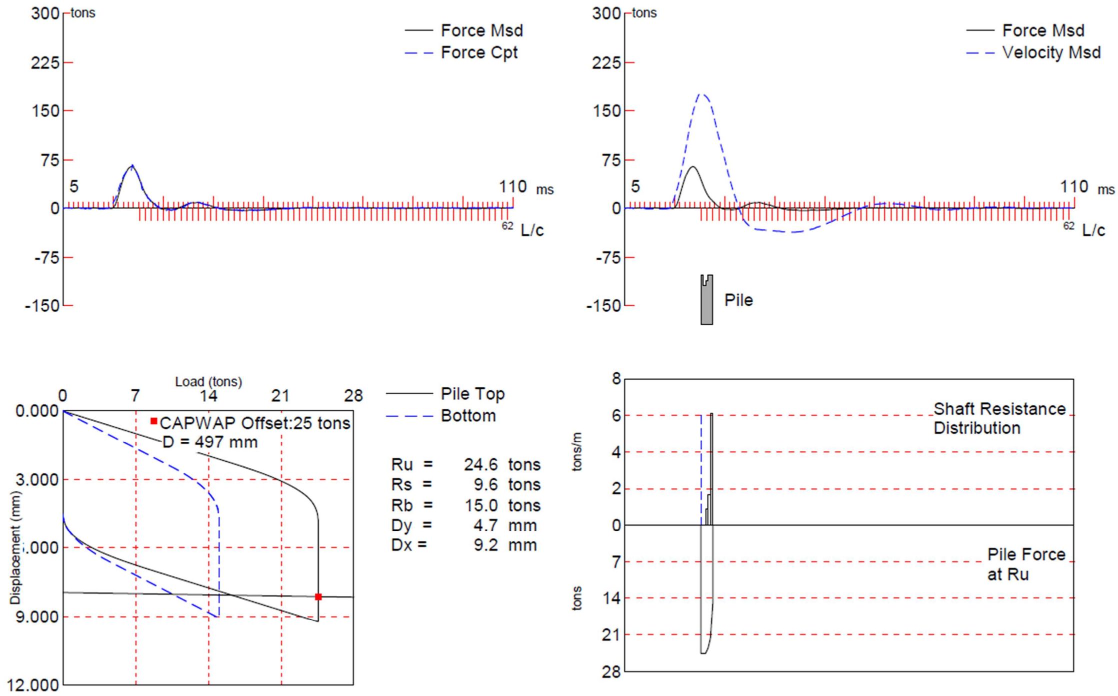

Figure 6. Simulated load vs. displacement curve of the CAPWAP (Pile E01)

