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Challenges from North to South
Des défis du Nord au Sud

Comparison of pile capacity estimated by signal matching (CAPWAP®), iCAP® and Case Method of driven steel piles installed at an industrial site near Edmonton, Alberta

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ABSTRACT
The standard approach used to estimate the pile capacity from high-strain dynamic testing (HSDT) is by signal matching technique using commercial software programs such as CAPWAP®, DLTWAVE® and AllWave-DLT®. This approach is relatively time consuming and requires an experienced person to properly interpret the results. A faster approach is the use of the Case Method, which is a closed form solution, but requires a selection of a damping constant, not always adequately known for the subject site. A new alternative is the iCAP® method, which is an automated signal matching procedure that provides a fast signal matching solution to estimate the pile capacity for uniform driven piles under simple pile-soil interaction conditions. As part of the quality control for driven steel pile installation at an industrial plant site near Edmonton, Alberta, 187 driven steel pipe piles were dynamically tested on pile sizes ranging from 254 mm to 762 mm and depths ranging from 10 m to 24 m. This paper provides a comparison of the estimated pile capacities from the 187 piles using CAPWAP® software, the automated signal matching iCAP® program and also with the Case Method.

RÉSUMÉ
La détermination de la capacité des pieux au moyen des essais de chargement dynamiques à grande déformation s'effectue habituellement par une corrélation des signaux utilisant des logiciels tels que CAPWAP®, DLTWAVE® et AllWave-DLT®, ce qui nécessite une certaine expérience lors de l'analyse. La méthode Case, plus efficace, est une solution fermée utilisant des constantes d'amortissements, souvent difficiles à déterminer pour un site donné. Une innovation plus récente est d'estimer la capacité des pieux foncés dans des conditions d'interactions pieux-sols simples par la méthode iCAP® utilisant une démarche automatisée plus rapide pour la corrélation des signaux. Près de 187 pieux foncés ont été analysés par la méthode dynamique sur un site industriel près d'Edmonton en Alberta. Ces essais ont été effectués sur des pieux variant entre 254 mm et 762 mm de diamètre et installés entre 10 m et 24 m de profondeur. Cet article présente une analyse comparative de l'estimation de la capacité portante des 187 pieux en utilisant les logiciels CAPWAP®, et iCAP®, ainsi que par la méthode Case.

1 INTRODUCTION

High-strain dynamic testing (HSDT) of piles (ASTM 2012) commonly referred to in the pile industry as PDA (or Pile Dynamic Analysis) testing has become a reliable, efficient, and cost-effective method for estimation of pile capacity and also as a quality control method for driven piles during construction.

This approach was recently used during the construction of an industrial plant near Edmonton, Alberta, where a total of 187 piles, representing about 5% of the installed piles, were PDA tested during construction. The piles were open ended steel pipe with sizes ranging from 254 mm to 762 mm and embedment depths ranging from 10 m to 24 m. PDA tests were performed at the End of Drive (EOD) and at Beginning of Restrike (BOR) to provide an estimation of the expected resistance gain after a setup period.

The test piles selected were representative of the range of pile sizes, lengths and recorded sets at end of drive. The pile capacities were estimated by means of the signal matching method using the computer software CAPWAP® (PDI 2006). The majority of tests were conducted at Beginning of Restrike (BOR) after a setup period ranging from 12 to 34 days, however some piles were also tested at End of Drive (EOD) for comparative purposes.

Because of the fast pace of construction, there was a requirement for a quick turnaround of the PDA results, to confirm the estimated pile capacities. Since the signal matching approach is relatively time consuming, other quicker methods such as the Case Method (Goble, et al. 1975), which is a closed form solution for the estimation of the pile capacity, were also examined. However, the Case Method requires the selection of a soil damping constant, which may vary significantly across the site; and therefore, could provide unrealistic results.

In an attempt to provide a better assessment of the capacity of uniform piles in real time a new automatic signal matching analysis procedure, iCAP®, was developed (Likins et al. 2012). An overview of iCAP model and procedure is provided in Likins et al. (2012), and will not be repeated herein.

