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The Effect Of An Eccentric Blow In The High Strain Dynamic Pile Test

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ABSTRACT: The High Strain Dynamic Pile Test (HSDPT) has been used on piles to detect damage along the shaft and to determine the pile capacity. The Beta Method is commonly used to identify the magnitude of the pile damage. A broken pile may not support a low-energy blow applied to the pile top (Murakami et at, 2020). Moreover, good dynamic-collected data is fundamental for a reliable diagnosis of the piles, particularly for detecting pile damage (Murakami et al., 2022a, 2022b, 2023, 2024a, 2024b). This paper presents a case study in which poor data quality indicated false damage on 30 cm-square precast concrete piles. Furthermore, the set per blow was zero, and the force signals demonstrated an eccentric blow, with negative force values before the 2L/c time in one of the pair of sensors, indicating that this bending on the pile may have resulted in this “false pile damage.” This paper shows that the pile testing engineer may evaluate if the collected data is of good quality. If not, an investigation must be done to identify the cause of the bad-quality data. Otherwise, the outcome of the HSDPT will not be reliable and may indicate false pile damage on the pile shaft.

KEYWORDS: High Strain Dynamic Pile Test (HSDPT), Beta Method, False Pile Damage, Data Quality, Precast Concrete Piles

RESUMO: O Ensaio de Carregamento Dinâmico (ECD) tem sido utilizado em estacas para detectar danos ao longo do fuste e determinar a capacidade da estaca. O Método Beta é comumente usado para identificar a magnitude do dano na estaca. Uma estaca danificada pode não resistir a um impacto de baixa energia aplicado no topo da estaca (Murakami et al., 2020). Além disso, dados dinâmicos coletados com qualidade são fundamentais para um diagnóstico confiável das estacas, particularmente para detectar danos (Murakami et al., 2022a, 2022b, 2023, 2024a, 2024b). Este artigo apresenta um estudo de caso no qual a baixa qualidade dos dados indicou falsos danos em estacas pré-fabricadas de concreto de 30 cm de lado. Ademais, a nega por golpe foi zero, e os sinais de força demonstraram um golpe excêntrico, com valores de força negativos antes do tempo 2L/c em um dos pares dos sensores, indicando que esta flexão na estaca pode ter resultado neste "falso dano na estaca". Este artigo mostra que o engenheiro responsável pelo ensaio da estaca pode avaliar se os dados coletados são de boa qualidade. Caso contrário, uma investigação deve ser realizada para identificar a causa dos sinais de baixa qualidade. Do contrário, o resultado do ECD não será confiável e poderá indicar falsos danos no fuste da estaca.

PALAVRAS CHAVE: Ensaio de Carregamento Dinâmico (ECD), Método Beta, Falso dano na estaca, Qualidade dos sinais, Estacas pré moldadas

1 INTRODUCTION

The High Strain Dynamic Pile Test (HSDPT) (NBR 13208, ASTM D4945) has been used on piles to detect damage along the shaft and to determine the pile capacity. The Beta Method is commonly used to identify the magnitude of the pile damage.

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 1 shows an example of a force and velocity measurement on a broken pile (Rausche and Goble, 1979).

