The Effect of the Pile Cushion on the Data Quality 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: A good PDA Test outcome requires good dynamic data (Murakami, 2015). Moreover, sensors must be firmly attached to the pile to provide a good PDA test (Likins and Rausche, 2008). Some other effects may provide a bad outcome: an eccentric blow, the follower's failure, and the concrete's quality where the bolts were attached (Murakami et al., 2022). This paper presents a case study in which a different source caused poor-quality data. The Dynamic Test was performed in a 29.5cm-square precast concrete pile. For a low-energy blow (40cm drop height), the PDA showed a high tension stress of 3.0MPa, while in the other piles, this tension stress commonly occurred with higher energy (80cm drop height or more). In addition, the force and velocity signals qualitatively were different compared to the other piles. The sensors were firmly attached to the pile, and the pile-driving machine's hammer seemed well-adjusted to provide a non-eccentric blow. Then, after about 2cm of the pile cushion had been removed, the Dynamic Test has performed again, resulting in good-quality data. This case study shows the need for data quality in the Dynamic Load Test, and some unusual force and velocity signals must be investigated to provide good-quality data.

KEYWORDS: Dynamic Load Test, Pile Driving Analyzer (PDA), Data Quality, Pile Cushion, Tension Stress.

Aponte a câmera do seu smartphone para o QR Code ao lado e salve o evento na sua agenda.

10º SEMINÁRIO DE ENGENHARIA DE FUNDAÇÕES ESPECIAIS E GEOTECNIA

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
E-mail: **secretaria@qeeventos.com.br**
Site: **www.qeeventos.com.br**

1 Introduction

The High Strain Dynamic Pile Testing (HSDPT) (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).

A good PDA Test outcome requires good dynamic data (Murakami, 2015). Moreover, sensors must be firmly attached to the pile to provide a good PDA test (Likins and Rausche, 2008). Some other effects may provide a bad outcome: an eccentric blow, the follower's failure, and the concrete's quality where the bolts were attached (Murakami et al., 2022a, 2022b).

Figure 1 shows a Case Study in which the data quality could have been better due to the quality of the concrete where the bolts were fixed, and some bending effect was observed during the blow (Murakami, 2022a). The force and velocity were collected in a CFA pile.

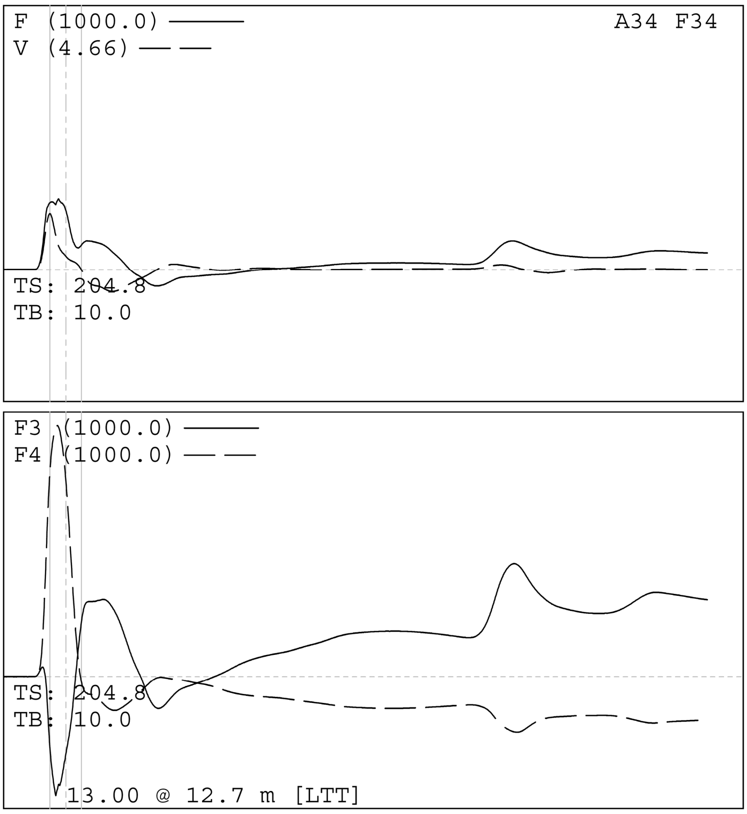

Figure 1. Bad-quality data caused by poor-quality concrete and eccentric blow (Murakami et al. 2022a)

10º SEMINÁRIO DE ENGENHARIA DE FUNDAÇÕES ESPECIAIS E GEOTECNIA

Aponte a câmera do seu smartphone para o QR Code ao lado e salve o evento na sua agenda.

