The Importance Of A Reliable SPT Test On Costs Of Deep Foundations

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ABSTRACT: Wave-equation analysis on piles may be done to select a hammer mass to install the deep foundations at the design length. GRLWEAP is a software commonly used for this purpose. In this project site, located in São Bernardo do Campo, SP, Brazil, 17cm-square precast concrete piles were driven by a 2.8-ton free fall hammer with a drop height of 30 cm for a workload of 25 tons. Moreover, the SPT tests showed clayey soil with low Nspt values of 1 blow/30 cm in the first 3m depth, followed by a layer of the same material with Nspt values between 4 blows/30 cm and 26 blows/30 cm up to 5m depth. Then, the SPT tests indicated higher than 50 blows/30cm between 6m and 7m depth for the clayey soil. The GRLWEAP analysis indicated that 17cm-square precast concrete piles would be embedded at 6m depth with a blow count higher than 860 blows/m for a drop height of 30 cm. However, during the pile driving, the soil demonstrated low strength at 6m depth for most of the piles, and the piles were driven between 5.9 m and 12.1 m depth, and the average pile penetration was 9.3 m. Once the average pile penetration was 3 m longer (70% longer) than the predicted lengths by the GRLWEAP, it was requested a new SPT test to confirm the soil profile. However, it was not possible due to the timeline restrictions. Then, five Dynamic Load Tests were performed on the piles with pile lengths between 8.8m and 12.1m, and the results confirmed a low-soil resistance at 6m depth. The mobilized loads were between 67.3 and 87.0 tons. In addition, the PDA indicated good results for the piles that reached longer depths than the ones predicted by the GRLWEAP, although the SPT suggested a lower pile length. This case study shows the importance of a reliable SPT test. Due to errors in the SPT test and timeline restrictions, the contractor's budget was severely affected. The PDA was fundamental for the quality assurance of the deep foundations, and the conclusion is that if the piles were embedded at 6 m depth according to the SPT tests, then a low pile capacity would be reached once the predicted blow count of 860 blows/m was not observed at this depth. Moreover, all the piles would be restriked to reach the workload with the minimal factor of safety.

KEYWORDS: SPT Test, Costs, GRLWEAP, Dynamic Load Test, Precast Concrete Piles

1 INTRODUCTION

Wave-equation analysis on piles may be done to select a hammer mass to install the deep foundations at the design length. GRLWEAP (Pile Dynamics, Inc., 2010) is a software commonly used for this purpose.

The hammer selected to install the piles may provide sufficient energy to drive the piles at the predicted depth and reach the design load. Compression and tension stresses during the pile driving may not exceed the material strength in order not to damage the piles.

Based on the soil profile obtained by the SPT test, it may be predicted the soil resistances along the pile shaft and the pile toe. Further, with those soil resistances in depth and other soil parameters (quake and damping), a prediction of the blow counts in depth may be done by the GRLWEAP.

Murakami et. al. (2022) observed good agreement between the force and velocity signals predicted by the GRLWEAP and the ones observed by the PDA (Pile Dynamics, Inc., 2009). The authors observed in a case study that the WEAP analysis was fundamental for the hammer selection, and the use of a hydraulic hammer with a smaller mass would not be able to mobilize the design load with a factor of safety.

2 OBJECTIVES

This case study shows the importance of a reliable SPT test. Due to errors in the SPT test and timeline restrictions, the contractor’s budget was severely affected. The PDA was fundamental for the quality assurance of the deep foundations.

3 METHODOLOGY

It is shown the drivability analysis performed by GRLWEAP. Based on the soil resistance predicted by Aoki & Velloso (1975), the software predicts the blow count in depth, and a comparison is made with the blow counts observed during the pile installation. In addition, a prediction of force and velocity signals is made by GRLWEAP, and those results are compared with the measured data in dynamic load test (NBR 13208; ASTM D4945). Moreover, the CAPWAP (Pile Dynamics, Inc., 2006) analysis provides the soil resistance along the shaft and the toe resistance.

