# A Comparison Between Static and Dynamic Load Tests Results in a 29.5 cm-Square Precast Concrete Pile

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ABSTRACT: The concept of Match Quality of Settlements (Murakami 2015, 2019) to correlate static and dynamic load tests has been used in different pile types, presenting some advantages compared to the traditional method to correlate both tests. This paper shows a case study in which 29.5 cm-square precast concrete piles were driven through a soft soil layer (32m depth), followed by a sandy soil where the pile toes were embedded (36m depth). The designed load was 110 tons. Furthermore, the static load test (pile ET01) was performed to reach the ultimate load through the slow maintained load, followed by the quick test. However, due to safety conditions, the load test was unloaded, and the next day the load test was performed through the quick test and reached 242 tons. The pile broke when the load test reached the maximum load. The dynamic test (pile E220) reached 250 tons. The ultimate load was not observed in both tests, and the Modified Davisson proposed by Murakami (2015) was used to compare the tests. Furthermore, the $R^2$ and the alpha values of the Match Quality of Settlements were close to the unit, indicating a good correlation between both tests.

KEYWORDS: Static Load Test, Dynamic Load Test, Precast Concrete Piles, Match Quality of Settlements, Soft Soil, Modified Davisson Offset

## 1 Introduction

The High Strain Dynamic Pile Testing (HSDPT) or the Dynamic Load Test (DLT) (ASTM D4945, NBR 13208) intends to determine the pile capacity and the pile shaft integrity. In the field, measurements are done from strain or force and acceleration, velocity, or displacement transducers. Moreover, the DLT collects the force and velocity induced in a pile during a centric impact load from a pair of sensors attached to the pile. The Pile Testing Engineer may use engineering principles and judgment to check out the captured data to inspect the impedance changes along the pile shaft, the efficiency of the hammer used to produce impact loads, and the peak tensile and compressive stresses appearing in a pile during the event.

The transducers' signals shall be transferred at the moment of the impact load to the device for recording, processing, and displaying the data. The Pile Driving Analyzer (PDA) is a frequently used equipment to attain dynamic data (Pile Dynamics, Inc, 2009).

Moreover, the dynamic data collected are analyzed through a signal-matching Method. The CAPWAP (Case Pile Wave Analysis Program) is a software commonly used for signal-matching analysis (Pile Dynamics, Inc, 2006).

Good correlations between dynamic and static load test (SLT) (ASTM D1143M-07, NBR 16903) results have been observed since the 1980s by various authors. The SLT and HSDPT results are traditionally compared through the Davisson Offset Limit Load (1972). When the deep foundation displacement is insufficient to reach this limit load, Murakami (2015) proposed the Modified Davisson Limit Load.

Besides, Murakami (2015) proposed a new procedure through which the signal-matching analysis may be performed in the dynamic increasing energy test (DIET) (Aoki, 1989, 1997) based on the Concept of Match Quality of Settlements and two boundary conditions.

Murakami (2019) proposed the use of the minor possible shaft quake to access the best traditional match quality, matching the slope of the pile top load versus the settlement curve at the early loads. Besides, Murakami (2019) proposed a graphical solution for the Match Quality of Settlements, plotting the settlement of the HSDPT and the SLT for each load increment of the SLT. The graph will show several points whose linear trend line passes through the origin (Eq. 1):

$$Y = \alpha \times X \qquad (1)$$

The closer the $\alpha$ and coefficient of determination ($R^2$) are to the unit, the better the Match Quality of Settlements will be. Initially, the procedure proposed by Murakami (2015) through the Concept of Match Quality of Settlements showed good correlations with SLTs for precast concrete piles (Murakami, 2015, Murakami et al., 2016). However, in the following years, it was observed that the $MQ_S$ concept also applies to other pile types, for example, steel (Murakami et al., 2018), CFA (Murakami, 2019), and Franki piles (Murakami et al., 2020).

## 2 Objectives

This paper aims to show a case study in which 29.5 cm-square precast concrete piles were driven through a soft soil layer (32m depth), followed by a sandy soil where the pile toes were embedded (38m depth). It is shown a comparison between the static load test (pile ET01) and the dynamic load test (pile E220). In addition, the distance between the tests was about 12m.

