The Influence of The Load Measurement Method in The Static Load Test to Correlate With The Dynamic Test in Piles

Daniel Kina Murakami
Universidade de São Paulo, São Paulo, Brazil, daniel.murakami@gmail.com

Fabian Corgnier
Teknier Engenharia; São Paulo; Brasil fabian@teknier.com.br

ABSTRACT: The same Static Load Test (SLT) can be represented by three different load vs. settlement curves: Load Cell (LC), Manometer (MA), and Theoretical SLT (TH) (Murakami et al., 2020a, 2022). Therefore, the analysis of the SLT will be different depending on the corresponding curve used in the analysis, for example, extrapolation methods. This paper presents a case study in which the same pile (steel) was tested by the SLT and the Dynamic Load Test (DLT). The load measurement method in the SLT was done by a Load Cell and Manometer, and the results were extrapolated by the Van der Veen Method. The Modified Davisson Offset (Murakami, 2015) and the Match Quality of Settlements (MQ_S) (Murakami, 2019) were used to correlate both tests. As expected, the results were: a) LC curve (7290 kN) had the best correlation with the DLT (7880 kN) (error of -8.0%), b) MA curve (8550 kN) over-predicted the load compared to the DLT (7740 kN) (error of + 9.5%), c) TH curve (7180 kN) under-predicted the load compared to the DLT (7880 kN) (error of -9.8%). Moreover, the LC curve had the best alpha and R_2 of the MQ_S, indicating a better correlation with the DLT.

KEYWORDS: Static Load Test, Manometer, Load Cell, Dynamic Load Test, Modified Davisson Offset, Match Quality of Settlements

1 Introduction

The static load test (SLT) in piles may provide the axial force applied at the top of the pile and its corresponding displacement. According to the ABNT NBR 16903, the measured load may be done through a calibrated Manometer or a Load Cell installed in series with the hydraulic jack. However, according to the ASTM D1143, if the maximum test load exceeds 900 kN, place a properly constructed load cell or equivalent device in series with each hydraulic jack. In addition, some authors observed that the load measured through the Manometer over-predicts the applied load, caused mainly by friction inside the jack due to unavoidable eccentric and inclined loading (Fellenius, 1984; Velloso and Lopes, 2010; Murakami et al., 2020).

Murakami et al. (2020a) concluded that the error of the load measured through the Manometer depends on numerous factors: eccentric load, inclined load, the inclination of the reaction beams, and the inclination of the pile cap. For the same load test, three different possible curves can represent the pile behavior depending on the measurement method: a) Load Cell (LC), b) Manometer (MA), and c) Theoretical SLT (TH). More details on the background related to the friction inside the jack can be found in Murakami et at. (2020a).

The Theoretical SLT (TH) represents a load test in which the manometer pressure is used as a reference to measure the load. Then, the real applied load is reduced due to the friction inside the hydraulic jack. In addition, the error of the load measured through the Manometer varies along with the load test, and it may affect the TH curve as well as the extrapolation of the ultimate load, as shown in case studies published by Murakami et al. (2022). Moreover, the three different possible curves for each pile were extrapolated, and the results obtained from the extrapolation methods showed a wide range of values in the same pile.

However, in the piles studied by Murakami et al. (2020a), the manometer error was not linear along the SLT, which indicates uncertainty on the applied load during the SLT when the Manometer is used as a reference to measure the applied load.

The High Strain Dynamic Pile Testing (HSDPT) or the Dynamic Load Test (DLT) (ASTM D4945, NBR 13208) has been performed intensively worldwide due to the speed and economy of its execution. Since the 1980s, many authors have shown good correlations between the DLT and the static loading test (SLT), such as Murakami et al. (2018, 2019, 2020b). Furthermore, the results are traditionally compared through the Davisson Offset (1972), requiring a minimal toe displacement.

In some cases, the maximum settlement of the pile is not sufficient to reach the Davisson Offset in the DLT or the SLT. In this case, Murakami (2015) proposed the Modified Davisson Offset (Figure 1), which is a parallel line to that of the original method, passing through the lowest settlement between the maximum values of the DLT and SLT curves.

Murakami (2015) proposed a new procedure to perform the CAPWAP analysis (Case Pile Wave Analysis Program) (Pile Dynamics, Inc., 2006) based on the determination of the shaft quake value of the pile (Murakami and Massad, 2014, 2016) through the Concept of Match Quality of Settlements (MQ_S) (Murakami, 2015).