Two types of analyses can be performed by iCAP. One is the Quick iCAP, which performs less iteration, and is suitable for use during pile driving when analysis speed is critical. The other is a Full iCAP where more iterations are performed, and thus, is better suited for use when analysis speed is less critical such as pile restrike or immediately after pile driving.

This paper provides a comparison of the estimated pile capacities obtained using CAPWAP and the results obtained by both iCAP methods, Quick iCAP and Full iCAP for all the 187 piles tested during the construction program.

2 BACKGROUND INFORMATION

The site is located about 45 km northeast of Edmonton, Alberta. The site geology consisted basically of thin discontinuous deposits of glaciolacustrine clay and discontinuous deposits of aeolian sand overlying a thick glacial clay till stratum containing sand layers.

The soil conditions encountered during the geotechnical investigation consisted predominantly of stiff to very stiff clay till in the upper 15 m, with SPT blow counts typically ranging from an average of 10 at the upper elevations to 25 near 15 m depth. Below 15 m depth the soil condition varied throughout the site; from clay till with SPT N values increasing gradually with depth to about 30 blows/300 mm, to sand layer with SPT N values over 50 blows/300 mm, to rafted clay shale stratum with SPT N values ranging from 24 to 100 blows/300 mm. The PDA tested piles were selected throughout the site and therefore were installed within all of the above noted soil formations.

During the design phase of the project, three static load tests were performed on open ended pipe piles with diameters consisting of 508 mm, 610 mm and 762 mm and embedment depths of approximately 20 m. PDA testing was also carried out on each test pile at EOD and again after a "set-up" period ranging from 12 to 34 days after installation. The static load test results were used as a basis for design and also for comparison with the results of the PDA tests during production.

3 RESULTS

The iCAP analysis can be performed using fresh initial data or using the result data from the previous analysis for each blow. By inheriting the previous analysis results, the current analysis converges faster and more consistently to the final result. Therefore, the results presented herein were run by using the inherited data from the analysis in the previous blow.

Based on the CAPWAP results the required damping values (J_c) of the Case Method were adjusted to obtain similar capacities. As shown in Figure 1, there was a significant variation in the values of J_c making it difficult to assess which value to select in the field. In addition, for the type of ground condition encountered at this site the J_c values were in general higher than 1.0, with more than 50% of the tests requiring J_c values of 1.7 or higher.

Two different approaches were adopted to obtain the iCAP results. The first consisted of running the analyses on the same blow as selected for the CAPWAP analyses and the second was obtained using the average of the iCAP results for the five blows before and five blows after the same selected CAWAP blow, including the selected blow, i.e., the average of eleven blow results, or less when less data were available.

Figures 2(a) and (b) to 5 (a) and (b) show the comparison of the pile capacities between the iCAP and CAPWAP and the relative differences between both results, respectively. Figure 2 shows the results for the Full iCAP analyses for the selected CAPWAP blows, while Figure 3 shows the same comparison using the average values. (i.e. from 11 blows). Similarly, Figures 4 and 5 show the results for the Quick iCAP for the selected CAPWAP blows and for the average values.

