Quake Values Over Time Determined By The High Strain Dynamic Pile Test

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ABSTRACT: The Pile Driving Analyzer (PDA) collects force and velocity signals from a pair of sensors attached to the pile. The signal-matching analysis is performed based on these collected signals to predict the pile capacity, damping, and quake values. Further, CAPWAP is a software commonly used for this purpose. Then, it provides a simulated load vs. settlement curve based on the soil parameters used in the analysis. However, some authors have observed that the soil parameters changes along the pile installation, and they change over time. As a consequence, the load vs. settlement curves may change with time. Moreover, the procedure proposed by (Murakami, 2015) may identify soils with large toe quakes (Qt) based on the Wave Up Curve, while the shaft quake (Qs) may be determined through the Concept of Match Quality of Settlements (Murakami, 2015, 2019). This paper shows three case studies in which the High Strain Dynamic Pile Test (HSDP) was performed during the end of initial driving (EOID) and at the beginning of restrike (BOR). The case studies show that the pile settlements reduce over time for the same load applied to the pile top due to soil set-up and toe quake reduction over time.

KEYWORDS: Quake, Set-Up, High Strain Dynamic Pile Test, Wave Up, Match Quality of Settlements, CAPWAP.

1 Introduction

The High Strain Dynamic Pile Testing (HSDPT) or the Dynamic Load Test (DLT) (ASTM D4945, NBR 13208) has become popular worldwide due to the speed and economy of its execution.

The Pile Driving Analyzer (PDA) (Pile Dynamics, Inc, 2009) collects force and velocity signals from a pair of sensors attached to the pile. The signal-matching analysis is performed based on these collected signals to predict the pile capacity, damping, and quake values. Further, CAPWAP (Pile Dynamics, Inc, 2006) is a software commonly used for this purpose. Then, it provides a simulated load vs. settlement curve based on the soil parameters used in the analysis.

However, some authors have observed that the soil parameters changes along the pile installation. In some cases, large toe quakes were observed during the pile driving, also known as “bouncy driving” (Hussein and Goble, 1987; Murakami and Cabette, 2014, 2022).

Based on the correlation between CAPWAP and static load tests, Likins et al. (1996) observed that the shaft quake typically is close to 2.54mm, and no trend line was observed regarding the change of its value with time. However, the toe quake values were lower during the restrike than during the pile driving.

Murakami (2015, 2019) proposed a new procedure to perform the CAPWAP analysis by determining the shaft quake value (Qs). It uses the new concept of match quality of settlements (MQ_S) for signal-matching analysis to determine the Qs values. This new concept needs a pile top load vs. settlement of the Static Load Test (SLT) in a pile tested through the DLT. Murakami (2019) concluded that the best traditional match quality (MQ_{WU}) is reached using the lowest Qs value possible in order to obtain the best MQ_S. When there is no information about the pile load-movement relationship through the SLT, using the smallest Qs value possible to obtain the best MQ_{WU} is recommended.

Many authors have observed the set-up effect on piles, indicating an increase in the pile capacity with time (Fellenius et al., 1989; Murakami and Cabette, 2022).

Consequently, the load vs. settlement curves may change with time due to the reduction of quake values with time and the set-up effect.

2 Objectives

This paper aims to present that the soil parameters change over time. Consequently, the simulated load vs. settlement curves of the CAPWAP may change with time. Furthermore, the three case studies show that the pile settlements reduce over time for the same load applied to the pile top due to soil set-up and quake reduction over time, indicating a stiffer response in an older pile.

3 Methodology

This paper shows three case studies in which the High Strain Dynamic Pile Test (HSDP) was performed during the end of initial driving (EOID), and at the beginning of restrike (BOR). The dynamic test was performed through the Dynamic Increasing Energy Test (DIET), proposed by Aoki (1989, 1997), and the CAPWAP analysis was performed through the procedure proposed by Murakami (2015, 2019). It is shown as a function of time: the pile capacity, quakes (shaft and toe), the stiffness of the piles, and the simulated load vs. displacement curves of the CAPWAP. A comparison of the load obtained through the Davisson Offset Limit Load (1972) over time is shown, and it was observed that this Limit Load was not reached at the beginning of restrike (BOR), which is an indication of a stiffer response of the pile with time.

