The Reliability of the Dynamic Load Test to Detect Pile Damage

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ABSTRACT: The Pile Driving Analyzer (PDA) obtains the force and velocity induced in a pile during an axial impact event. In the dynamic test, if the velocity increases sharply relative to the force at any point earlier than the 2L/c time, it indicates damage has weakened the pile (Goble et al., 1977). A broken pile may not support a low-energy blow applied to the pile top (Murakami et at, 2020), which indicates that the pile may have been damaged along the pile shaft. Moreover, good dynamic collected data is fundamental for a reliable diagnosis of the piles, particularly for detecting pile damage (Murakami et al., 2022a, 2022b). This paper aims to demonstrate the reliability of the dynamic test to detect damage on piles. In two case studies where precast concrete piles were driven, known damages between the sensors and the ground level were observed during the dynamic load test. It was expected that the PDA would indicate damages on the known region of the pile, and the CAPWAP analysis confirmed these damages on the piles. These two case studies show the dynamic test's reliability in detecting damage on piles.

KEYWORDS: Dynamic Load Test, Pile Driving Analyzer (PDA), Data Quality, Pile Damage.

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 integrity of the pile, the performance of the impact system, and the maximum compressive and tensile stresses occurring in the 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).

In the HSDPT, if the velocity increases sharply relative to the force at any point earlier than the 2L/c time, it indicates damage has weakened the pile (Goble et al., 1977). Figure 2 shows an example of a force and velocity measurement on a broken pile (Rausche and Goble, 1979).

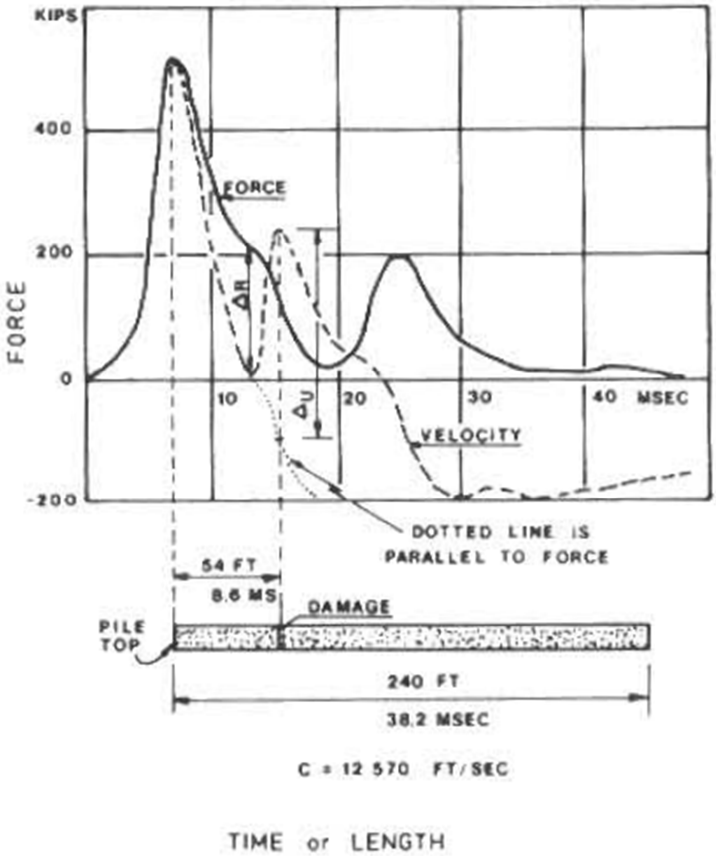

Figure 2. Example of a force and velocity measurement on a broken pile (Rausche and Goble, 1979)

The pile data collected in the HSDPT 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). The pile impedance is defined as:

$$Z = \frac{EA}{c} = \rho c A = A\sqrt{E\rho} \quad (1)$$

Where: A: Pile cross-section; ρ: Mass density of the pile material; c: Wave speed; E: Elastic modulus.

The Pile Driving Analyzer (PDA) calculates the β value. Further, a signal-matching analysis models the pile-soil system, adjusting the pile impedance along the pile length. Categories of pile integrity are suggested as a function of the β values, according to Rausche and Globe (1979):

Table 1. Pile description as a function of β values.