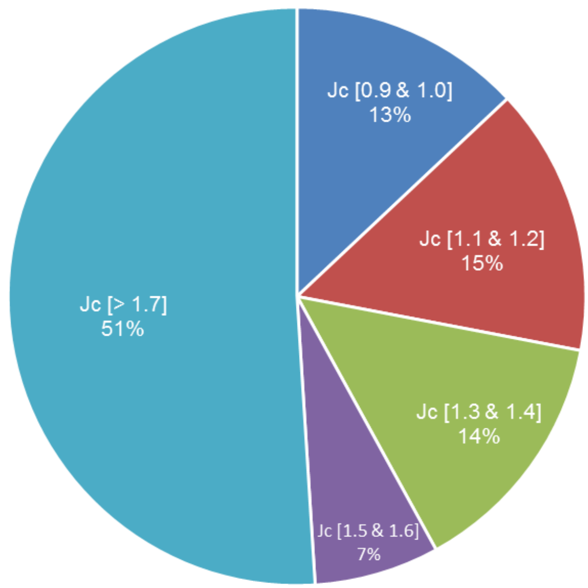


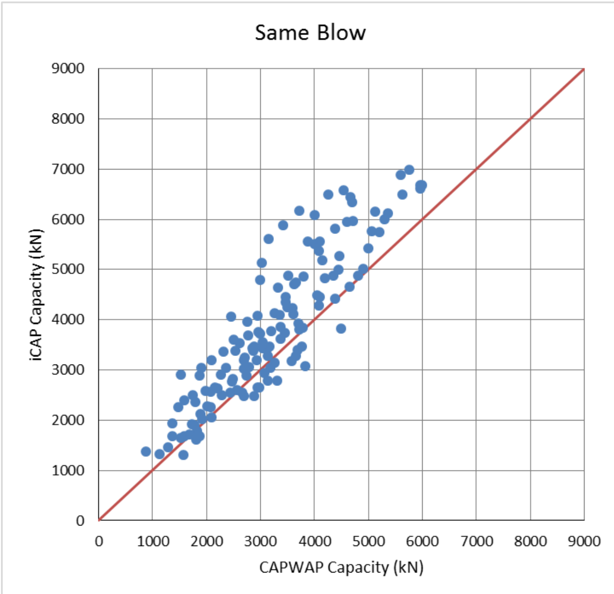
Figure 1. Case Method - variation of damping values (J_c).

4 DISCUSSION

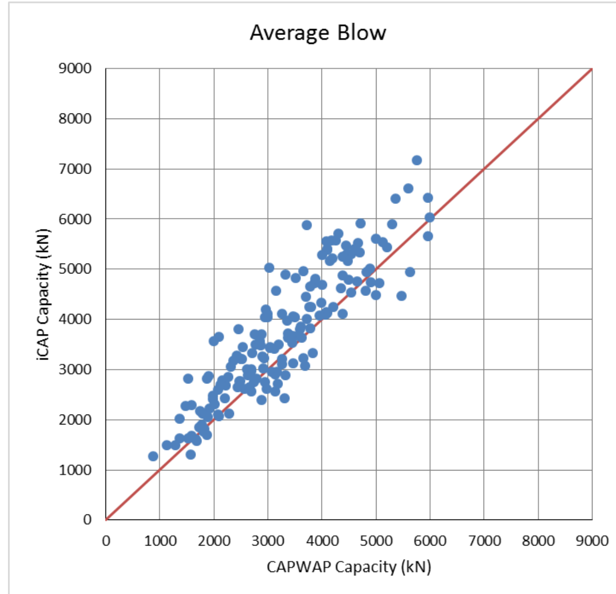
Inspection of the iCAP and CAPWAP results in Figures 2 to 5 indicate that the iCAP results tend to predict higher capacities in comparison to the CAPWAP results.

As shown in the above plots, the Full iCAP with the average of the adjacent blow results (i.e. the results of before and after the selected CAPWAP blow) provided the least data dispersion, with a mean of 14.7% above the CAPWAP results and a standard deviation of 19.5%. In comparison, the Quick iCAP results analysed on the same blows as analysed with CAPWAP, gave a mean value of 24.8% above the CAPWAP derived values and a standard deviation of 27.6%.

It could be argued that the CAPWAP analyses require significant interpretation and engineering judgment of the data to assess the pile capacity and hence may involve some conservatism in the reported pile capacities. Whereas, the iCAP results are generated automatically and hence do not involve such interpretations by the user.