4 Case Studies

4.1 Guarujá, SP, Brazil

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 38m depth using refusal criteria of 10mm/10 blows, while the 29.5 cm-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.

Table 1 shows the results of the CAPWAP performed with different set-up ratios. Moreover, due to the set-up effect, the pile capacity increased with time from 100.8 tons (EOID) to 201.0 tons (BOR 5 days). The shaft quake (Qs) was assumed equal for all CAPWAP analyses (2.209 mm) with no trend line with time. However, the toe quake (Qt) decreased with time, starting with 4.481mm (EOID) to 1.004mm (BOR 5 days). As a consequence, the stiffness of the pile increased over time from 3.06 tons/mm (EOID) to 7.36 tons/mm (BOR 5 days), and it was calculated by dividing the Total CAPWAP Resistance by the Maximum Displacement of the Simulated Load vs. Displacement curve of the CAPWAP. These curves are shown in Figures 1 to 3, and it may be observed that the Maximum Displacement of these curves reduces over time, starting with 32.9mm (EOID) to 27.3mm (BOR 5 days). Further, the Davisson Offset is only reached at the End of Initial Driving (EOID), which indicates that the toe displacement is higher at the EOID and lower at the Beginning of Restrike (BOR 0.21 days and 5 days).

Table 1. Results of the CAPWAP analysis (Pile E31)

Pile	Drop Height (m)	Set (mm/blow)	Set-up (days)	Shaft friction (tons)	Toe Resistance (tons)	Total CAPWAP Resistance (tons)	Qs (mm)	Qt (mm)	Stiffness (tons/mm)
E31	0.60	4.0	0.00	58.8	42.0	100.8	2.209	4.481	3.06
E31	0.50	1.0	0.21	124.5	23.0	147.5	2.209	1.250	5.12
E31	0.90	0.1	5.00	186.0	15.0	201.0	2.209	1.004	7.36

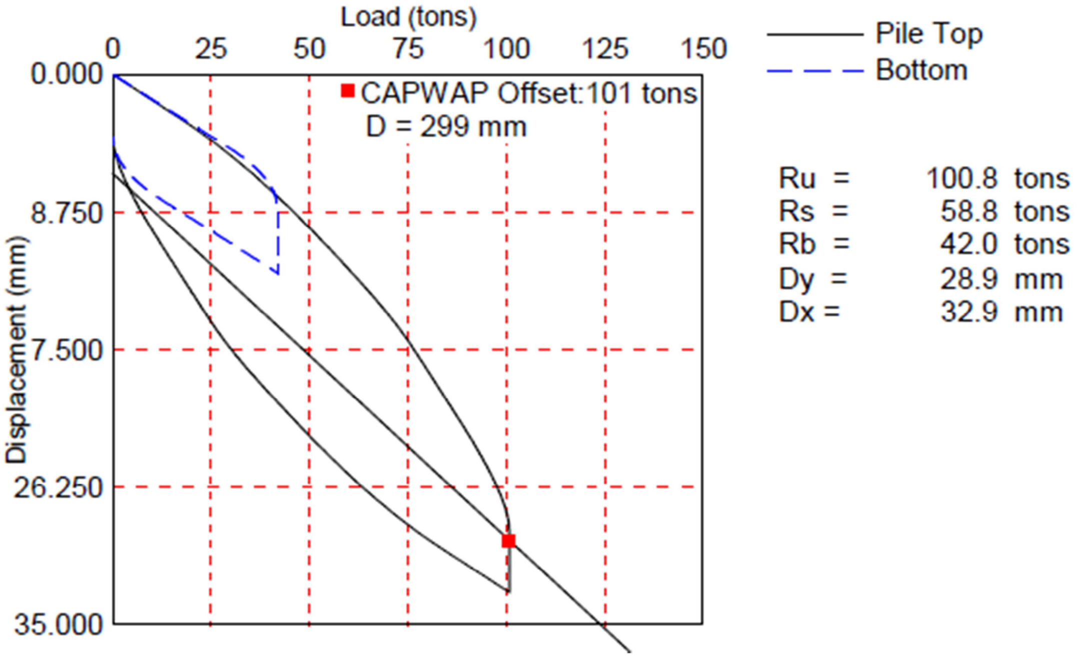

Figure 1. Simulated load vs. Displacement EOID (Pile E31)