Realização: ABEF 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: QE Eventos Especiais
Avenida T-9, 2310 - Ed. Inove Inteligent Place
Sala B701, Jardim América, Goiânia/GO, 74255-220
E-mail: secretaria@qeeventos.com.br
Site: www.qeeventos.com.br

Figure 2 shows a case study in which the follower broke in the fourth blow. It is observed that both force sensors did not return to zero, indicating that a plastic deformation had occurred. This dynamic test was performed in a CFA pile.

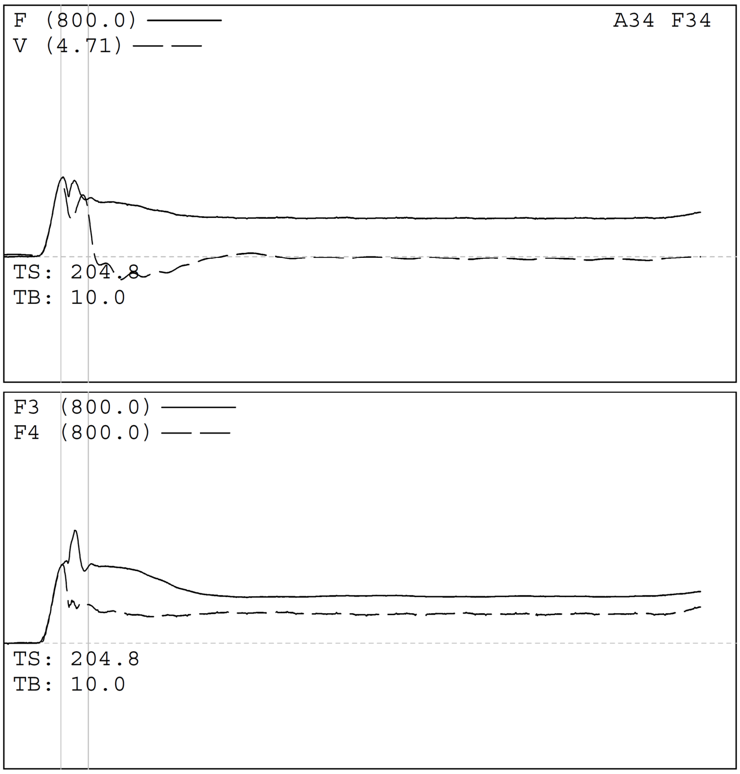

Figure 2. Bad-collected data caused by a failure of the follower (Murakami et al. 2022a)

Figure 3 shows that force sensor F3 is qualitatively different from sensor F4, demonstrating a significant oscillation in its values. This fact is an indication of a smaller tightening of one of the screws that fixed the sensor F3.

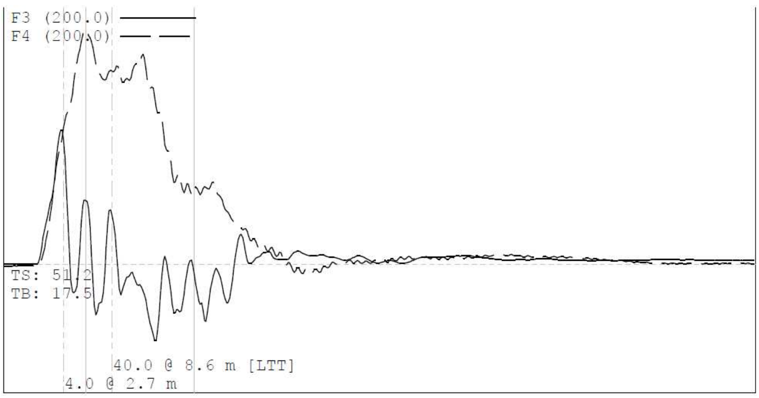

Figure 3. Bad-collected data was caused by a smaller tightening of one of the screws that fixed the sensor F3 (Murakami et al. 2022b)

Aponte a câmera do seu smartphone para o QR Code ao lado e salve o evento na sua agenda.

For the Case Studies shown in Figures 1 to 3, any interpretation of these dynamic tests could provide an incorrect diagnosis of the pile, including the values of RMX (Maximum Static Resistance), compression and tension stresses, and damage on the piles.