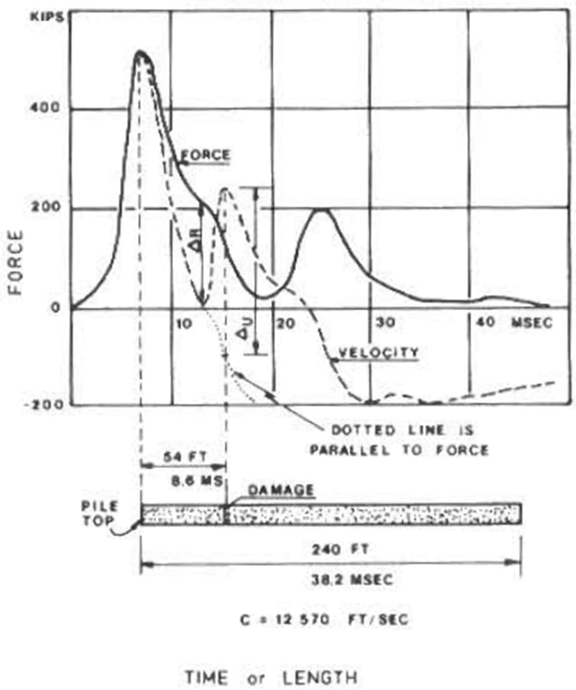

Figure 1. Example of a force and velocity measurement on a broken pile (Rausche and Goble, 1979)

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).

In the field, 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). Moreover, good dynamic-collected data is fundamental for a reliable diagnosis of the piles, particularly for detecting pile damage (Murakami et al., 2022a, 2022b, 2023, 2024a, 2024b).

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 was 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 to quality assurance of the collected data.

2 OBJECTIVES

This paper aims to present the effect of an eccentric blow in the high-strain dynamic pile test. It is shown in a Case Study that an eccentric blow applied at the pile top (pile E10) may cause bad-quality data, indicating false pile damage on the pile shaft. This Case Study shows the importance of good-quality data in the Dynamic test. In addition, the collected signals with bad quality (negative force values at the beginning of the strike) shown in this paper are one of the collected signal types that Murakami (2024a) suggests that a CAPWAP analysis cannot be performed.

3 METHODOLOGY

The results obtained in the field through the CASE Method are shown. Then, the CAPWAP analyzed signals from the blow with the highest energy level. Different force and velocity signals collected by the Pile Driving Analyzer (PDA) for the same pile with the same drop height of 40 cm are shown. Moreover, the HSDPT was performed in a 30 cm-square precast concrete pile for a design load of 70 tons.

In addition, the bad-quality and good data are compared in the same pile tested by the HSDPT (pile E10). Further, these results are compared with another pile (E92) with good-quality data, close to pile E10. The results of the bad-quality data are entirely different from the good ones.

Moreover, the pile damage determined by the Case Method demonstrated low Beta values for the bad-quality data, indicating that the pile would be considered broken. However, the good-quality data indicated that the pile was not broken but had slight damage.

4 CASE STUDY

The project site was in Cubatão, SP, Brazil, and the 30 cm-square precast concrete piles were driven by a 5-ton hydraulic hammer up to 32m depth. The soil profile indicated a thick, soft clay layer up to 28m depth, followed by a sandy layer up to 38m depth. The 5-ton hydraulic hammer applied four blows with a drop height of 40cm, and the β values were between 52% and 90%, indicating severe pile damage (broken pile). These magnitudes of the β values mean that the pile would not be able to support the loads from the structures, according to Table 1. Nonetheless, it will be shown in this paper that bad-quality data caused this false pile damage.

For those four blows on pile E10 with a drop height of 40 cm (Blow numbers between 4 and 7), the RMX (maximum static resistance) was between 107 tons and 132 tons, as shown in Table 2. However, the set per blow was zero, and the force signals demonstrated an eccentric blow, indicating that this bending on the pile may have resulted in this “false pile damage.” Normally, a broken pile may not support a low-energy blow applied to the pile top (Murakami et at, 2020). Once the pile set was zero, it would be an indication that the pile would not be broken.

The two worst collected data were observed on blow numbers 5 and 6 (BN 5 and 6). Figure 2 shows the pair of force signals collected on pile E10 (BN 5). It was observed that sensor F3 measured negative values at the beginning of the strike before the 2l/c period caused by an eccentric blow. This eccentric blow caused a bad proportionality between force and velocity signals, with a FVP (proportionality between force and velocity) of 0.9, as shown in Table 2. Further, this bending on the pile indicated false pile damage (β of 79.0 at 1.0m and 52 at 6.8m, as shown in Table 2) once the β values are calculated on force and velocity collected signals. For precast concrete piles, a good collected signal normally indicates an FVP of 1.0.