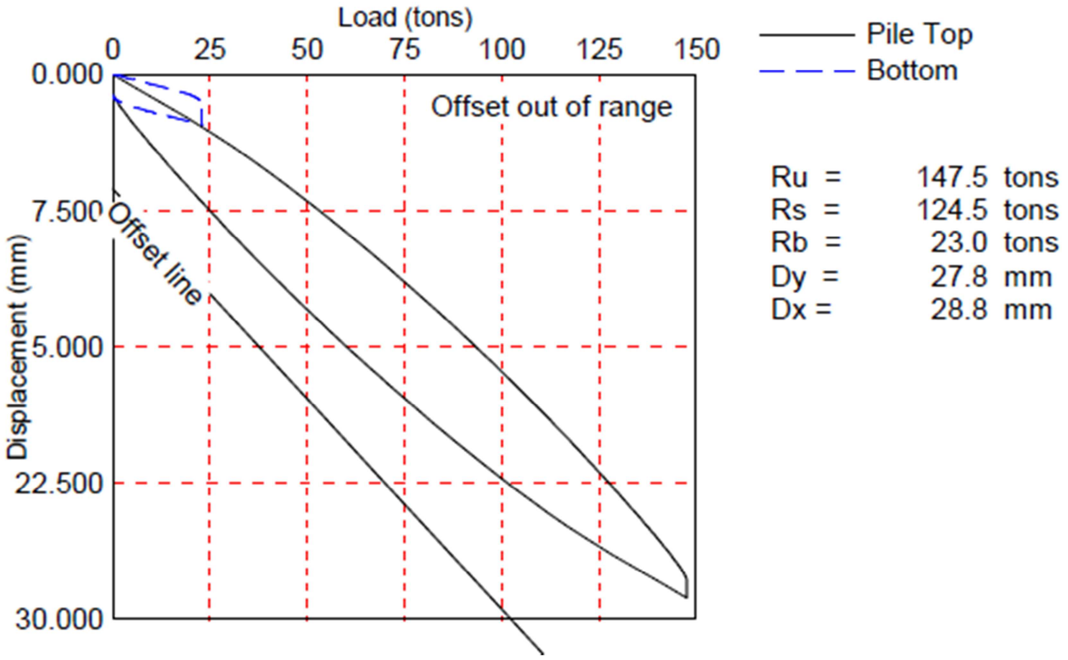

Figure 2. Simulated load vs. Displacement BOR 0.21D (Pile E31)