β (%)	Description
100	Uniform pile
80<β<100	Slight damage
60<β<80	Damage
β<60	Pile broken

A broken pile may not support a low-energy blow applied to the pile top (Murakami et at, 2020), which indicates that the pile may have been damaged along the pile shaft. Moreover, good dynamic collected data is fundamental for a reliable diagnosis of the piles, particularly for detecting pile damage (Murakami et al., 2022a, 2022b).

Murakami et al. (2022b) showed a case study in which a root pile was considered broken based on the impedance reduction calculated by the CAPWAP analysis. However, poor-quality collected data was observed, and the dynamic test had performed again. The second test, with good-quality collected data, confirmed that the pile was still functional. On both tests, the match quality number was acceptable. Furthermore, the authors concluded that the match quality number in a CAPWAP analysis is not the only parameter to be analyzed as a quality parameter of the tested piles, being fundamental the quality assurance of the collected data.

2 Objectives

This paper aims to demonstrate the reliability of the dynamic test to detect damage on piles. In two project sites where precast concrete piles were driven, known damages between the sensors and the ground level were observed during the dynamic load test. It was expected that the PDA would indicate damages on the known region of the pile, and the CAPWAP analysis confirmed these damages on the piles. These two case studies show the dynamic test's reliability in detecting damage on piles.

3 Methodology

It is shown the force and velocity signals collected from the pair of sensors. The two case studies demonstrated that the velocity increased sharply relative to the force before the 2L/c time. Furthermore, the CAPWAP analyses confirmed pile damages on the pile shaft at the known region above the ground level.

4 Case Studies

4.1 29.5cm Square Precast Concrete Pile (Guarujá, SP)

The design of the deep foundations foresaw precast concrete piles with cross-sectional sections of 26.5cm and 29.5cm square piles for design loads of 90 tons and 40 tons, respectively. The 26.5cm-square piles were driven up to 38m depth using refusal criteria of 10mm/10 blows, while the 29.5cm-square piles were driven up to 30m depth with defined pile lengths (floating piles). A 6-ton drop hammer was used to install the piles with a drop height of 40cm.

The project site is located in Guarujá, SP, Brazil, and the soil profile indicated a sandy landfill layer up to 3m depth, followed by a soft clay layer up to 36m depth. Then, a compact sandy layer was observed up to 42m depth.

Figure 1 shows the force and velocity signals collected in a 29.5-square precast pile (30m depth floating pile). It is observed that the velocity increased sharply relative to the force before the 2L/c time, which is an indication of pile damage. Furthermore, a 6m-element of precast concrete pile was welded to the installed pile, allowing the execution of the Dynamic Load Test (DLT). In addition, the pair of sensors was attached to the pile 1.5m above the welding area. Figure 2 shows that the welding was not perfect because part of the cross-sectional area of the installed pile was damaged.