Figure 3 shows the pair of force signals on BN 6. The sensor F3 is still negative at the beginning of the strike before the 2L/c period. This eccentric blow caused a bad proportionality between force and velocity signals, with a FVP of 0.5, as shown in Table 2. Further, this bending on the pile indicated false pile damage (β of 79.0 at 6.6m and 90 at 18.3m, as shown in table 2) once the β values are calculated on force and velocity collected signals. For precast concrete piles, a good collected signal normally indicates an FVP of 1.0. Although the Beta values on BN 6 were higher than the ones observed on BN 5, it is expected that a CAPWAP analysis would indicate more severe damage on BN 6 once the velocity increased sharply relative to the force signal before the 2L/c time. This fact would indicate that damage on the pile had weakened it (Goble et al., 1977; Murakami and Cabette, 2023).

The pile E10 was slightly inclined, which made it harder to collect good-quality data (Murakami, 2024a). In this case, the hammer should be adjusted with the same inclination of the pile. Then, during those four blows with the same drop height (BN between 4 and 7), the pile testing engineer tried to properly adjust the pile driving machine in order to collect good-quality data. Further, the pile-driving machine's hammer had been appropriately adjusted on blow number 7 (figure 3) with no indication of negative values at the beginning of the strike on sensor F3. An additional blow of 60 cm drop height (BN 8) was applied at the pile top (figure 5), and the β value was conservative (71.0 at 16.4m). However, the CAPWAP demonstrated slight damage on the pile, with two compression slacks (0.10mm with an efficiency of 0.10 at 12.11m and 0.25mm with an efficiency of 0.20 at 17.15m) and one tension slack (1 tf with an efficiency of 1.0 at 1.0 m). In addition, with a blow of 60 cm, the RMX was 192 tons, as shown in Table 2.

Table 2. Case Method results for pile E10

Blow number (BN)	Drop Height (cm)	RMX (tf)	β	EMX (tf.m)	FVP
2	20	105	-	0.42	1.0
4	40	132	71.0@7.4m	0.68	1.0
5	40	107	79.0@1.0m / 52.0@6.8m	0.45	0.9
6	40	125	79.0@6.6m / 90.0@18.3m	0.61	0.5
7	40	139	80.0@7.0m / 60.0@18.9m	0.74	0.9
8	60	192	71.0@16.4m	1.41	1.0

Where: RMX = maximum static resistance; β = Beta values; EMX = maximum transferred energy; FVP = proportionality between force and velocity.