Murakami (2019) improved the MQ_S concept with a graphical solution that correlates the settlement of the static loading test with the settlement predicted by the CAPWAP for each load increment of the SLT. The chart shows a series of points whose trend line is given by an expression passing through the origin (1):

$$y = \alpha \times x \tag{1}$$

The closer the value of α and the coefficient of determination (R^2) are to the unit, the better the match quality of settlements will be.

2 Objectives

This paper aims to present a case study in which the same pile (steel) was tested by the Static Load Test (SLT) and the Dynamic Load Test (DLT). It is shown in this paper that the load vs. settlement of the SLT may diverge from the DLT curve depending on the load measurement method in the SLT.

3 Methodology

The load measurement method in the SLT was done by a Load Cell and Manometer, and the results were extrapolated by the Van der Veen Method. The Modified Davisson Offset (Murakami, 2015) and the Match Quality of Settlements (MQ_S) (Murakami, 2019) were used to correlate both tests. The three possible SLT curves were compared to the DLT: Load Cell (LC), Manometer (MA), and Theoretical SLT (TH) (Murakami et al., 2020a, 2022).

4 Case Study

The Deep Foundations of this case study are part of the expansion of a seaport project located in Itapoá, SC (Murakami et al., 2018). This site is an offshore project where open-ended steel pipe piles were driven to approximately 30m depth using a vibratory hammer. Subsequently, the piles were driven to refusal using a 14-ton hydraulic hammer, achieving lengths of approximately 40m.

The project foresaw piles with a diameter of 1.0m and a wall thickness of 9.5mm.

The boreholes indicated a water layer thickness of approximately 18m, followed by alternating layers of very soft to medium silty clay and loose to compact clayey sand until approximately 30m depth. Below these layers, the boreholes detected a layer of hard sandy clay until approximately 39m depth, followed by a layer of compact to very compact silty sand until the limit of the test at 56m depth.

The dynamic increasing energy test (DIET) (Aoki, 1989, 1997) was conducted at the end of initial driving (EOID) and the beginning of restrike after 15 days (BOR15). The static load test (SLT), performed on the same pile as the dynamic test, was carried out in two cycles (slow maintained load). The first cycle, with five load increments, reached 370tf and was conducted after 13 days of the initial driving. Furthermore, with eight load increments, the second cycle reached up to 592tf and was conducted after 14 days of the initial driving.

The CAPWAP analyses were performed through the procedure proposed by Murakami (2015, 2019).

4.1 Load Cell

Figure 1 shows the correlation between the SLT (Load Cell) and the DLT. Due to a small toe displacement, the Davisson Offset was not reached. Then, the Modified Davisson Offset (Murakami, 2015) was used to correlate both tests. For the SLT, the Modified Davisson Offset indicated 729 tons, while for the CAPWAP, it was 788 tons. The difference between the tests was +59 tons (+8,1%). Moreover, both tests demonstrated good agreement through the MQ_S (Figure 2) with α and R^2 close to the unit (0.9939 and 0.9938, respectively).