(a)



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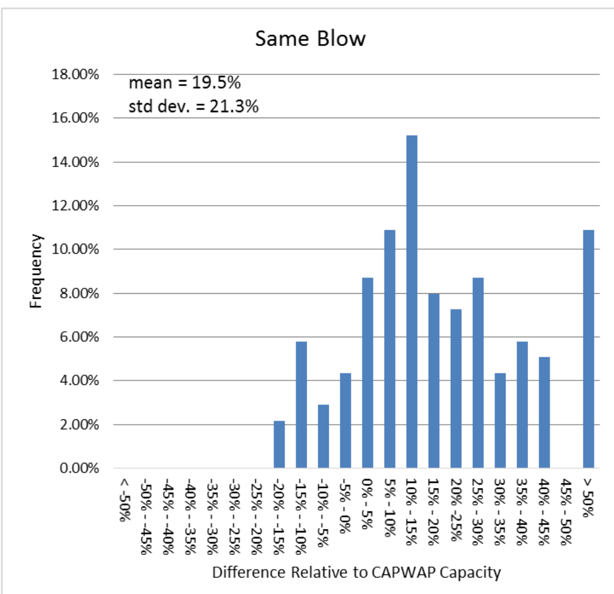

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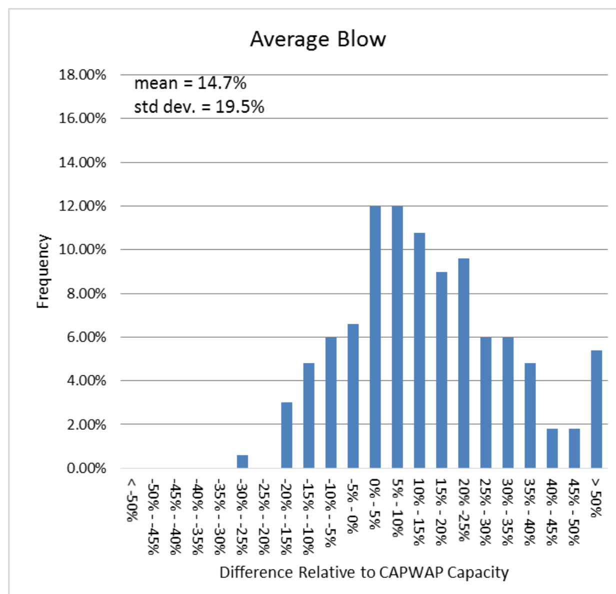
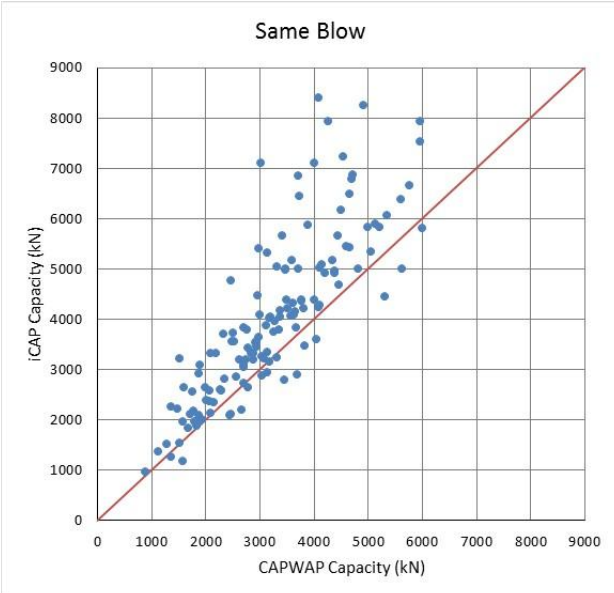


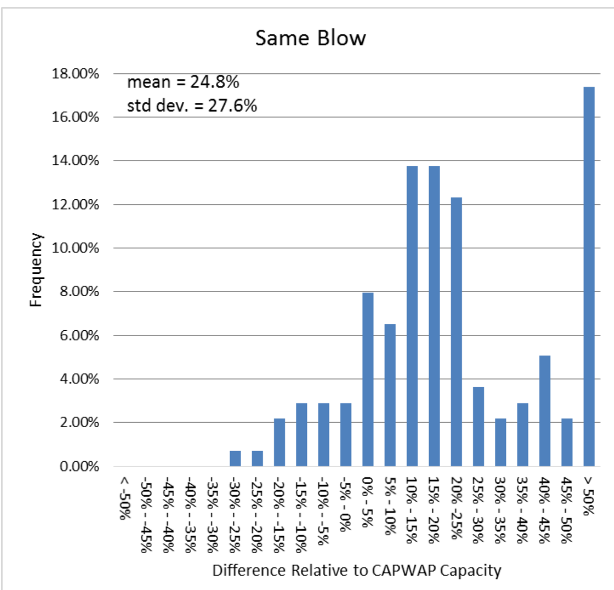
(b)

Figure 2. – a) Full iCAP (same blow) vs CAPWAP resistance. b) Frequency distribution of difference relative to CAPWAP result.