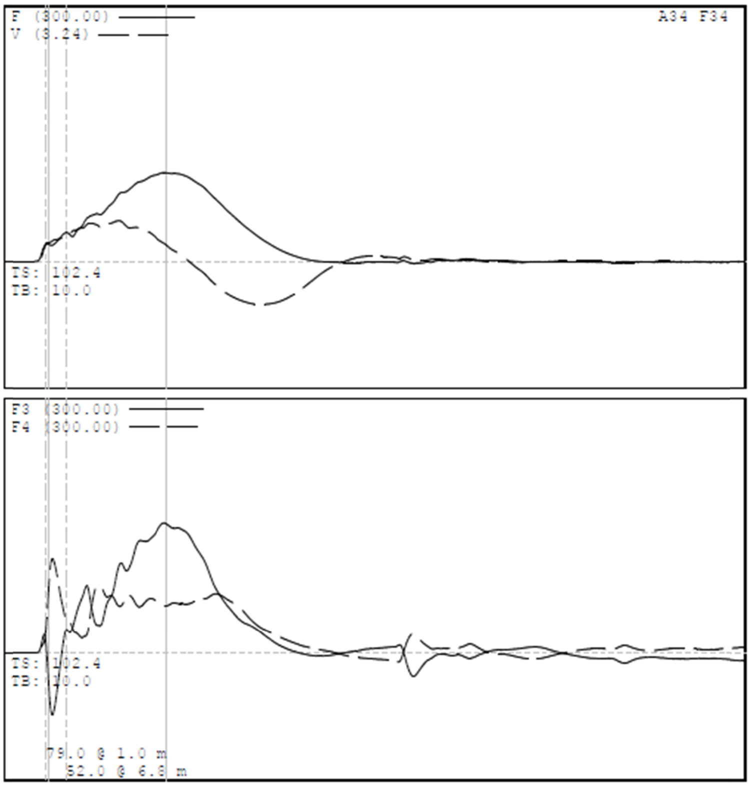

Figure 2. Collected data on pile E10 with a drop height of 40cm (Blow number 5)

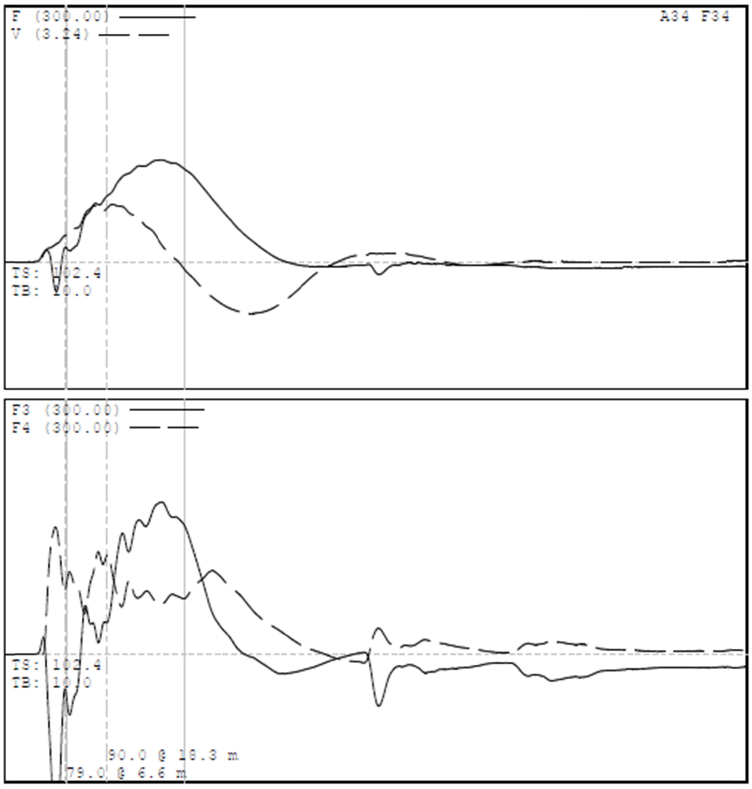

Figure 3. Collected data on pile E10 with a drop height of 40cm (Blow number 6)