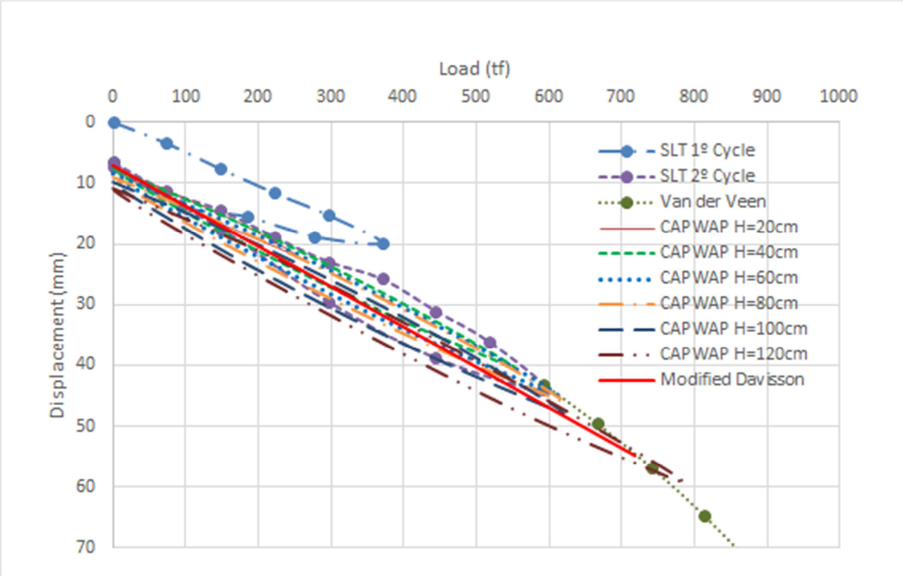

Figure 1. SLT (Load Cell) vs. CAPWAP

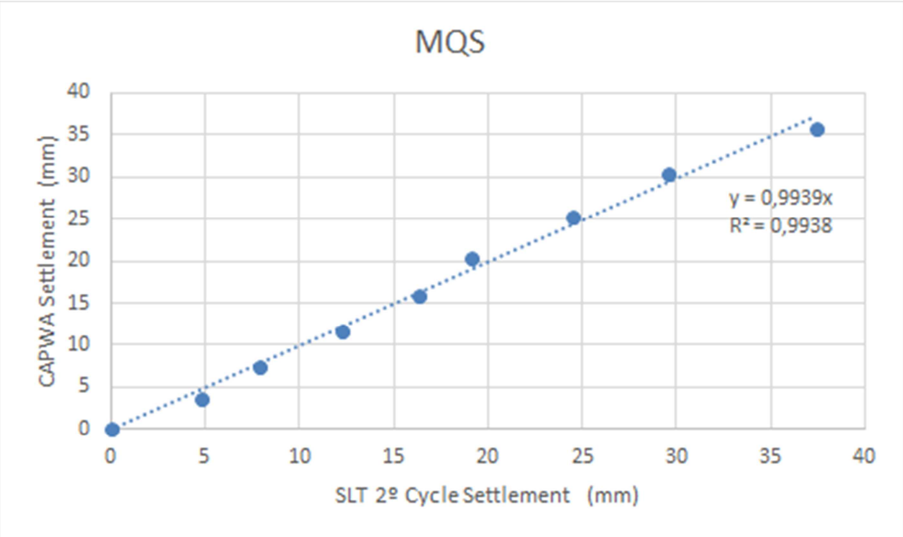

Figure 2. Match Quality of Settlements - SLT (Load Cell) vs. CAPWAP

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4.2 Manometer

Figure 3 shows the correlation between the SLT (Manometer) and the DLT. Due to a small toe displacement, the Davisson Offset was not reached. Then, the Modified Davisson Offset (Murakami, 2015) was used to correlate both tests. For the SLT, the Modified Davisson Offset indicated 855 tons, while for the CAPWAP, it was 774 tons. The difference between the tests was -81 tons (-9,47%). Moreover, compared to the Load Cell, the SLT curve determined by the Manometer demonstrated worse agreement through the MQ_S (Figure 4) with α and R^2 equal to 1.0864 and 0.9921, respectively.