## 3 Methodology

The piles were designed to support loads of 110 tons from the structure. Furthermore, the static load test (pile ET01) was performed to reach the ultimate load through the slow maintained load, followed by the quick test. However, due to safety conditions, the load test was unloaded, and the next day the load test was performed through the quick test and reached 242 tons. The pile broke when the load test reached the maximum load. The dynamic test (pile E220) reached 250 tons. In both tests, the ultimate load was not observed. Traditionally, the Davisson Offset Limit Load is used to correlate the static and dynamic tests. However, this Limit Load was not reached on the tests due to a small toe displacement, and the Modified Davisson proposed by Murakami (2015) was used to correlate the tests. Moreover, the $R^2$ and the $\alpha$ values of the Match Quality of Settlements were close to the unit, indicating a good correlation between both tests.

## 4 Case Study

The project site was located in São Vicente, SP, Brazil, and the deep foundations were designed to support loads from a 29-floor building. The project foresaw 29.5 cm-square precast concrete piles for a design load of 110 tons. 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).

Moreover, the static load test (pile ET01) was performed to reach the ultimate load through the slow maintained load, followed by the quick test. However, due to safety conditions, the load test was unloaded, and the next day the load test was performed through the quick test and reached 242 tons. The pile broke when the load test reached the maximum load, as shown in Figures 1 and 2, and the extension of the damage was 1.2 m in depth. Table 1 shows more information on the piles tested by the SLT (pile ET01) and DLT (pile E220).

Figure 1. The pile ET01 broke when it reached a load of 242 tons.

Figure 2. The extension of the damage on pile ET01.

Table 1. Information on the SLT (pile ET01) and CAPWAP (pile E220)

| Pile | Cross-Sectional | Pile penetration (LP) (m) | Set-Up (days) |
|---|---|---|---|
| ET01 (SLT) | 29.5 cm Square | 38.0 | 10 |
| E220 (CAPWAP) | 29.5 cm Square | 38.0 | 24 |

The dynamic test was performed according to the Dynamic Increasing Energy Test (Aoki, 1989, 1997), and the maximum drop height was 1.20 m. Figure 3 shows the collected signals of Force, Velocity, and Wave Up (pile E220) for the maximum drop height. In addition, the signal-matching analysis was performed according to the procedure proposed by Murakami (2015) through the Concept of Match Quality of Settlements (Murakami, 2015, 2019).

Figure 4 shows the load vs. settlement curves of the SLT (pile ET01) and the CAPWAP (pile E220). The maximum load in the SLT was 242 tons for a pile settlement of 28.33mm; in the CAPWAP, it was 250 tons for a pile settlement of 27.40mm. It may be observed that the toe displacement was not sufficient to reach the Davisson Offset or the NBR 6122 criteria. In this case, the Modified Davisson proposed by Murakami (2015) was used to correlate both tests, and the results were: 220 tons for the SLT (pile ET01) and 250 tons for the CAPWAP (pile E220).

As expected, the CAPWAP (pile E220) showed a stiffer response at the design load of 110 tons, with a pile settlement of 7.64mm, while the SLT indicated a pile settlement of 9.30mm at the design load. The pile tested by the dynamic test was tested 24 days after the pile installation, and the SLT was tested 10 days after the pile installation. Once the pile tested by the dynamic test is older than the SLT, the dynamic test may demonstrate a stiffer response, as observed by Murakami and Cabette (2014, 2022). Table 2 shows a comparison between the SLT and the CAPWAP.