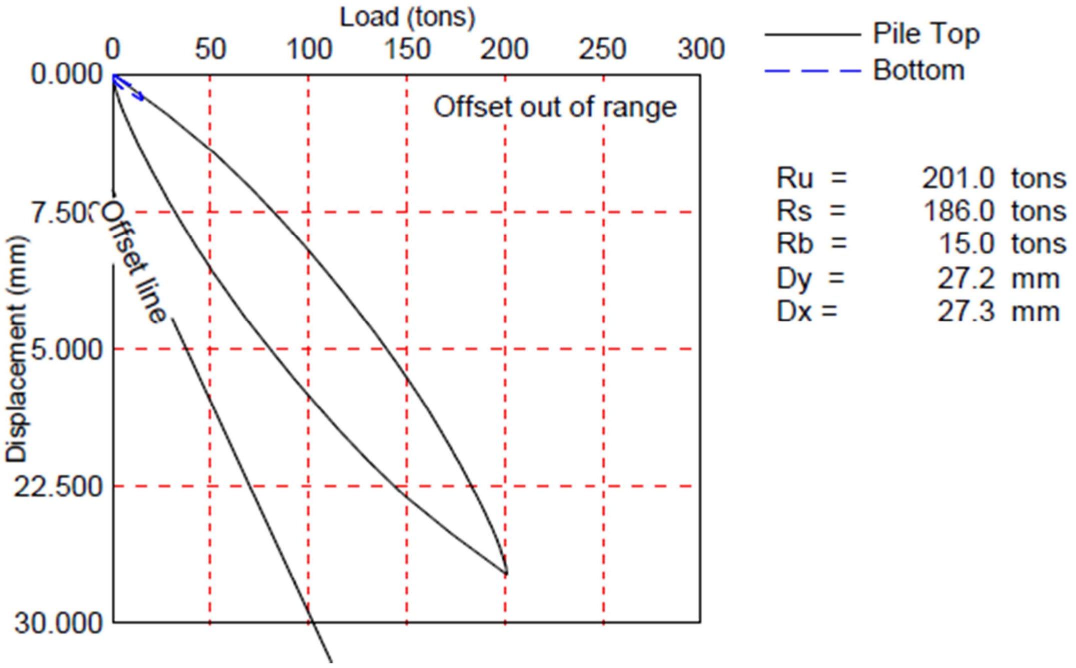

Figure 3. Simulated load vs. Displacement BOR 5D (Pile E31)

4.2 São Vicente, SP, Brazil

The project site is in São Vicente, SP, Brazil, and the deep foundations were designed to support loads from a 28-floor building. The project foresaw 29.5 cm-square precast concrete piles for a design load of 110 tons. In addition, the piles were driven by a 6-ton drop hammer through a soft soil layer (32m depth), followed by a sandy soil where the pile toes were embedded (38m depth).

Table 2 shows the results of the CAPWAP performed with different set-up ratios. Moreover, the pile capacity increased with time from 154.0 tons to 192.0 tons due to the set-up effect. The shaft quake (Qs) was assumed equal for all CAPWAP analyses (3.450 mm) with no trend line with time. However, the toe quake (Qt) decreased with time, starting with 9.413mm (EOID) to 1.711mm (BOR 5 days). As a consequence, the stiffness of the pile increased over time from 4.93 tons/mm (EOID) to 7.44 tons/mm (BOR 5 days), and it was calculated by dividing the Total CAPWAP Resistance by the Maximum Displacement of the Simulated Load vs. Displacement curve of the CAPWAP. These curves are shown in Figures 4 and 5, and it may be observed that the Maximum Displacement of these curves reduces over time, starting with 31.2mm (EOID) to 25.8mm (BOR 5 days). Further, the Davisson Offset is only reached at the End of Initial Driving (EOID), which indicates that the toe displacement is higher at the EOID and lower at the Beginning of Restrike (BOR 5 days).

Table 2. Results of the CAPWAP analysis (Pile E275)

Pile	Drop Height (m)	Set (mm/ blow)	Set-up (days)	Shaft friction (tons)	Toe Resistance (tons)	Total CAPWAP Resistance (tons)	Qs (mm)	Qt (mm)	Stiffness (tons/ mm)
E275	0.40	0.1	0	49.0	105.0	154.0	3.450	9.413	4.93
E275	1.00	1.0	5	98.0	94.0	192.0	3.450	1.711	7.44