2 Objectives

This paper aims to present a Case Study in which unusual collected data was observed, and bad-quality data caused it. It is shown a comparison between the bad-quality data and the good one in the same pile tested by the Dynamic Load Test. The results are entirely different, and this Case Study shows the importance of good-quality data in the Dynamic test.

3 Methodology

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. The Dynamic test was performed in a 29.5 cm-square precast concrete pile for a design load of 40 tons. The results of RMX (Maximum Static Mobilized Load), CSX (Average Compression Stress), CSI (Maximum Compression Stress), and TSX (Average Tension Stress) were different for the bad-quality data and good-quality data. However, the drop height was the same.

4 Case Study

The design of the deep foundations foresaw precast concrete piles with cross-sectional sections of 26.5 cm and 29.5 cm square piles for design loads of 90 tons and 40 tons, respectively. The 26.5 cm-square piles were driven up to 38 m depth using refusal criteria of 10mm/10 blows, while the 29.5 cm-square piles were driven up to 30 m 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. More information regarding the pile installation and the dynamic tests can be found in Murakami and Cabette (2023a, 2023b) and Cabette and Murakami (2023).

Increasing the thickness of the cushion on the pile will reduce the compression and tension stresses along the pile for the same drop height. However, this case study shows that increasing the cushion thickness on one of the piles (pile EP70) for some unusual reason increased the tension stress and reduced the compression stress. Before starting the Dynamic Test, it was placed on the pile about 2 cm of new cushion and the old cushions (about 6 cm) were maintained inside the hammer helmet.

Aponte a câmera do seu smartphone para o QR Code ao lado e salve o evento na sua agenda.

10º SEMINÁRIO DE ENGENHARIA DE FUNDAÇÕES ESPECIAIS E GEOTECNIA
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
E-mail: secretaria@qeeventos.com.br
Site: www.qeeventos.com.br

Figure 4 shows an unusual collected signal from force and velocity for a 29.5 cm-square precast concrete pile (pile EP70) after adding about 2 cm of new cushion. It may be observed that the pair of force signals were close, but after the 2L/c time, it went negative and did not return to zero. This fact indicates a permanent deformation on the concrete close to the sensors. Murakami et al. (2022a, 2022b) showed some case studies similar to the pile EP70, and the authors concluded that the bad collected signal was caused by a low concrete strength where the sensors were attached (Figure 1) or a failure of the concrete were the sensors were attached (Figure 2). None of those facts happened in this Case Study, and some additional investigations were made during the dynamic test. Another fact that could cause bad-quality data could be a smaller tightening of the screws that fixed the sensors (Figure 3). However, in the field, it was observed a good tightening of the screws. The pile-driving machine's hammer seemed well-adjusted to provide a non-eccentric blow. Then, after about 2cm of the pile cushion had been removed, the Dynamic Test has performed again, resulting in good-quality data, as shown in Figure 5.