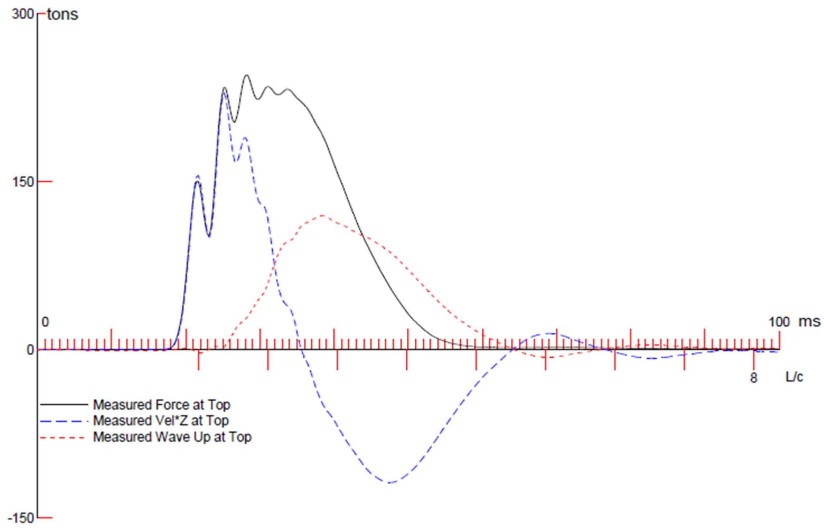


Figure 3. Force, Velocity, and Wave Up vs. time (pile E220)

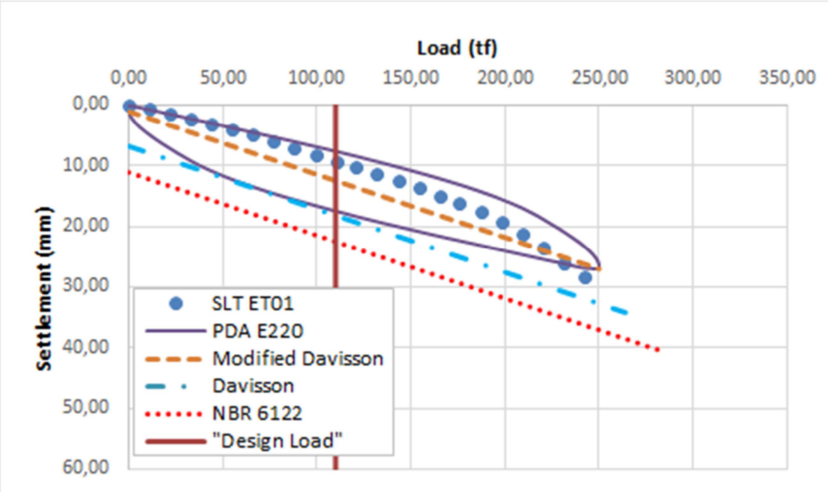

Figure 4. Load vs. Settlement curves of the SLT (pile ET01) and CAPWAP (pile E220)

Table 2. Comparison of the SLT (pile ET01) and CAPWAP (pile E220)

| Pile | Maximum Load (tons) | Maximum Settlement (mm) | Settlement at the design load of 110 tons (mm) | Pile Stiffness (tons/mm) | Modified Davisson | |
|---|---|---|---|---|---|---|
| | | | | | (tons) | (%) |
| ET01 (SLT) | 242 | 28.33 | 9.30 | 11.83 | 220 | - |
| E220 (CAPWAP) | 250 | 27.40 | 7.64 | 14.40 | 250 | +13.6 |

Figure 5 shows the Match Quality of Settlements. It is observed that the α and $R^2$ are close to the unit (0.8128 and 0.9981, respectively). However, as commented before, due to the time between the tests being different, then, it is expected a stiffer response for the DLT. This fact would explain why the α value is lower than one.