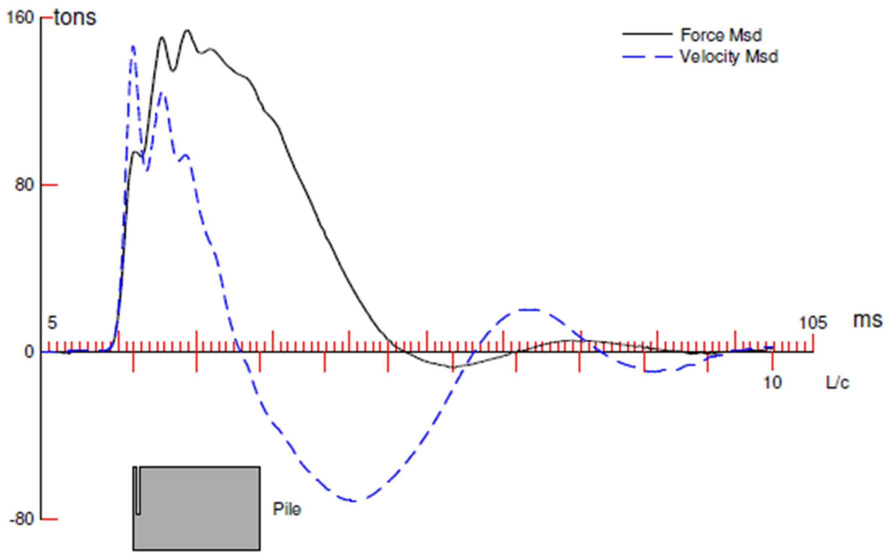

Figure 1. Force and Velocity signals from a 29.5cm square pile

Figure 2. The welding area of the 29.5cm-square pile

Due to the welding problem, it was expected that the PDA would indicate damage on the pile at this position. The CAPWAP analysis was performed, and it indicated an impedance reduction of 57%. This magnitude of pile impedance reduction would consider that the pile was broken, but the pile cap would be installed below the damaged area. Then, this damaged area would be removed to install the pile cap, indicating that the pile could support the loads from the structure. Figure 3 shows the load vs. displacement curve of the CAPWAP.

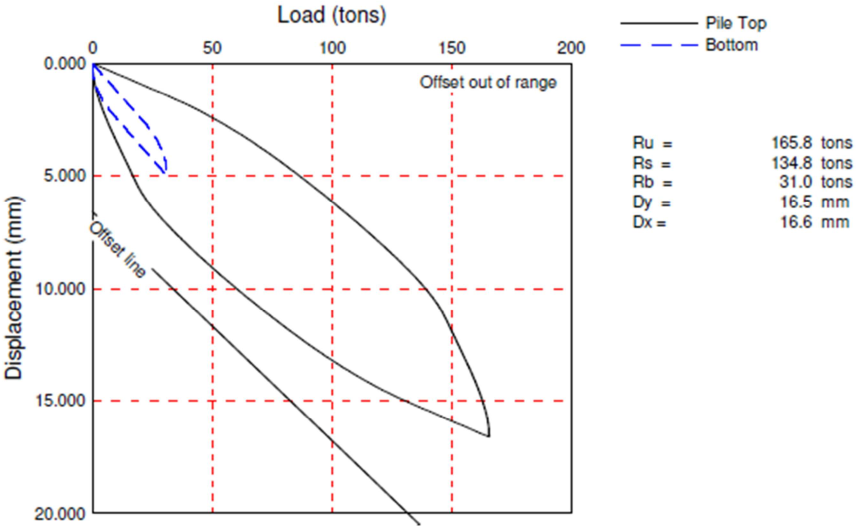

Figure 3. Load vs. displacement of the CAPWAP

4.2 45cm Hexagonal Precast Concrete Pile (Praia Grande, SP)

The design of the deep foundations foresaw precast concrete piles with a cross-sectional section of 45cm hexagonal pile for a design load of 90 tons. The 45cm-hexagonal piles were driven up to 10m depth using refusal criteria of 10mm/10 blows. A 4-ton drop hammer was used to install the piles with a drop height of 80cm.

The project site is in Praia Grande, SP, Brazil, and the soil profile indicated a sandy layer up to 15m depth. The Nspt values increased with the depth, reaching more than 30 blows/30cm between 9m and 15m depth.

Figure 4 shows the force and velocity signals collected in one of the piles. It is observed that the velocity increased sharply relative to the force before the 2L/c time, which is an indication of pile damage. Furthermore, the PDA was used during the pile installation for monitoring the compression and tension stresses. This procedure helps select the ideal drop height of the hammer, avoiding damage to the piles (Murakami and Cabette, 2014, 2022). Although the stresses along the pile were acceptable, damage about 5m below the sensors was observed. When it happened, the damage was above ground level, as shown in Figure 5.

The 4-ton drop hammer continued the application of the blows at the pile top, aiming to reach the design depth. Moreover, monitoring pile driving allowed us to successfully install the deep foundation to the design depth.