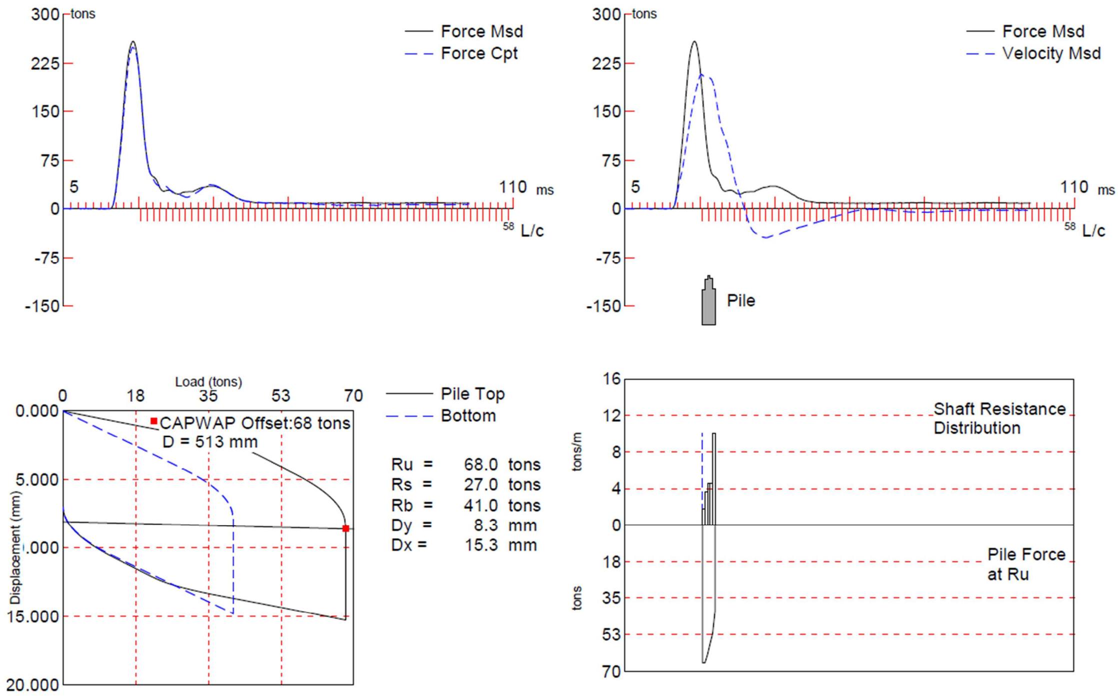

Figure 7. Simulated load vs. displacement curve of the CAPWAP (Pile E12)

Realização:
ASSOCIAÇÃO BRASILEIRA DE EMPRESAS DE ENGENHARIA DE FUNDAÇÕES E GEOTECNIA
Avenida Rebouças, 353, Sala 74 A
Cerqueira César, São Paulo/SP, 05401-900
Telefone: **(11) 3052-1284**
E-mail: **abef@abef.org.br**

Organização:
Eventos Especiais
Avenida T-9, 2310 - Ed. Inove Inteligent Place
Sala B701, Jardim América, Goiânia/GO, 74255-220
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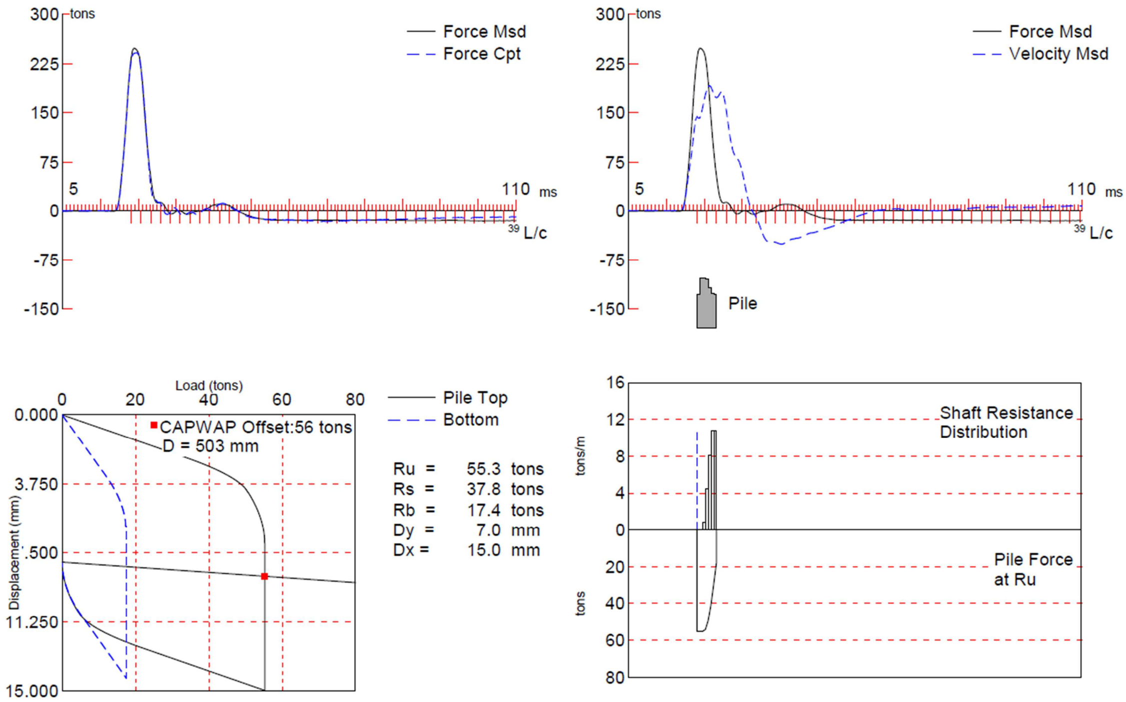