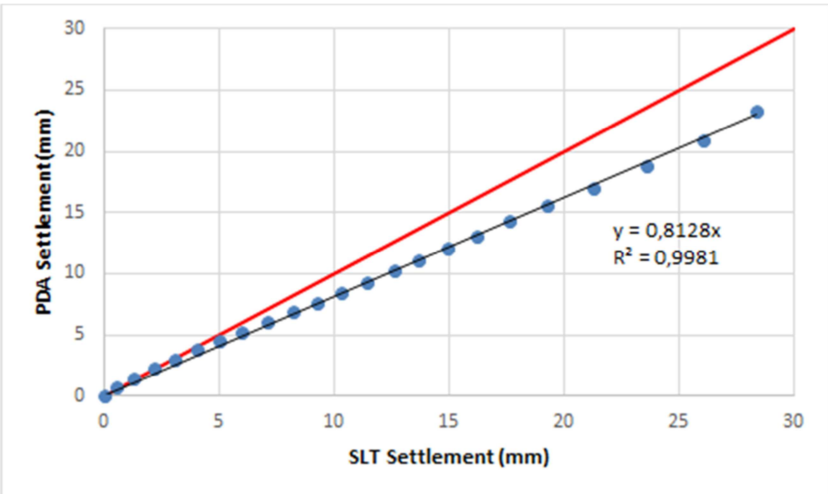

Figure 5. Match Quality of Settlements

Once the SLT did not reach the ultimate load, then the load vs. settlement of the SLT was extrapolated to predict the ultimate load, as shown in Table 3. It was used three methods to extrapolate the ultimate load: Decourt (1999, 2008), Chin-Kondner (1970, 1971), and Veen (1953).

As expected, the Decourt (1999, 2008) and Chin-Kondner (1970, 1971) results were close, obtaining ultimate loads of 460 tons and 469 tons, respectively, while the Veen (1953) result was 343 tons. Although the Veen Method (1953) indicated a lower ultimate load, the Davisson Offset Limit Load and the NBR 6122 criteria were close for the three Extrapolation Methods.

Table 3. Extrapolation of the SLT results (pile ET01)

| Pile | Decourt Extrapolation (tons) | | | Chin-Kondner Extrapolation | | | Veen Extrapolation | | |
|---|---|---|---|---|---|---|---|---|---|
| | RU | Davisson | NBR 6122 | RU | Davisson | NBR 6122 | RU | Davisson | NBR 6122 |
| ET01 (SLT) | 460 | 264 | 282 | 469 | 264 | 283 | 343 | 264 | 285 |

Figure 6 shows the extrapolated load vs. settlement curve predicted by the Decourt Method (1999, 2008). It may be observed that the Davisson Offset was reached at 264 tons, and the NBR 6122 criteria was reached at 282 tons.

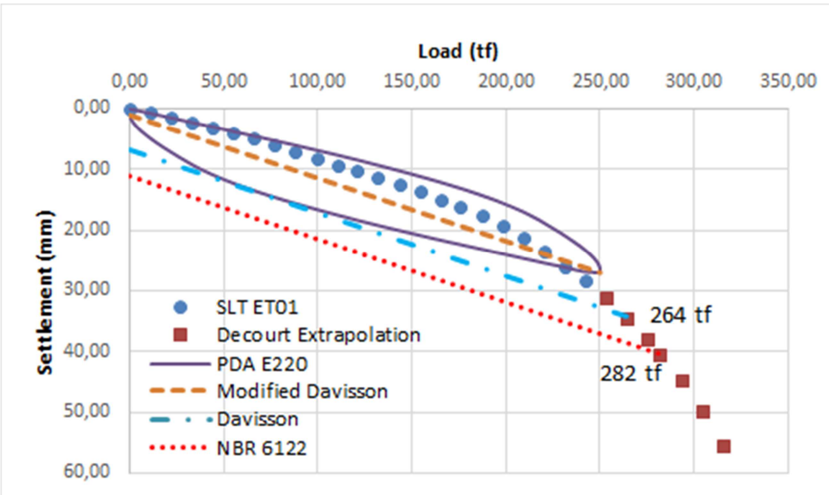

Figure 6. Decourt Extrapolation of the SLT (pile ET01)

Figure 7 shows the extrapolated load vs. settlement curve predicted by the Chin-Kondner Method (1971). It may be observed that the Davisson Offset was reached at 264 tons, and the NBR 6122 criteria was reached at 283 tons.