Figure 3. – a) Full iCAP (average) vs CAPWAP resistance. b) Frequency distribution of difference relative to CAPWAP result.

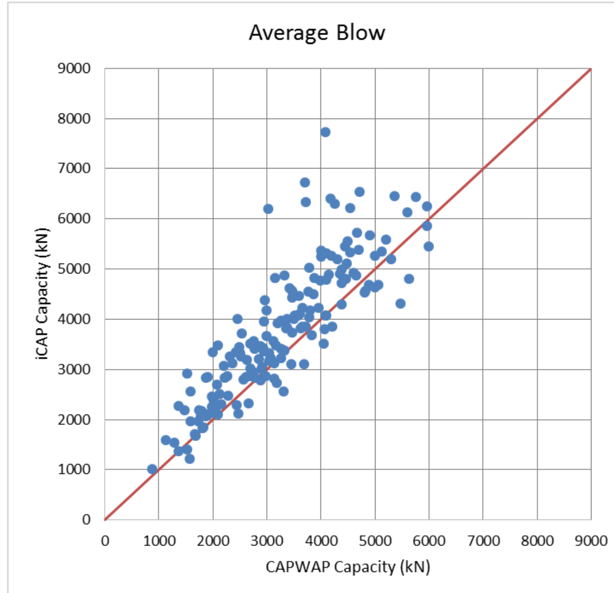


(a)



(b)

Figure 4. – a) Quick iCAP (same blow) vs CAPWAP resistance. b) Frequency distribution of difference relative to CAPWAP result.



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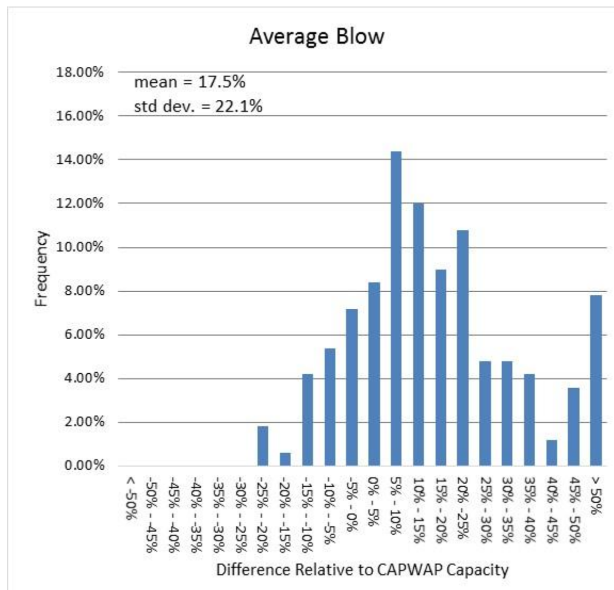

(b)

Figure 5. – a) Quick iCAP (average) vs CAPWAP resistance. b) Frequency distribution of difference relative to CAPWAP result.

In order to further assess the difference between the CAPWAP and iCAP results, reference was made to the results of three static load tests that were performed at this site on prototype piles prior to construction. These piles consisted of a 508 mm, 610 mm, and 762 mm diameter open ended pipe piles embedded at approximately 20 m depth. Results of these test piles are included in Figures 6, 7, and 8.