4 CASE STUDY

In this project site, located in São Bernardo do Campo, SP, Brazil, 17cm-square precast concrete piles were driven by a 2.8-ton free fall hammer with a drop height of 30 cm for a workload of 25 tons. Moreover, the SPT tests showed clayey soil with low Nspt values of 1 blow/30 cm in the first 3m depth, followed by a layer of the same material with Nspt values between 4 blows/30 cm and 14 blows/30 cm up to 5m depth. Then, the SPT tests indicated higher than 50 blows/30cm between 6m and 7m depth for the clayey soil.

The GRLWEAP analysis indicated that 17cm-square precast concrete piles would be embedded between 5 m and 5.5 m depth with a blow count higher than 860 blows/m for a drop height of 30 cm, as shown in Table 1, while Figure 1 shows the predicted force and velocity signals.

During the pile driving, the soil demonstrated low strength at 5 m depth for most of the piles, and the piles were driven between 5.9 m and 12.1 m depth, and the average pile penetration was 9.3 m. Once the average pile penetration was 3 m longer (about 70% longer) than the predicted lengths by the GRLWEAP, it was requested a new SPT test to confirm the soil profile.

However, it was not possible due to the timeline restrictions. Then, five Dynamic Load Tests were performed on the piles with pile lengths between 8.4m and 12.1m, and the results confirmed a low-soil resistance at 6m depth. The mobilized loads were between 67.3 and 87.0 tons. In addition, the PDA indicated good results for the piles that reached longer depths than the ones predicted by the GRLWEAP, although the SPT suggested a lower pile length.

Table 1. GRLWEAP drivability results

Depth m	Ultimate Capacity kN	Friction kN	End Bearing kN	Blow Count blows/m	Comp. Stress MPa	Tension Stress MPa	Stroke m	ENTHRU kJ
1.0	5.6	1.5	4.2	0.0	0.000	0.000	0.30	0.0
2.0	7.1	2.9	4.2	0.0	0.000	0.000	0.30	0.0
3.0	34.7	5.7	29.0	20.8	9.247	-2.305	0.30	2.4
4.0	93.1	13.3	79.7	52.4	9.258	0.000	0.30	2.8
5.0	461.3	48.2	413.1	861.7	18.343	-0.935	0.30	2.0
5.5	490.5	77.4	413.1	1446.3	18.728	-1.127	0.30	1.9
6.0	519.8	106.7	413.1	2582.5	19.080	-1.356	0.30	1.9
7.0	578.3	165.2	413.1	9999.0	19.226	-1.729	0.30	1.9