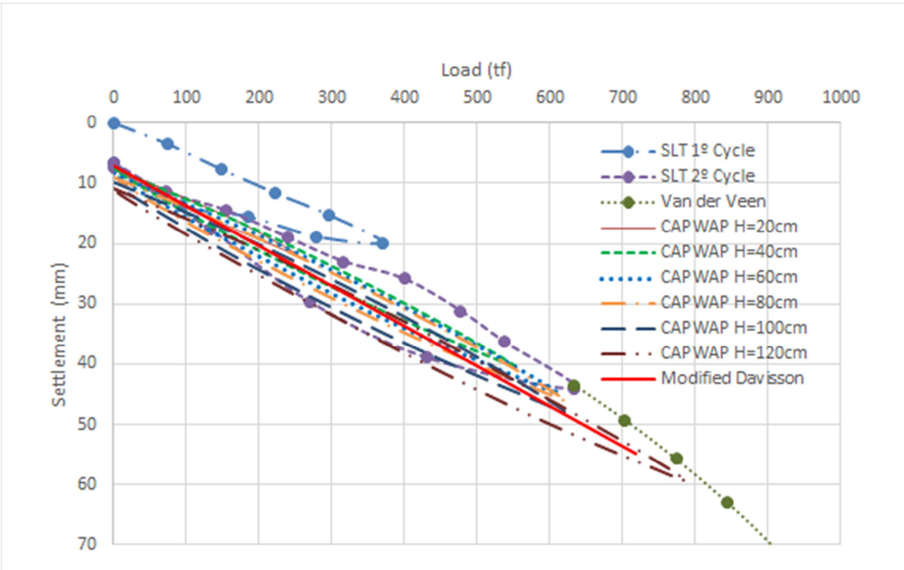

Figure 3. SLT (Manometer) vs. CAPWAP

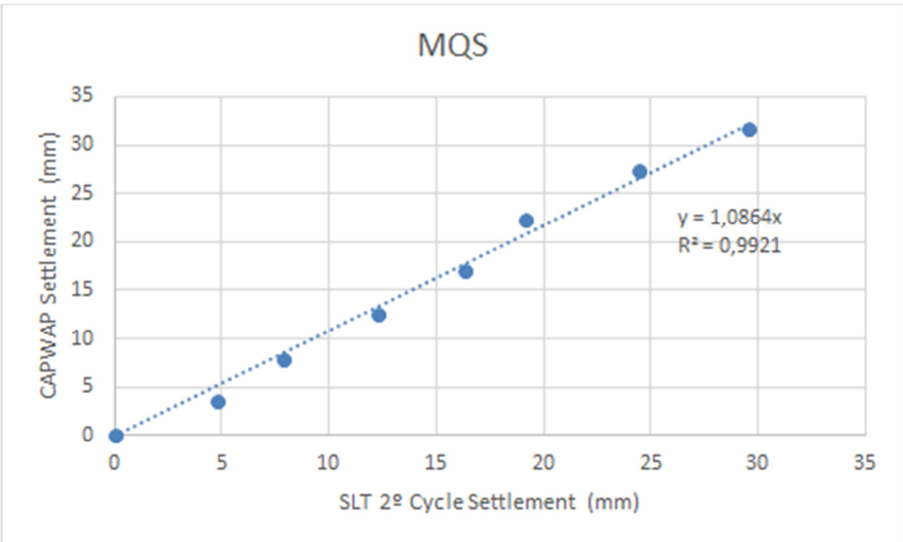

Figure 4. Match Quality of Settlements - SLT (Manometer) vs. CAPWAP

4.3 Theoretical

Figure 5 shows the correlation between the SLT (Theoretical) and the DLT. Due to a small toe displacement, the Davisson Offset was not reached. Then, the Modified Davisson Offset (Murakami, 2015) was used to correlate both tests. For the SLT, the Modified Davisson Offset indicated 718 tons, while for the CAPWAP, it was 788 tons. The difference between the tests was +70 tons (+9,75%). Moreover, compared to the Load Cell, the SLT curve determined by the Theoretical Curve demonstrated worse agreement through the MQ_S (Figure 6) with α and R^2 equal to 0.9291 and 0.9942, respectively.