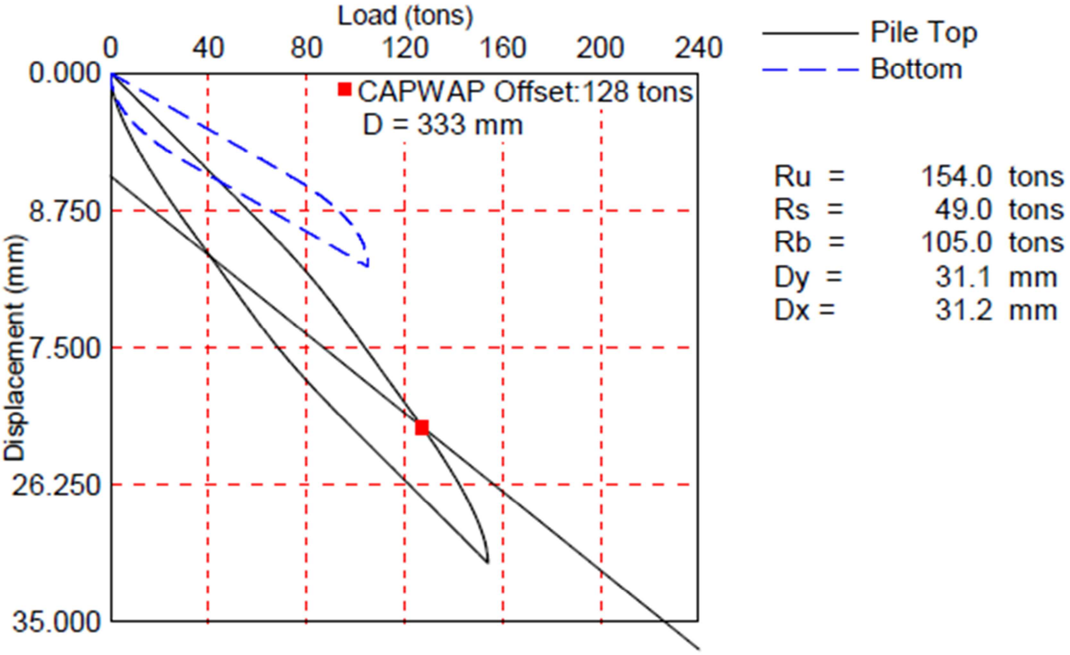

Figure 4. Simulated load vs. Displacement EOID (Pile E275)

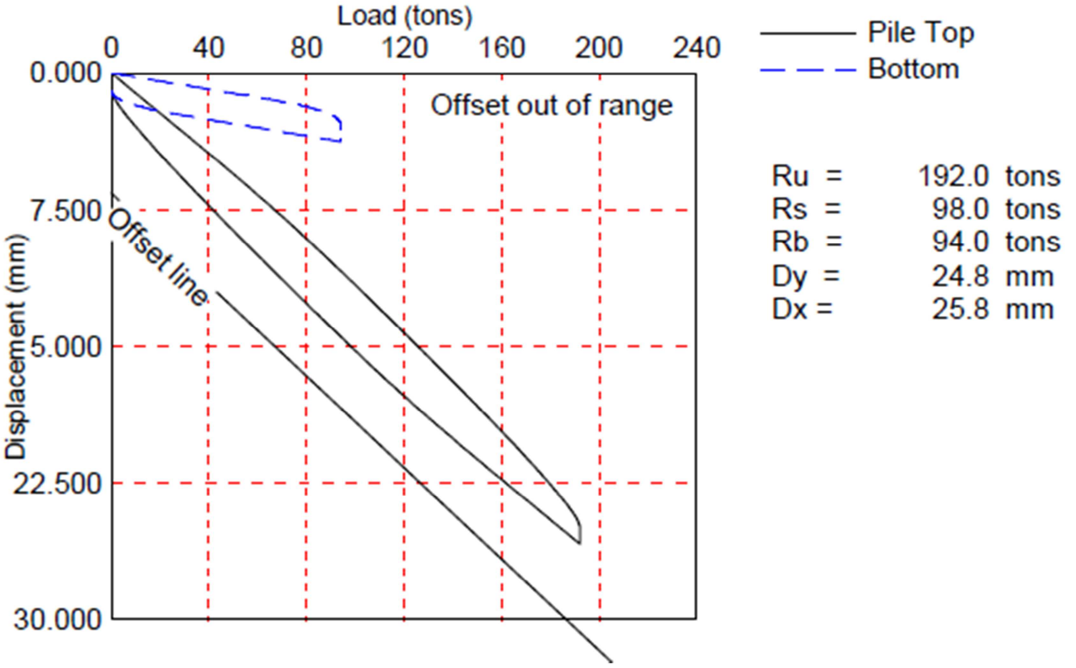

Figure 5. Simulated load vs. Displacement BOR5 (Pile E275)