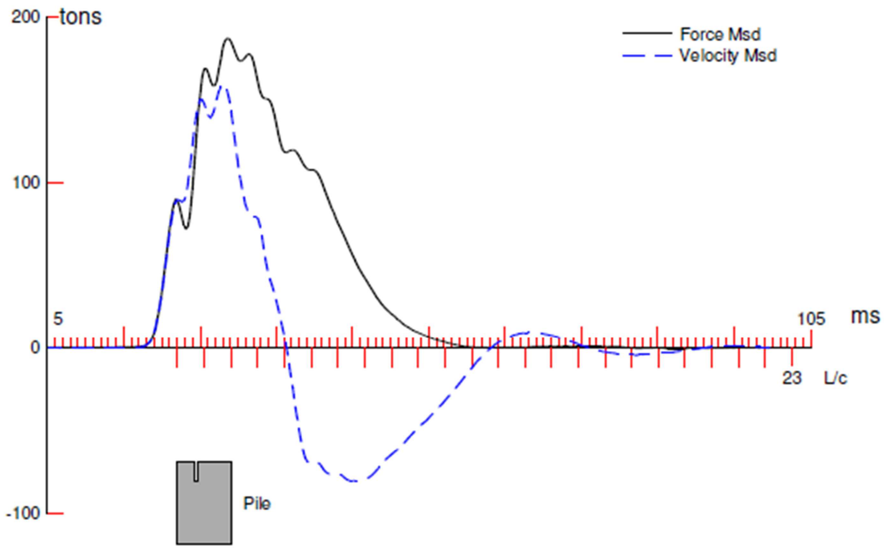

Figure 4. Force and Velocity signals from a 45cm-hexagonal pile

Figure 5. The damaged area of the 45cm-hexagonal pile

Due to the damaged area observed above the ground level, it was expected that the PDA would indicate damage on the pile at this position. The CAPWAP analysis was performed, and it indicated an impedance reduction of 23%. This magnitude of pile impedance reduction means that the pile has slight damage. Once the damage was close to the ground level, it was possible to reconstruct the damaged area on the pile, although the magnitude of the damage was acceptable. Figure 6 shows the load vs. displacement curve of the CAPWAP.

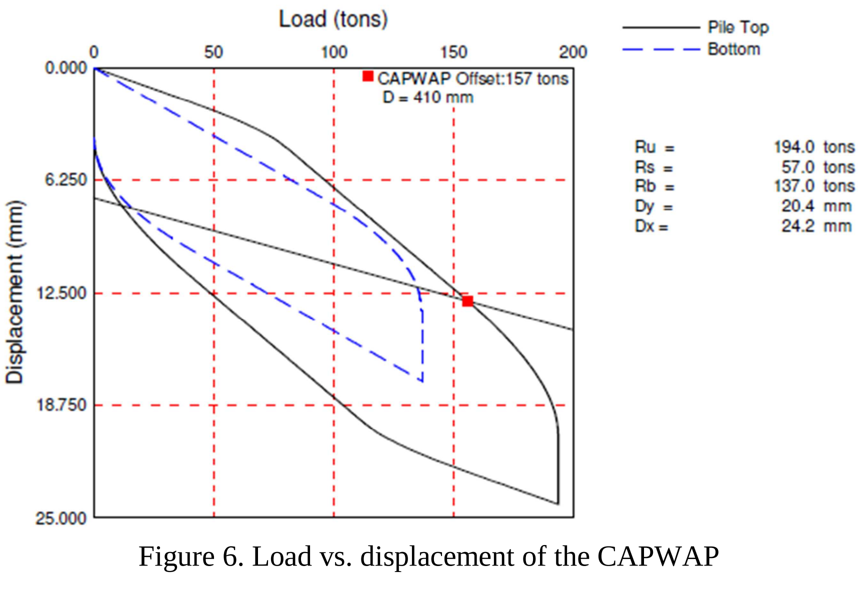

Figure 6. Load vs. displacement of the CAPWAP

5 Conclusions

This paper showed two case studies where damage on the piles was observed above the ground level. The piles were tested by the Dynamic Load Test, and as expected, the PDA indicated pile damage in the known area. Furthermore, the CAPWAP analyses confirmed the damage on piles.

These damages were close to the ground level. Furthermore, in the first case study, the pile cap would be installed below the pile damage. Then, this damaged area would be removed to install the pile cap, indicating that the pile could support the loads from the structure. It was possible to reconstruct the pile in the second case study, although it would be considered slight damage.

These two case studies showed the dynamic test's reliability in detecting damage on piles.

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