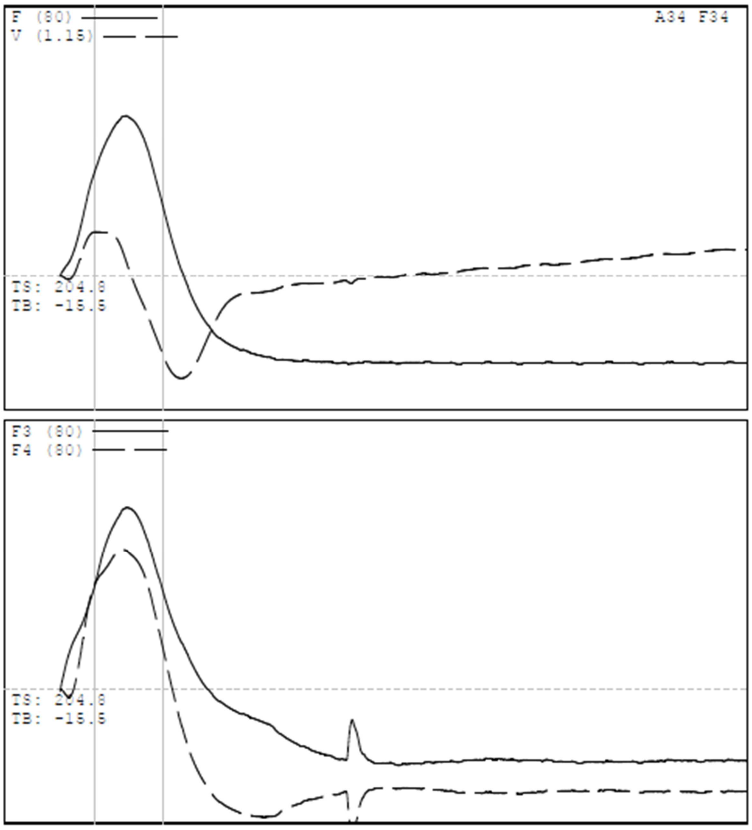

Figure 4. Bad-quality data was collected on pile EP70 with a drop height of 40 cm

Aponte a câmera do seu smartphone para o QR Code ao lado e salve o evento na sua agenda.

10º SEMINÁRIO DE ENGENHARIA DE FUNDAÇÕES ESPECIAIS E GEOTECNIA
Realização: ABEF – 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: QE Eventos Especiais
Avenida T-9, 2310 - Ed. Inove Inteligent Place
Sala B701, Jardim América, Goiânia/GO, 74255-220
E-mail: secretaria@qeeventos.com.br
Site: www.qeeventos.com.br

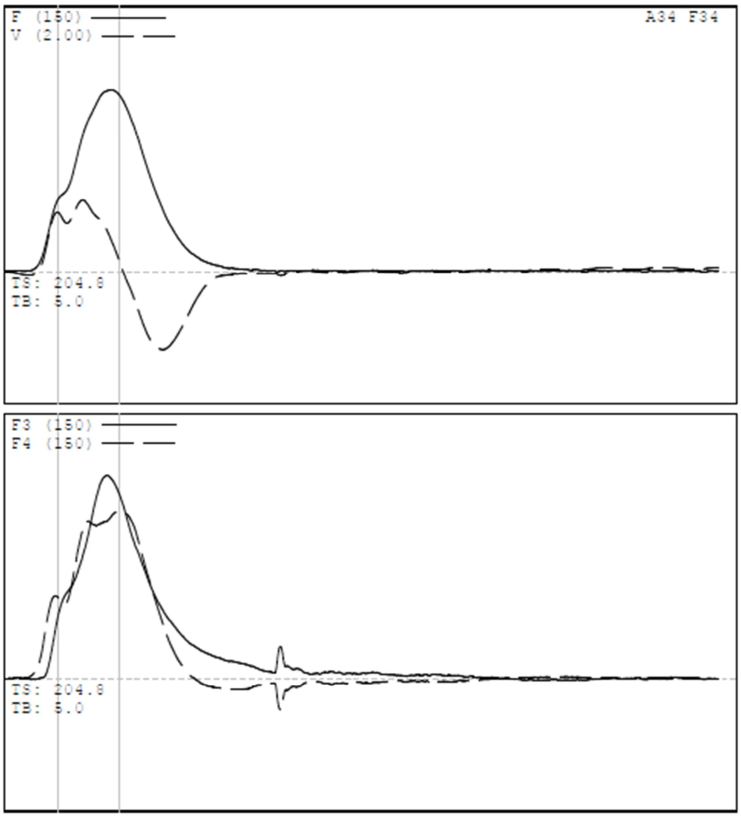

Figure 5. Good-quality data on pile EP70 with drop a height of 40 cm

Table 1 compares the results between the bad-quality data and good-quality data. Based only on the TSX value from the bad-quality data, the pile testing engineer could be decided not to increase the applied energy to the pile top avoiding damage to the pile, once this TSX value was close to the allowed tension stress. If that happened, a low RMX would be observed, and the dynamic test would indicate that this pile would not support the load from the structure with a minimal factor of safety. The design load was 40 tons, but the RMX was only 44 tons, and the set per blow was zero, indicating that this value is not the ultimate load.

However, as mentioned before, about 2 cm of pile cushion was removed, and the new dynamic test showed good-quality data. All the parameters listed in Table 1 are entirely different, and the good-quality data indicated that the pile could support the loads from the structures (40 tons) with a minimal factor of safety. Once all the parameters listed in Table 1 are calculated on the collected force and velocity signals, a bad-quality signal would not provide a reliable result. This Case Study shows the importance of reliably collected data for the correct pile diagnosis.