Figure 8. Simulated load vs. displacement curve of the CAPWAP (Pile E35)

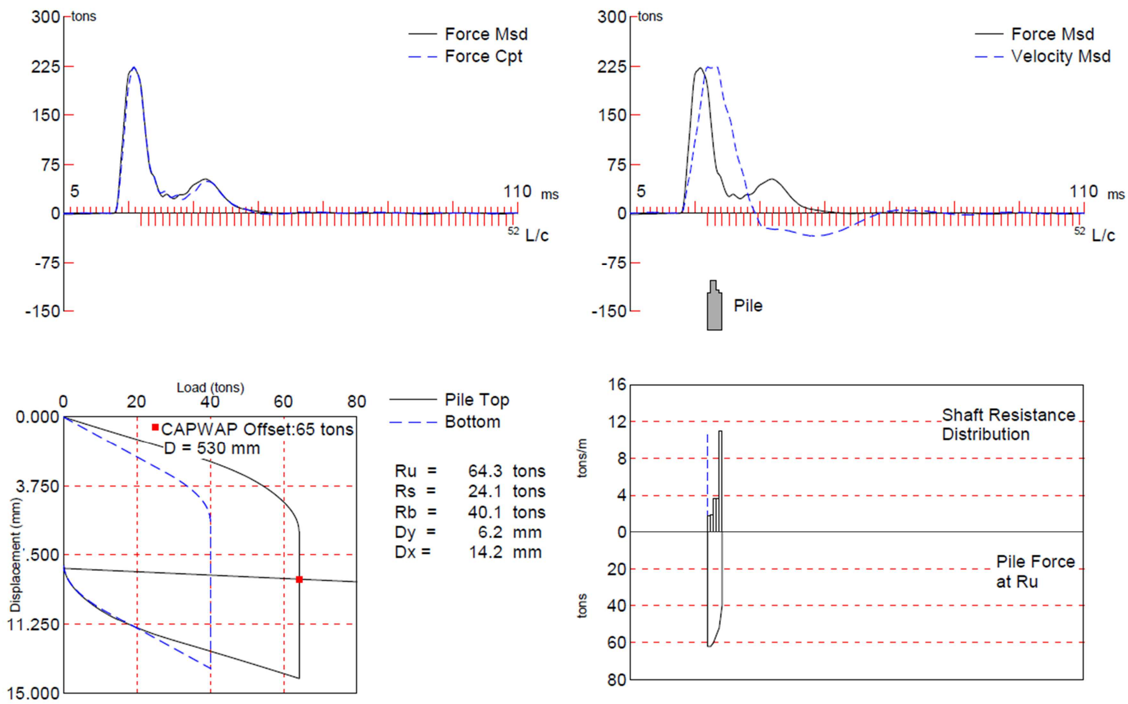

Figure 9. Simulated load vs. displacement curve of the CAPWAP (Pile E37)

5 Conclusions

Usually, a 50cm-diameter CFA pile is designed to support higher loads than 280kN. However, this project site foresaw this pile type for a load of 280kN. Based on the number of piles on this project site or the allowable stress of the pile, it was not mandatory to perform static load tests or dynamic tests. Nonetheless, the contractor requested four dynamic load tests on the piles.

The CAPWAP analysis showed that the pile E01 (4.9m depth) obtained only 246kN, lower than the designed load. However, piles E12 (5.1m depth) and E25 (5.1m depth) reached 680kN and 643kN, respectively. The most extended pile (E35, 7.0m depth) obtained 553kN. This paper shows the need for quality assurance of the deep foundations, even in small project sites, that are not mandatory according to the Brazilian Standard.

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