4.3 Itaquaquecetuba, SP, Brazil

The case study was conducted at a site in Itaquaquecetuba County, in the State of São Paulo, Brazil. The soil profile was a saturated silty sand soil with Nspt values increasing with depth, reaching 15 to 45 blows/0.30m between 27m to 30m depth. Precast concrete piles were driven up to 30m depth, and the pile diameters were 0.42m and 0.50m. During the pile installation of a 0.50m-diameter pile, the PDA measured the compression and tension stresses. The hammer mass of the pile driving machine was a 6.2-ton drop hammer, and soil settlements were observed around some piles. In some cases, a soil settlement of 1.2m diameter wide with 0.6m depth was observed. More information on the pile installation can be found in Murakami and Cabette (2014, 2022), and this paper shows the results of the pile P11 (diameter of 50cm).

Table 3 shows the results of the CAPWAP performed with different set-up ratios. Moreover, the pile capacity increased with time from 229.7 tons (EOID) to 283.4 tons (BOR 1 day) due to the set-up effect. The shaft quake (Qs) was assumed equal for all CAPWAP analyses (1.004 mm) with no trend line with time. However, the toe quake (Qt) decreased with time, starting with 9.490mm (EOID) to 4.500mm (BOR 1 day). As a consequence, the stiffness of the pile increased over time from 9.04 tons/mm (EOID) to 15.32 tons/mm (BOR 1 day), and it was calculated by dividing the Total CAPWAP Resistance by the Maximum Displacement of the Simulated Load vs. Displacement curve of the CAPWAP. These curves are shown in Figures 5 and 6, and it may be observed that the Maximum Displacement of these curves reduces over time, starting with 26.4mm (EOID) to 18.6mm (BOR 1 day). Further, the Davisson Offset is only reached at the End of Initial Driving (EOID), which indicates that the toe displacement is higher at the EOID and lower at the Beginning of Restrike (BOR 1 day).

Table 3. Results of the CAPWAP analysis (Pile P11)

Pile	Drop Height (m)	Set (mm/ blow)	Set-up (days)	Shaft friction (tons)	Toe Resistance (tons)	Total CAPWAP Resistance (tons)	Qs (mm)	Qt (mm)	Stiffness (tons/ mm)
P11	0.60	1.5	0	68.9	150.8	229.7	1.004	9.490	9.04
P11	0.70	0.0	1	201.9	81.5	283.4	1.004	4.500	15.32

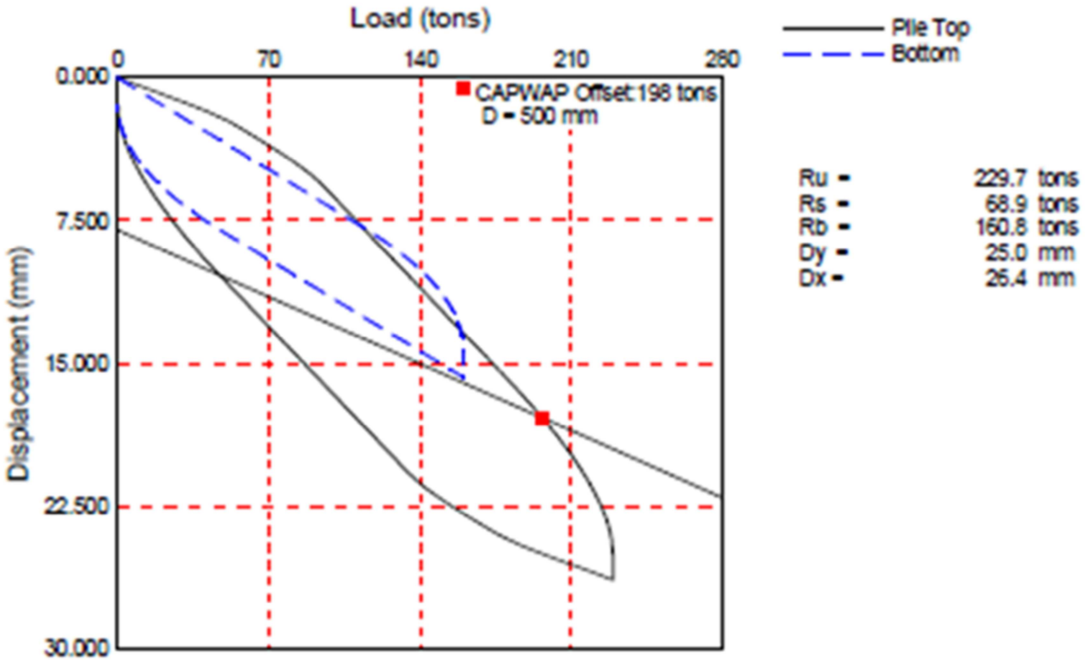

Figure 5. Simulated load vs. Displacement EOID (Pile P11)