The solution for this bad-quality signal was not obvious (removing about 2 cm of pile cushion), and a non-experienced engineer could present the first result with bad-quality data being the “correct” diagnosis of the pile.

Aponte a câmera do seu smartphone para o QR Code ao lado e salve o evento na sua agenda.

Realização:
Abef
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:
QE Eventos Especiais
Avenida T-9, 2310 - Ed. Inove Inteligent Place
Sala B701, Jardim América, Goiânia/GO, 74255-220
E-mail: secretaria@qeeventos.com.br
Site: www.qeeventos.com.br

Table 1. Comparison between bad and good-quality data for pile EP70 with the same drop height of 40 cm.

Signal	RMX (tons)	CSX (MPa)	CSI (MPa)	Set (mm/blow)	EMX (tons.m)	DMX (mm)	TSX (MPa)	FMX (tons)
Bad quality	44	5.4	6.1	0	0.09	2	3.1	48
Good quality	103	11.6	13.0	0	0.55	8	0.8	103

Table 2 shows the Dynamic Increasing Energy Test (DIET) (Aoki, 1989, 1997) results after removing about 2 cm of pile cushion. Even in the highest drop height of 50 cm, the TSX value (1.4 MPa) was lower than the bad-quality data with a drop height of 40 cm (TSX = 3.1 MPa). This fact clearly shows that the bad-quality data caused the “false” high TSX value.

Table 2. Results of the DIET after the removal of about 2 cm of pile cushion (pile EP70)

Drop Height (cm)	RMX (tons)	CSX (MPa)	CSI (MPa)	Set (mm/blow)	EMX (tons.m)	DMX (mm)	TSX (MPa)	FMX (tons)
20	71	8.2	8.6	0	0.28	6	0.1	73
30	83	9.5	10.2	0	0.36	6	0.3	84
40	103	11.6	13.0	0	0.55	8	0.8	103
50	120	13.7	14.4	0	0.89	11	1.4	121

Figure 6 shows the force and velocity signals of the pile EP70 with a drop height of 50 cm. Furthermore, Figure 7 shows the simulated load vs. settlement of the CAPWAP.

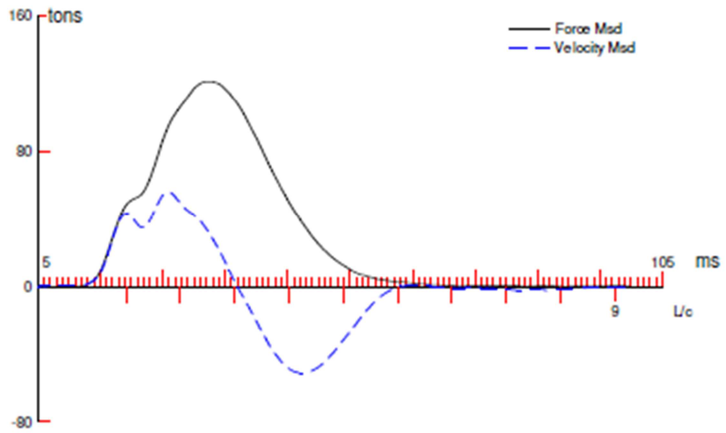

Figure 6. Force and velocity signals of the pile EP70 with a drop height of 50 cm

Aponte a câmera do seu smartphone para o QR Code ao lado e salve o evento na sua agenda.

10º SEMINÁRIO DE ENGENHARIA DE FUNDAÇÕES ESPECIAIS E GEOTECNIA
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
E-mail: secretaria@qeeventos.com.br
Site: www.qeeventos.com.br

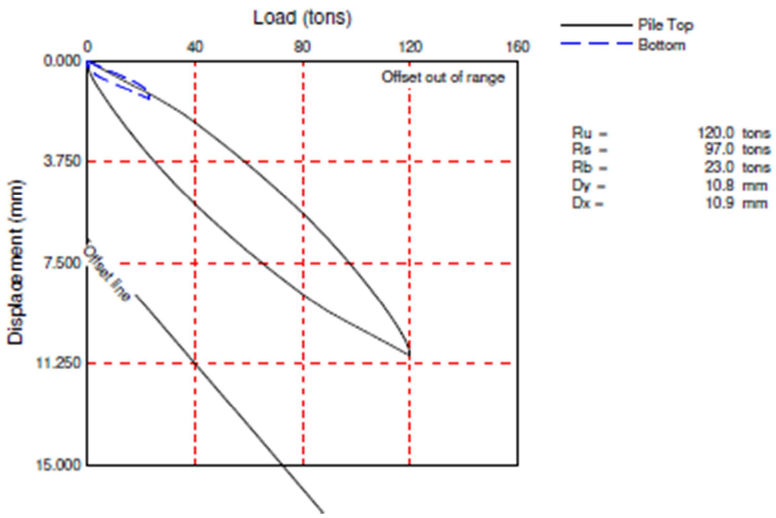

Figure 7. Simulated load vs. settlement of the CAPWAP (pile EP70)