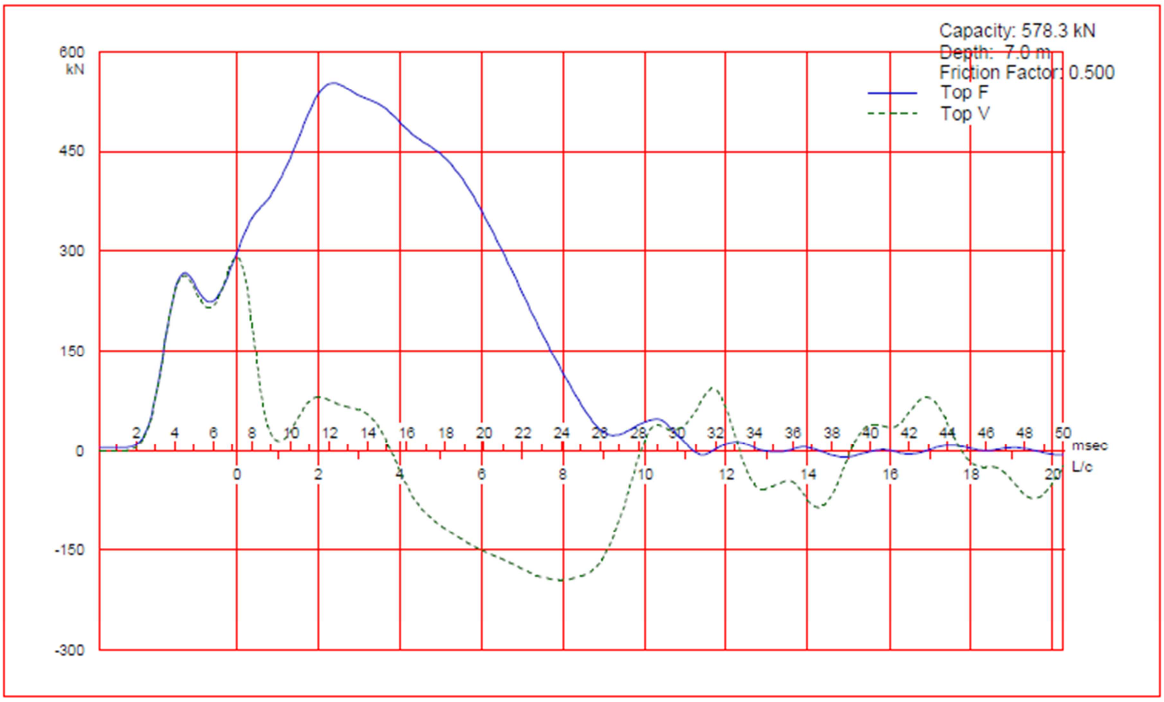

Figure 1. Predicted force and velocity signals by GRLWEAP

Table 2 shows the summary of results of the dynamic tests. The RMX values were between 67.3 tf and 87.0 tf for drop heights between 30 cm and 40 cm. Moreover, the piles were tested between zero and one day after the pile installation (Set Up). The tested piles achieved lengths between 8.8 m and 12.1 m. As mentioned before, those pile penetrations were higher than the ones predicted by the GRLWEAP analysis, between 5.0 m and 5.5 m.

Table 2. Summary of results

Pile	Length (m)	H (cm)	Set Up (days)	Shaft (tf)	Toe (tf)	RMX (tf)	Set (mm/blow)
PB8	8.8	40	0	35.7	40.8	76.5	0
PB21	12.0	40	1	56.1	31.1	86.2	0
PB23	12.1	30	1	37.5	29.8	67.3	1
PB26	9.8	30	1	44.4	42.6	87.0	1
`PC92	9.0	30	1	31.5	47.5	79.0	1

Table 3 shows the blow counts observed in pile PB8 with pile penetration of 8.8 m. It may be observed that the blow counts differ from the predicted by the GRLWEAP. Figure 2 and Table 4 shows the CAPWAP results of pile PB8. It may be observed that the measured force and velocity signals (Figure 2) are qualitatively close to the one predicted by the GRLWEAP (Figure 1). However, the pile penetrations were different due to the difference between the soil resistances observed in the SPT and the pile installation (Table 3). Table 4 indicates that the shaft friction between 4.8 m and 5.8 m was low, with friction resistances between 3.21 tf/m2 and 4.43 tf/m2. Further, the friction resistances were higher between 7.8 m and 8.8 m, with friction resistances between 13.85 tf/m2 and 20.24 tf/m2.