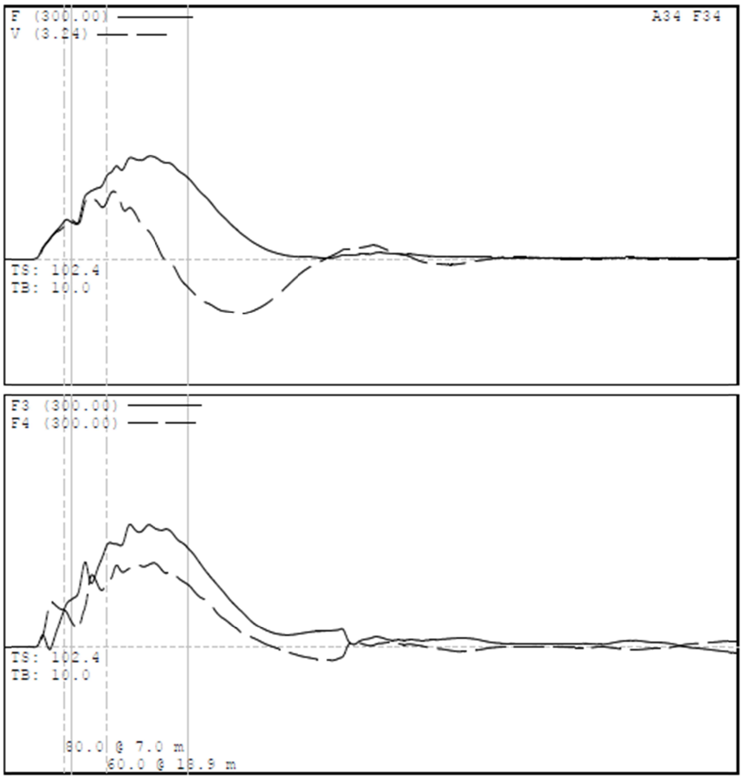

Figure 4. Collected data on pile E10 with a drop height of 40 cm (Blow number 7)

Figures 5 and 6 show the force signals for piles E10 (60 cm drop height) and E92 (80 cm drop height), respectively. The shape of force and velocity on both collected signals are qualitatively close, with no negative force values at the beginning of the strike before the 2L/c time. The pile E92 showed slight damage through the Case Method (β of 78 at 31.6m). However, the CAPWAP analysis showed no signs of damage along the pile shaft.

Likewise, the signals with good-quality data (figures 5 and 6) are different from the bad-quality data from figures 2 to 4. This would explain the reason for detecting false pile damage on bad-quality signals (figures 2 to 4). As Murakami (2024a, 2024b) observed, the match quality number is not the only parameter to be analyzed on the HSDPT for the quality of the test; the quality of the collected data is fundamental for the quality assurance of the deep foundations.

Ensuring high-quality collected data is fundamental for reliable HSDPT results and deep foundation quality assurance, as the match quality number alone is not sufficient for assessing test quality (Murakami, 2024a, 2024b).

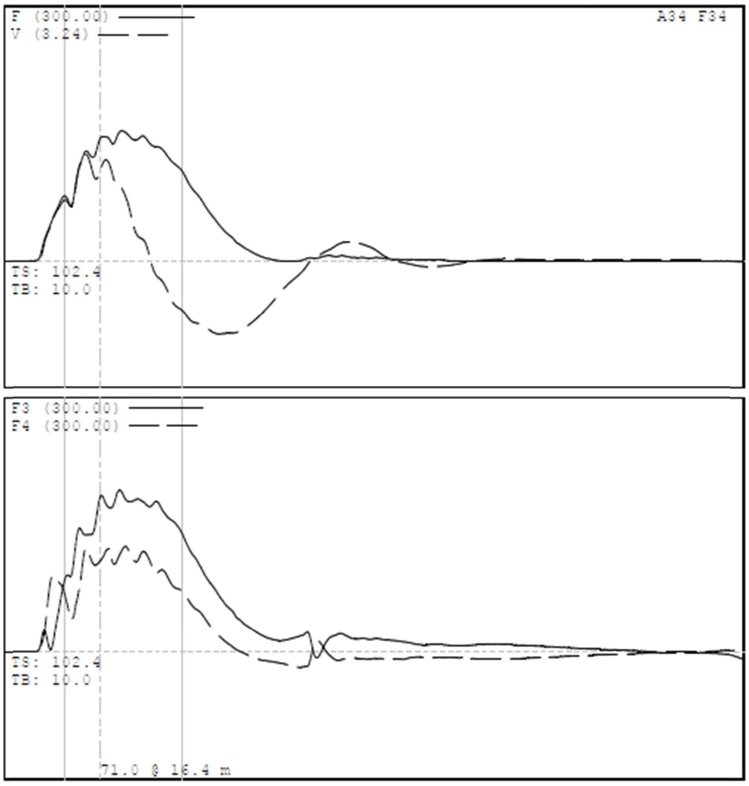

Figure 5. Collected data on pile E10 with a drop height of 60cm (Blow number 8)