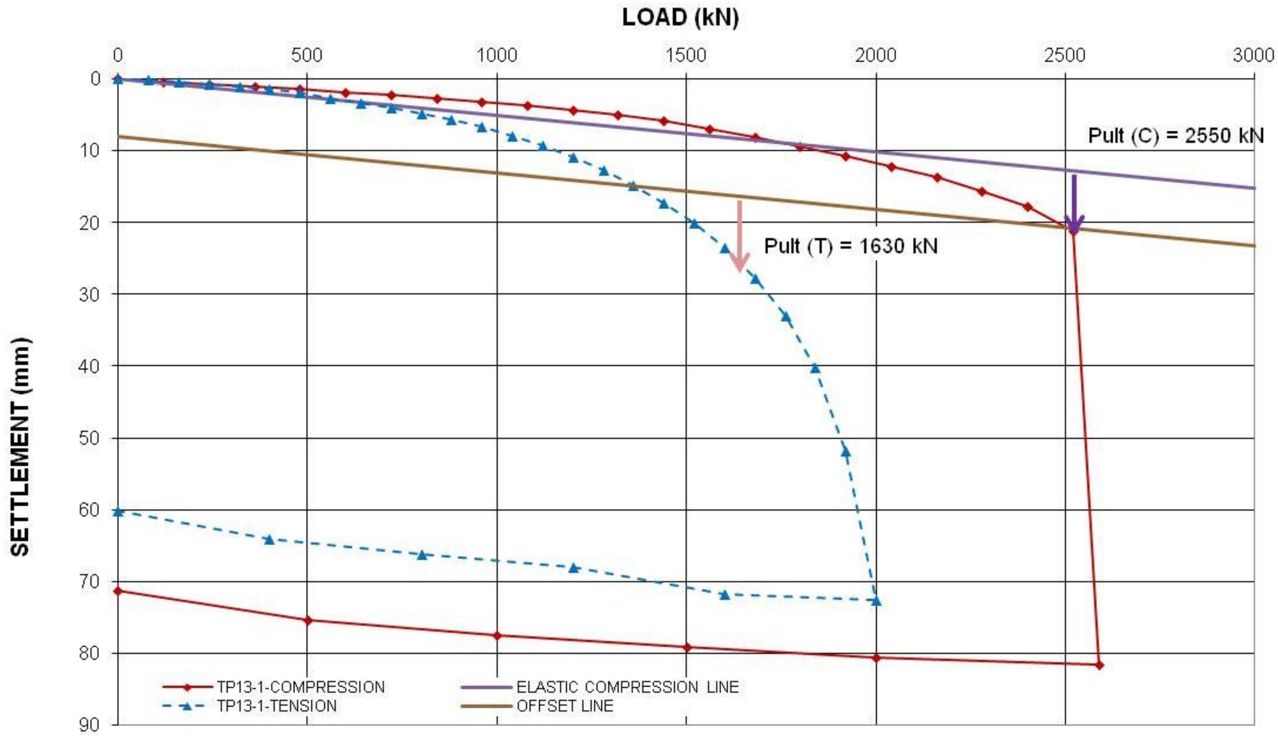

Figure 6. Static load test results of a 508 mm diameter open ended driven steel pipe pile embedded to 20 m.