Table 3. Blow count in depth for pile PB8

Depth (m)	Nspt	Soil	Pile Installation (blows/m)	GRLWEAP (blows/m)
1	1	Clay	4	0
2	1	Clay	2	0
3	1	Clay	5	20
4	4	Clay	12	52
5	11	Clay	29	861
6	50	Clay	58	1446
7	50	Clay	49	2582
8	50	Clay	66	9999

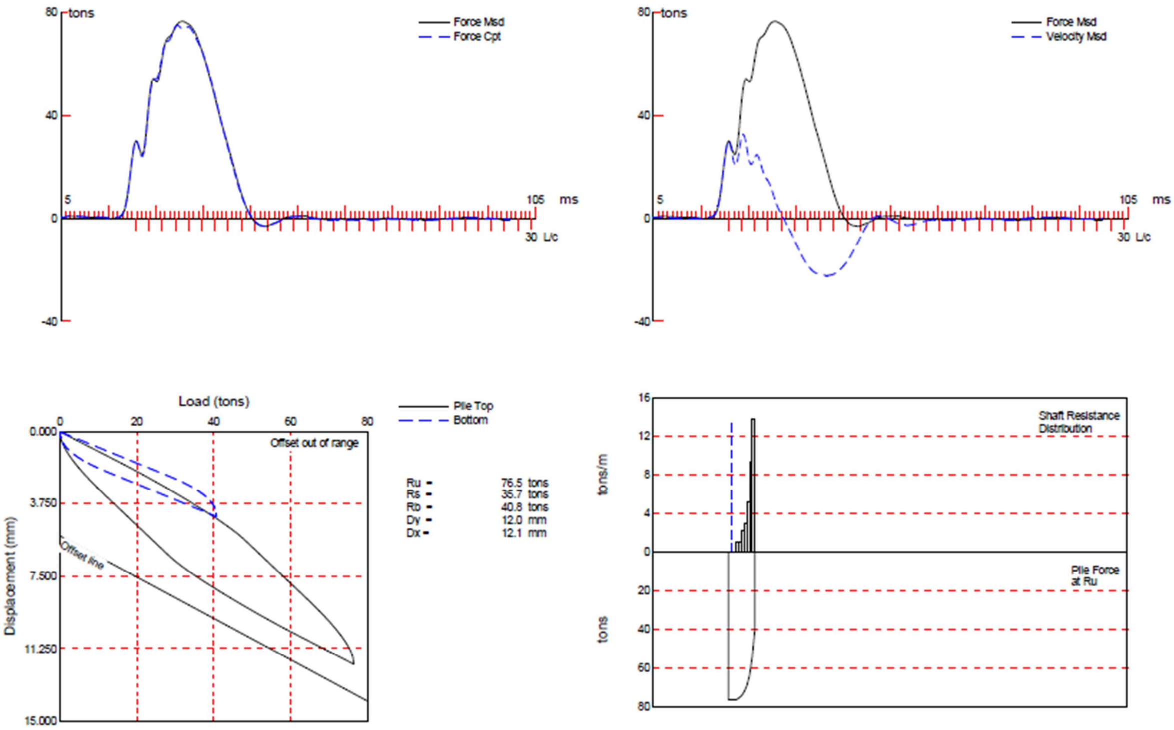

Figure 2. CAPWAP results of pile PB8 (pile length of 8.8 m)

Table 4. Summary results of pile PB8 (pile length of 8.8 m)

CAPWAP SUMMARY RESULTS

Total CAPWAP Capacity: 76.5; along Shaft 35.7; at Toe 40.8 tons

Soil Sgmnt No.	Dist. Below Gages m	Depth Below Grade m	Ru tons	Force in Pile tons	Sum of Ru tons	Unit Resist. (Depth) tons/m	Unit Resist. (Area) tons/m²	Smith Damping Factor s/m	Quake mm
				76.5					
1	1.0	-0.2	0.0	76.5	0.0	0.00*	0.00*	0.000	1.004
2	2.0	0.8	0.0	76.5	0.0	0.00	0.00	0.000	1.004
3	3.0	1.8	0.0	76.5	0.0	0.00	0.00	0.000	1.004
4	4.0	2.8	1.0	75.4	1.0	1.04	1.53	1.313	1.004
5	5.0	3.8	1.1	74.4	2.1	1.08	1.59	1.313	1.004
6	6.0	4.8	2.2	72.2	4.3	2.18	3.21	1.313	1.004
7	7.0	5.8	3.0	69.2	7.3	3.01	4.43	1.313	1.004
8	8.0	6.8	5.2	63.9	12.5	5.23	7.69	1.313	1.004
9	9.0	7.8	9.4	54.5	22.0	9.42	13.85	1.313	1.004
10	10.0	8.8	13.8	40.8	35.7	13.76	20.24	1.313	0.743
Avg. Shaft			3.6			4.06	5.36	1.313	0.903
Toe			40.8				1410.39	1.313	3.323