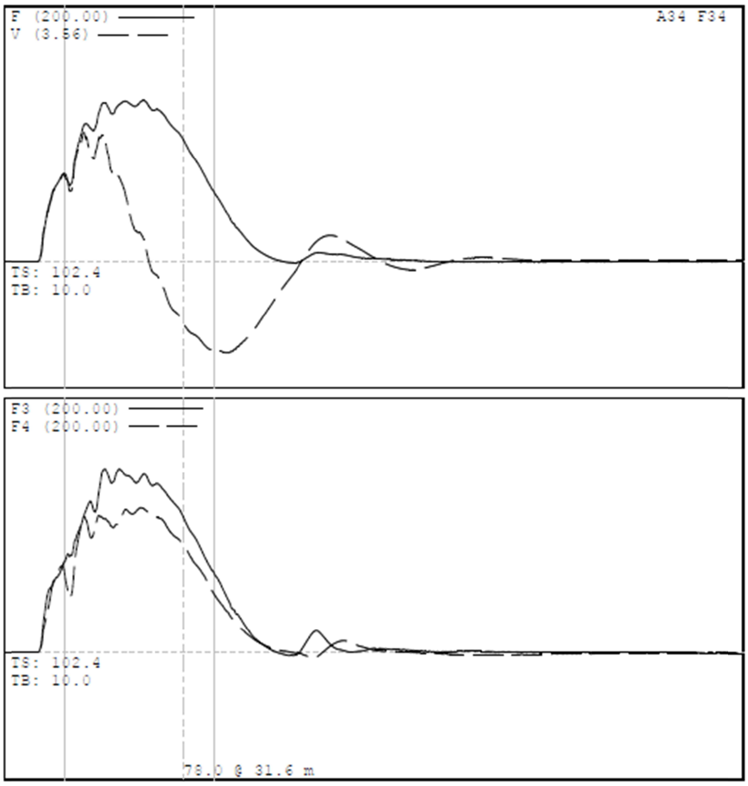

Figure 6. Collected data on pile E92 with a drop height of 80cm

This paper demonstrated that the pile testing engineer must evaluate the collected-data quality; if inadequate, an investigation is necessary to identify the cause. Failure to ensure high-quality data may yield unreliable HSDPT results, potentially leading to the misinterpretation of pile integrity, as highlighted by Murakami et al. (2020, 2022, 2023, 2024a, 2024b).

5 CONCLUSIONS

This paper aims to present the effect of an eccentric blow in the high-strain dynamic pile test. It is shown in a Case Study that an eccentric blow applied at the pile top (pile E10) may cause bad-quality data.

In addition, a comparison between the bad-quality data and the good one in the same pile tested by the Dynamic Load Test was made. Further, these results are compared with another pile (E92) with good-quality data. The results of the bad-quality data are entirely different from the good one, and the bad one indicated false pile damage on the pile shaft. This Case Study shows the importance of good-quality data in the Dynamic test.

This paper demonstrated that the pile testing engineer must evaluate the collected-data quality. If not, an investigation must be done to identify the cause of the bad-quality data. Otherwise, the outcome of the HSDPT will not be reliable and may indicate false pile damage on the pile shaft, as observed by Murakami et al. (2020, 2022, 2023, 2024a, 2024b).

In this case study, the bad-quality data resulted from the misalignment of the pile driving hammer. The pile was slightly inclined, and in this case, the hammer should be adjusted with the same inclination of the pile. After several adjustments, the hammer was correctly aligned, yielding good-quality data.

Furthermore, after proper hammer alignment, the negative force values before 2L/c, initially indicative of severe pile damage, were no longer observed. This correction in the readings confirmed that the initial diagnosis was inaccurate, highlighting the critical influence of proper equipment setup on data quality and accurate pile integrity assessment.

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