5 Conclusions

This paper aims to present a Case Study in which unusual collected data was observed, and bad-quality data caused it. It is shown a comparison between the bad-quality data and the good one from the same pile tested by the Dynamic Load Test.

The solution for this bad-quality signal was not obvious (removing about 2 cm of pile cushion), and a non-experienced engineer could present the first result with bad-quality data being the "correct" diagnosis of the pile. However, it could indicate a low pile capacity of 44 tons, while the good-quality data indicated an RMX of 120 tons.

The results were completely different depending on the quality of the collected data, and this Case Study shows the importance of good-quality data in the Dynamic test.

BIBLIOGRAPHIC REFERENCES

ABNT (2007) NBR 13208. Estacas Ensaio de carregamento dinâmico. Rio de Janeiro.

ABNT (2019) NBR 6122 Projeto e execução de fundações profundas. Rio de Janeiro.

ASTM D4945 (2017) Standard Test Method for High-Strain Dynamic Testing of Deep Foundations, West Conshohocken, PA, USA.

Aoki, N.; A new dynamic load test concept.; Drivability of piles (1): 1-4, Proc. Discussion Session 14, Int. Conf. Soil Mech. And Found. Eng. (12), Rio de Janeiro, 1989

Aoki, N.; Determination of Pile Capacity of Driven Piles on the Dynamic Increasing Energy Test," D.Sc. thesis, University of São Paulo at São Carlos School of Engineering, São Carlos, Brazil, 1997(in Portuguese)

10º SEMINÁRIO DE ENGENHARIA DE FUNDAÇÕES ESPECIAIS E GEOTECNIA

Aponte a câmera do seu smartphone para o QR Code ao lado e salve o evento na sua agenda.

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
E-mail: secretaria@qeeventos.com.br
Site: www.qeeventos.com.br

Cabette, J. F., Murakami, D. K.; (2023) Ajuste de Fórmulas Dinâmicas em Estacas Pré-Moldadas de Concreto com Verificação do Efeito de Cicatrização "Set-Up". SEFE 10, São Paulo, SP (paper submitted)

Likins, G., RauscheF. (2008) What constitutes a good PDA test? Proceedings of the Eighth International Conference on the Application of Stress-Wave Theory to Piles, Lisbon.

Murakami, D. K., 2015, "New procedure to perform CAPWAP analysis on the dynamic load test in precast concrete piles" MSc Thesis in Geotechnical Engineering, Escola Politécnica, Universidade de São Paulo, São Paulo, SP. (in Portuguese)

Murakami, D. K., Corgnier, F., Godinho, H., Saito, E. (2022a) Data Quality in the High Strain Dynamic Pile Test in Cast in Place Piles. XX Congresso Brasileiro de Mecânica dos Solos e Engenharia Geotécnica, Campinas, SP.

Murakami, D. K., Corgnier, F., Godinho, H., Saito, E. (2022b) Pile Damage Evaluation Through Low Strain Integrity Test and High Strain Dynamic Pile Test in Root Piles. XX Congresso Brasileiro de Mecânica dos Solos e Engenharia Geotécnica, Campinas, SP.

Murakami, D. K., Cabette, J. F.; (2023a) The Reliability of the Dynamic Load Test to Detect Pile Damage. SEFE 10, São Paulo, SP (paper submitted)

Murakami, D. K., Cabette, J. F.; (2023b) Quake Values Over Time Determined By The High Strain Dynamic Pile Test. SEFE 10, São Paulo, SP (paper submitted)

Pile Dynamics, Inc. (2009). PDA-W Manual. Cleveland, Ohio.

Aponte a câmera do seu smartphone para o QR Code ao lado e salve o evento na sua agenda.

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
E-mail: secretaria@qeeventos.com.br
Site: www.qeeventos.com.br