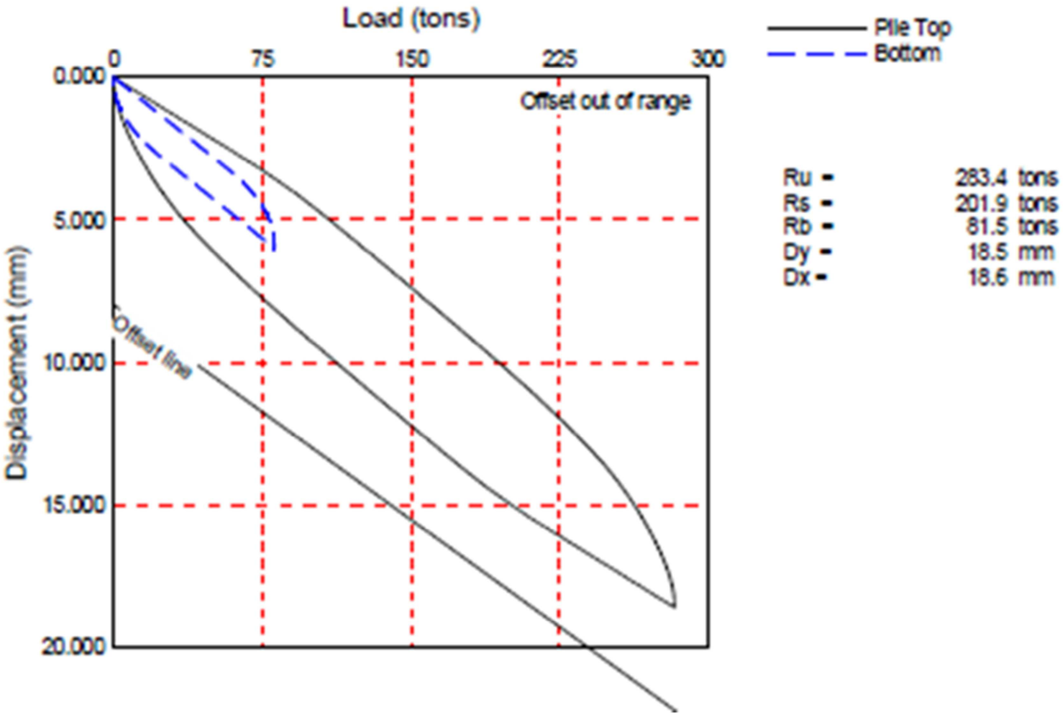

Figure 6. Simulated load vs. Displacement BOR1 (Pile P11)

5 Conclusions

This paper showed the variation of the quake values over time. The three case studies demonstrated that the toe quake values reduced as a function of time, while the shaft quake value was assumed to be the same at the end of initial driving and restrike, with no trend line over time.

The dynamic test was performed through the Dynamic Increasing Energy Test (DIET), proposed by Aoki (1989, 1997), and the CAPWAP analysis was performed through the procedure proposed by Murakami (2015, 2019).

Moreover, for the case studies, it was observed set-up effect on the shaft friction, which increases its value over time. The set-up effect and the reduction of the toe quake values over time influenced the simulated load vs. displacement curve of the CAPWAP, indicating a stiffer response for an older pile tested by the dynamic test.

Furthermore, the Davisson Offset was reached on the piles tested at the end of initial driving for the three case studies. However, the Davisson Offset was not reached during the restrike, even though the pile capacity increased. This fact is evidence that an older pile may provide a stiffer response.

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