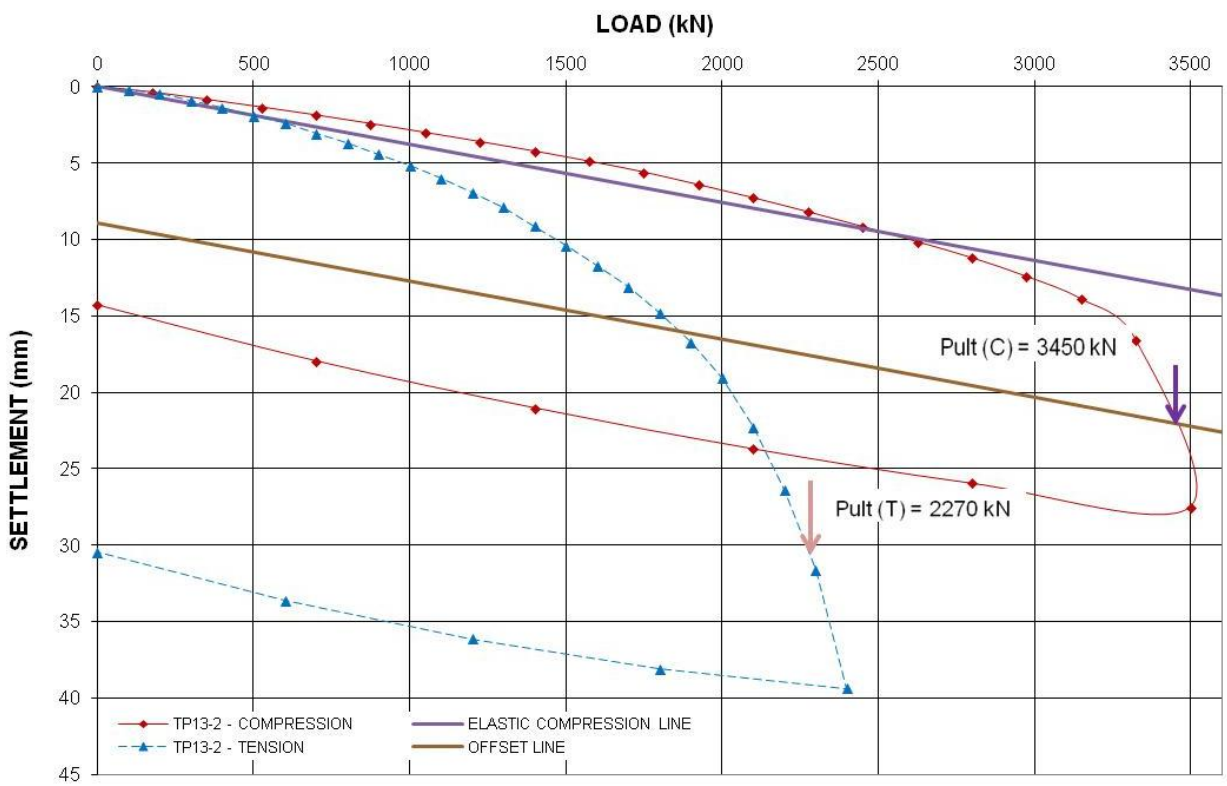

Figure 7. Static load test results of a 610 mm diameter open ended driven steel pipe pile embedded to 20 m.