Table 5 shows the blow counts observed in pile PB23 with pile penetration of 12.1 m. It may be observed that the blow counts differ from the predicted by the GRLWEAP. Figure 3 and Table 6 shows the CAPWAP results of pile PB23. It may be observed that the measured force and velocity signals (Figure 3) are qualitatively close to the one predicted by the GRLWEAP (Figure 1). However, the pile penetrations were different due to the difference between the soil resistances observed in the SPT and the pile installation (Table 5). Table 6 indicates that the shaft friction between 5.0 m and 6.0 m was low, with friction resistance of 4.98 tf/m2. Further, the friction resistances were higher between 9.1 m and 12.1 m, with friction resistances between 7.87 tf/m2 and 9.80 tf/m2.

Table 5. Blow count in depth for pile PB23

Depth (m)	Nspt	Soil	Pile Instalation (blows/m)	GRLWEAP (blows/m)
1	1	Clay	2	0
2	1	Clay	3	0
3	1	Clay	2	20
4	4	Clay	5	52
5	11	Clay	8	861
6	50	Clay	34	1446
7	50	Clay	48	2582
8	50	Clay	58	9999
9	-	-	67	-
10	-	-	82	-
11	-	-	115	-
12	-	-	122	-

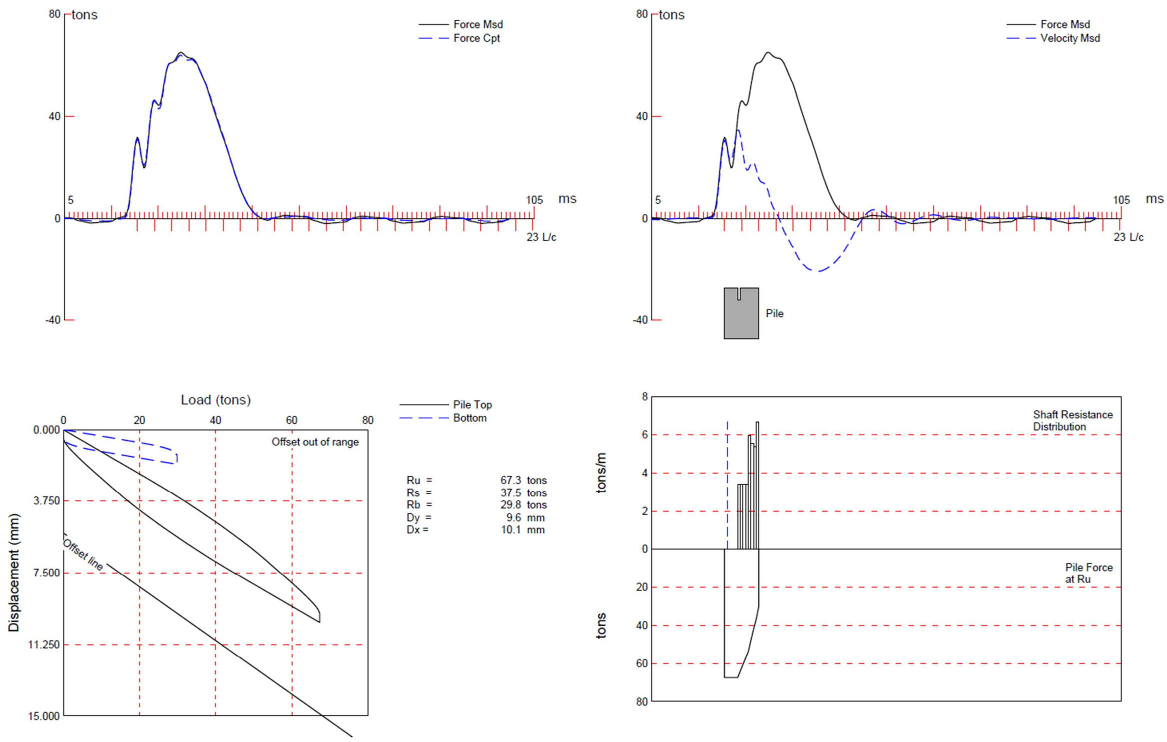

Figure 3. CAPWAP results of pile PB23 (pile length of 12.1 m)

Table 6. Summary results of pile PB23 (pile length of 12.1 m)

CAPWAP SUMMARY RESULTS

Total CAPWAP Capacity: 67.3; along Shaft 37.5; at Toe 29.8 tons

Soil Sgmnt No.	Dist. Below Gages m	Depth Below Grade m	Ru tons	Force in Pile tons	Sum of Ru tons	Unit Resist. (Depth) tons/m	Unit Resist. (Area) tons/m²	Smith Damping Factor s/m	Quake mm
				67.3					
1	1.0	-0.1	0.0	67.3	0.0	0.00*	0.00*	0.000	1.320
2	2.0	1.0	0.0	67.3	0.0	0.00	0.00	0.000	1.321
3	3.0	2.0	0.0	67.3	0.0	0.00	0.00	0.000	1.321