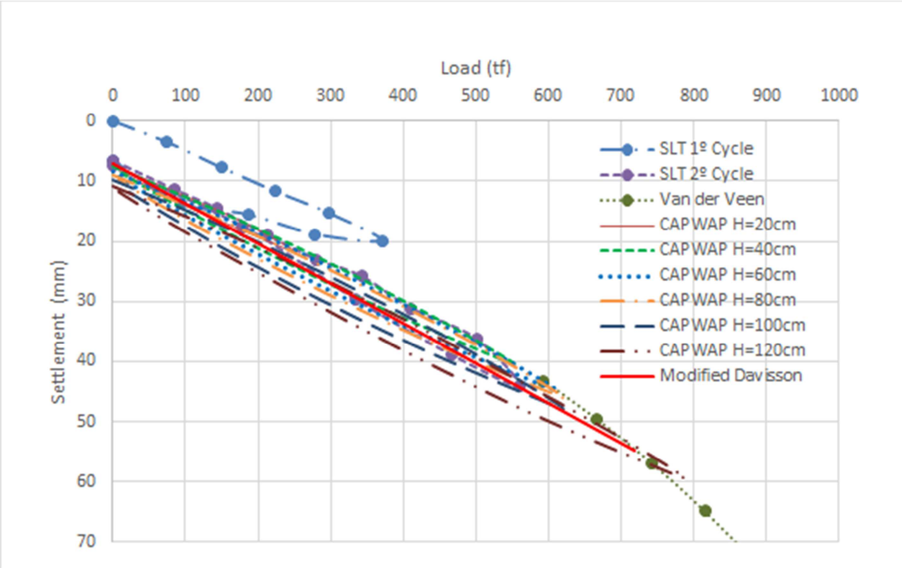

Figure 5. SLT (Theoretical) vs. CAPWAP

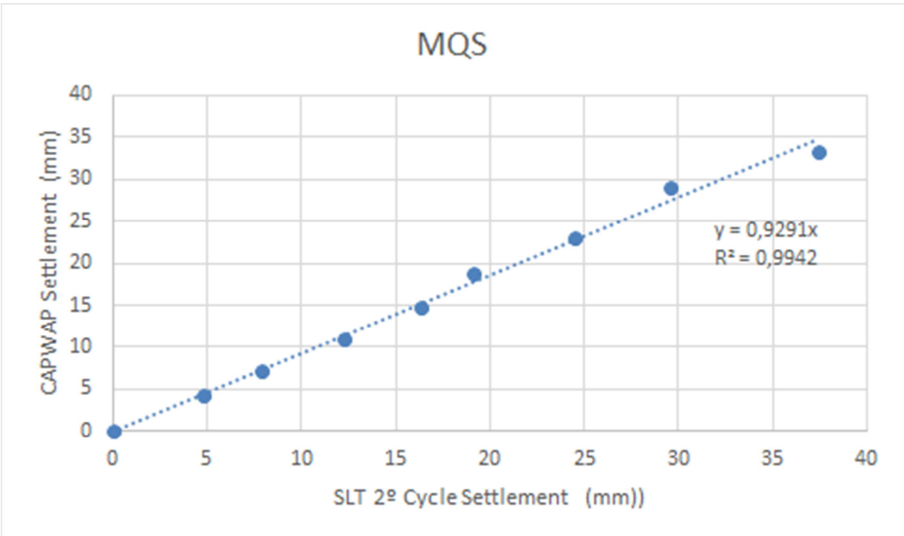

Figure 6. Match Quality of Settlements - SLT (Theoretical) vs. CAPWAP

4.3 Comparison between SLT and CAPWAP

Table 1 compares the SLT for the three Curves (Load Cell, Manometer, and Theoretical) and the CAPWAP. The correlation through the Modified Davisson Offset (Murakami, 2015) indicated that the Load Cell provided a better correlation with the CAPWAP than the other SLT curves (Manometer and Theoretical). In addition, the Load Cell also demonstrated a better correlation through the MQ_S concept, obtaining α and R^2 close to the unit. This fact indicates that the pile settlements of both tests are close for each load increment of the SLT. On the other hand, the Manometer curve (SLT) showed α value higher than one, indicating higher pile settlements for the CAPWAP than the Manometer curve for each load increment of the SLT. Moreover, the Theoretical Curve (SLT) showed α value lower than one, indicating lower pile settlements for the CAPWAP than the Theoretical curve for each load increment of the SLT.

Table 1. Comparison of the results

SLT Type	Modified Davisson (tf)			MQ_S	
	SLT	CAPWAP	Error (%)	α	R^2
Load Cell	729	788	8.09	0.9939	0.9938
Manometer	855	774	-9.47	1.0864	0.9921
Theoretical	718	788	9.75	0.9291	0.9942

Furthermore, Table 1 and Figures 1 to 6 clearly show that the SLT may provide different load vs. settlement curves depending on the load measurement method. In addition, although the SLT was the same, three possible curves (Load Cell, Manometer, and Theoretical) represented three different correlations with the CAPWAP curve.

5 Conclusions

This paper showed that the same Static Load Test (SLT) may be represented by three possible curves, depending on the load measurement method (Load Cell, Manometer, and Theoretical). Moreover, for the same SLT, there were three different correlations with the CAPWAP.

Compared to the Manometer and Theoretical Curve of the SLT, the Load Cell Curve provided a better correlation with the CAPWAP, not only by the Modified Davisson Offset (Murakami, 2015) but also through the MQ_S concept, obtaining α and R^2 close to the unit, which indicates that the pile settlements of both tests are close for each load increment of the SLT.

This paper clearly shows that the load measurement method may affect the quality of the SLT, and also it may affect the correlation with the Dynamic Load Test.

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