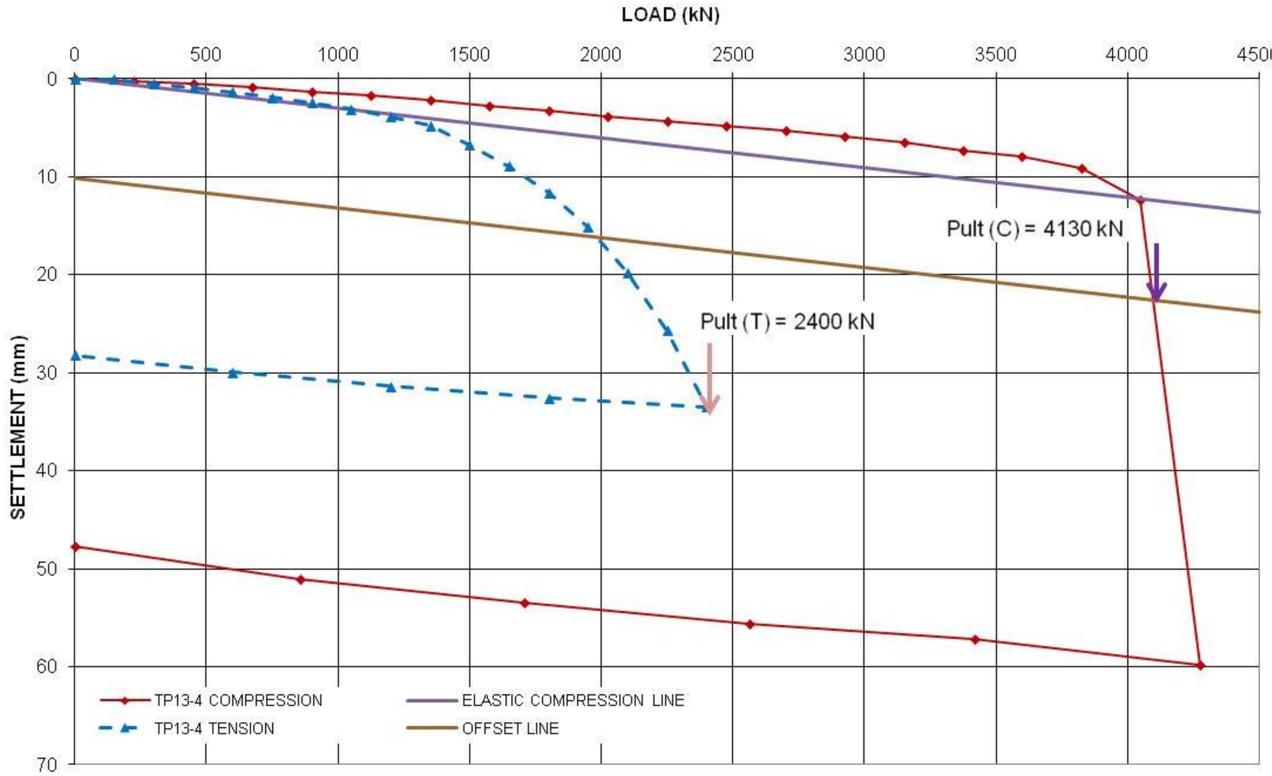

Figure 8. Static load test results of a 762 mm diameter open ended driven steel pipe pile embedded to 20 m.

PDA tests were also performed on the test piles at EOD and BOR in order to correlate the static and dynamic test results for future application of quality assurance testing during construction.

The difference between static load test capacity and CAPWAP interpreted capacity was -5% for the 508 mm diameter pile, +2% for the 610 mm diameter pile, and +18% for the 762 mm diameter pile, which is considered reasonable agreement of CAPWAP results and the static load results as shown in Likins and Rausche (2004).

Full iCAP analyses using average of blows before and after the selected blow was also carried out for these three piles. Table 1 provides a summary of the results from the static load test, CAPWAP and iCAP. The results in Table 1 show that the difference in interpreted capacities using full iCAP were +15%, -4%, and +14% higher than the static load test values for the 508 mm, 610 mm, and 762 mm diameter pile, respectively. The iCAP results indicate somewhat larger variation from the static pile capacity than the CAPWAP results, but still within reasonable range compared to the static load tests. It is noted that the two highest differences (+14% and +15%) occurred on the un-conservative side, which is consistent with the trend provided in Figure 3(a), suggesting that the iCAP results may tend to overestimate the pile capacities for this project site.

Nevertheless, if used with caution, and once more data and experience is gained with iCAP, it appears that with some site specific calibration, iCAP can provide a quick and useful preliminary estimation of the static pile capacity on site. However, the values should always be validated with proper CAPWAP analysis.

Table 1. Summary of pile capacity assessment using different methods.

Method	Days after installation	Capacity (kN)	Difference (%)
Pile 508 mm diameter			
Static load test	18	2550	--
PDA (CAPWAP)	34	2428	-5
Full iCAP	--	2920	+15
Pile 610 mm diameter			
Static load test	44	3450	--
PDA (CAPWAP)	12	3538	+2
Full iCAP	--	3319	-4
Pile 762 mm diameter			
Static load test	56	4130	--
PDA (CAPWAP)	17	4856	+18
Full iCAP	--	4709	+14

5 CONCLUSION

The use of the Case Method to evaluate the static pile capacity of dynamic load test on site is dependent on the selected soil damping constant, which can be highly variable even within the same site, and therefore, can be difficult to apply and may provide significant variation in results.

The iCAP program is an automated procedure that does not rely on the selection of a damping value and can provide quick estimation of the pile capacities. It is therefore a useful tool of assessing potential pile capacities on a timely basis to aid in decision making regarding acceptance of piles.

However, the iCAP results for the studied site, appear to give higher capacities on average than the CAPWAP capacities and should therefore be used with caution. It is critical to correlate the results of the iCAP with capacities derived from more rigorous CAPWAP analyses in order to gain proper understanding of the variations in capacity and allow the application of the iCAP results on a specific project.

ACKNOWLEDGEMENTS

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