4	4.1	3.0	0.0	67.3	0.0	0.00	0.00	0.000	1.321
5	5.1	4.0	0.0	67.3	0.0	0.00	0.00	0.000	1.321
6	6.1	5.0	3.4	63.9	3.4	3.39	4.98	1.313	1.321
7	7.1	6.0	3.4	60.5	6.9	3.39	4.98	1.313	1.321
8	8.1	7.0	3.4	57.0	10.3	3.39	4.98	1.313	1.321
9	9.1	8.0	3.4	53.6	13.7	3.39	4.98	1.313	1.321
10	10.1	9.1	6.0	47.6	19.7	5.94	8.74	1.313	1.063
11	11.1	10.1	5.6	42.0	25.3	5.54	8.14	1.313	0.899
12	12.2	11.1	5.4	36.6	30.8	5.35	7.87	1.313	0.622
13	13.2	12.1	6.8	29.8	37.5	6.66	9.80	1.313	0.267
Avg. Shaft			2.9			3.10	4.21	1.313	0.926
Toe			29.8				1031.49	0.946	1.004

5 CONCLUSIONS

This case study shows the importance of a reliable SPT test. Due to errors in the SPT test and timeline restrictions, the contractor's budget was severely affected. The PDA was fundamental for the quality assurance of the deep foundations.

If the piles were embedded at 6 m depth according to the SPT tests, then a low pile capacity would be reached once the blow count of 860 blows/m predicted by the GRLWEP was not observed at this depth. Moreover, all the piles would be restriked to reach the workload with the minimal factor of safety.

BIBLIOGRAFIC REFERENCES

AOKI, N. e VELLOSO, D. A.; An Aproximate Method to Estimate the Bearing Capacity of Piles.; Proceedings of the 5th Pan American Conference on Soil Mechanics and Foundation Engineering, Buenos Aires, vol. 1, 1975.

Associação Brasileira de Normas Técnicas (2007) NBR 13208. *Estacas Ensaio de carregamento dinâmico*. Rio de Janeiro.

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

Pile Dynamics, Inc. (2006) CAPWAP manual, Cleveland, Ohio.

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

Pile Dynamics, Inc. (2010). GRLWEAP Manual. Cleveland, Ohio.