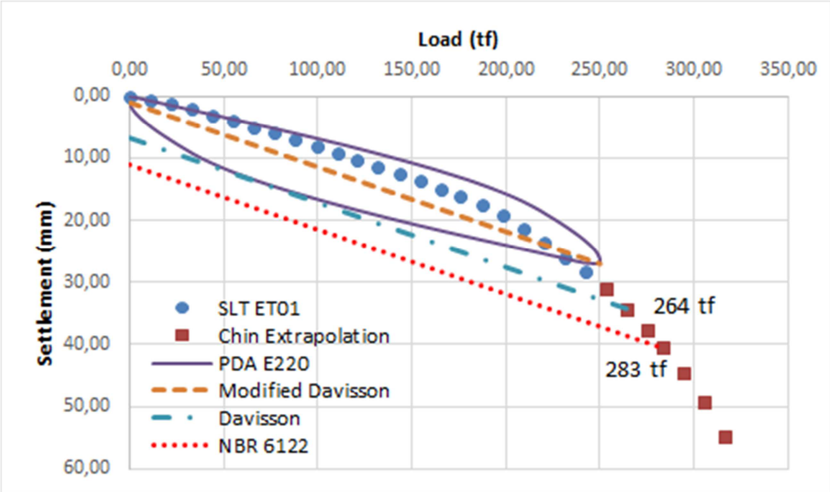


Figure 7. Chin Extrapolation of the SLT (pile ET01)

Figure 8 shows the extrapolated load vs. settlement curve predicted by the Veen Method (1953). It may be observed that the Davisson Offset was reached at 264 tons, and the NBR 6122 criteria was reached at 285 tons.

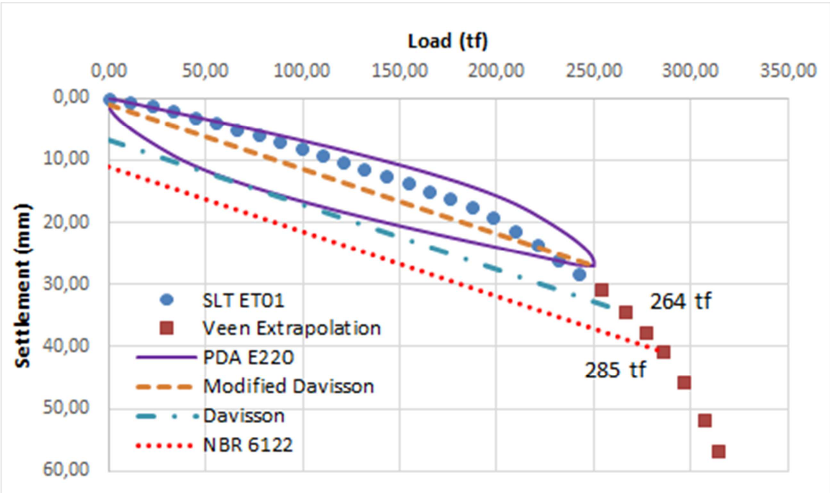


Figure 8. Veen Extrapolation of the SLT (pile ET01)

## 5 Conclusions

This paper presented a case study in which 29.5 cm-square precast concrete piles were driven by a 6-ton drop hammer installed through soft clay followed by sandy soil where the toe of the piles was embedded (38m depth).

The piles were designed to support loads of 110 tons from the structure. Furthermore, the static load test (pile ET01) was performed to reach the ultimate load, and the quick test reached 242 tons. The pile broke when the load test reached the maximum load. The dynamic test (pile

E220) reached 250 tons. In both tests, the ultimate load was not observed. Traditionally, the Davisson Offset Limit Load is used to correlate the static and dynamic tests. However, this Limit Load was not reached on the tests due to a small toe displacement, and the Modified Davisson proposed by Murakami (2015) was used to correlate the tests.

Moreover, a good Match Quality of Settlements (Murakami, 2015, 2019) close to the unit was observed, with α and $R^2$ of 0.8128 and 0.9981, respectively. As expected, a stiffer response was observed on the CAPWAP's load vs. settlement curve once the DLT was performed 24 days after the pile installation, while the SLT was performed 10 days after the pile installation. This fact would explain α value lower than one. In addition, the Modified Davisson proposed by Murakami (2015) indicated a load of 220 tons for the SLT (pile ET01) and 250 tons for the CAPWAP (pile E220).

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