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Forum Paper

Increase of CPT Cone Resistance in Sand due to Installation of Press-in Piles

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Abstract: A pile testing programme in Tuas Racetrack, South-west Singapore, involved installing 600-mm diameter 30 m long, closed-toe, spun piles by jacking (press-in system) through about 10 m thick loose hydraulic sand fill and 20 m of marine clay, sandy silt, and into weathered mudstone. Static cone penetrometers soundings, CPTU, were pushed both before and after the pile installation at each pile location and two distances away from the test pile. The post-test CPTU soundings showed that the press-in installation resulted in significant increase of cone resistance in the sand fill even at several pile diameters away from the piles. No similar effect occurred in the natural soils.

Keywords: Spun piles, CPTU sounding, strain gage instrumentation, installation effect

Introduction

When back-calculating results from static loading tests and correlating the results to the soil profile as established by an in-situ test, it is normally not expected that the pile installation would have affected the soil and, thus, the in-situ test results are still considered representative for the response of the test pile. Yet, it is known, for example, that driving piles in granular soil usually increases the soil density of sand, in particular, when several piles are driven in the vicinity of each other. It has not been considered that press-in piles, being installed by in essence static means, might also affect the soil density conditions.

N.B., when loading a pile, the interaction between the pile surface and the soil does not occur as a localized slip between the pile surface and the soil, but in a zone or band around the pile, where shear forces develop along with compression of the soil. The pile movement is the relative movement between the pile outer surface in reference to the zone boundary to the unaffected soil. A question is how thick that zone is. Measurements on piles near loaded piles (as in a static loading test) have shown that loading the test pile imposed "passive" movements on piles located several pile diameters away. Figure 1 shows results of measurements by Caputo and Viggiani (1984) and Lee and Xiao (2001) of movements of "load-free" bored piles (passive) constructed in volcanic sand at different distances (3 to 7 diameters) away from a pile (active) subjected to a static loading test. Passive movements were about 8 to 10% of active. However, this over-distance interference is not considered to have any effect on the evaluation of the test results.

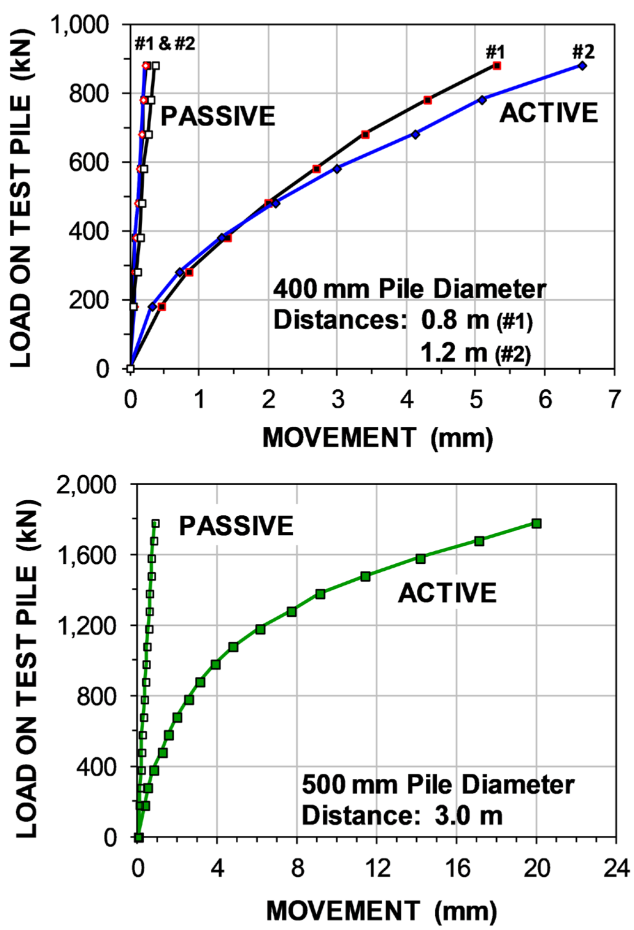

Figure 1. Movement of "passive piles" when a static loading test was performed on "active" pile (after Lee and Xiao, 2001)

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A series of CPT soundings before and after installation of three press-in piles in a 10-m sand layer above cohesive soil gave an opportunity to explore if the installation of the press-in piles would have caused any noticeable change in CPTU resistance near and away from the test pile location. This paper presents the results.

Geology and Soil Profile

The site was located in a reclaimed area in Tuas, South-west Singapore. The soil profile comprised a 10 to 12 m thick very loose, to loose, to medium dense sand fill overlying approximately 4 m of soft marine clay (Kalang formation) deposited on stiff to very stiff sandy clay above completely weathered sandstone/mudstone (Jurong Formation). The groundwater table was located at 3.7 m below the ground surface.

Three boreholes, BH-1, BH-2, and BH-3, about 8 to 15 m apart, were drilled a the test site and three test piles, and the test piles, Piles TP1, TP2, and TP3, were installed, one at each borehole center. Figure 2 shows the distributions of the SPT N-indices and of cone resistances measured at three CPTU soundings, CPT-1, CPT-2, and CPT-3, pushed at 600 mm distance from the center of each borehole, respectively, and soil layering charts determined by applying three SBT methods to the TP1 CPT-1 sounding.

The sand fill was dredged sand placed hydraulically without any particular compaction effort. Thus, it can be assumed that it is normally consolidated, at least below the groundwater table with some incidental compaction due to the travel of construction equipment on the finished surface.

Test Arrangement and Testing Programme

The three boreholes (BH1, BH2, BH3), were drilled on October 9, 2009, at the site followed two weeks later by pushing ten CPTU soundings (TP1 CPT-1 through TP1 CPT-4 at TP1, TP2 CPT-1 through TP2 CPT-4 at TP2, and TP3 CPT-1 through TP3 CPT-4 at TP3). The CPTU soundings were pushed at distances of 0.6, 0.9, and 1.5 m away from the center of the borehole and to depths ranging from 11 m through 30 m. An extra sounding, CPT-4, was pushed 3,000 mm out from TP1. On October 23, 22, 24, three test piles (600 mm diameter, about 30 m long, closed-toe, spun piles) were installed by press-in procedure at the precise borehole locations to depths of 28.7 m, 29.9 m, and 31.7 m respectively. A repeat series of CPTU soundings was then pushed (TP1 CPT-1a through TP1 CPT-4a at TP1, TP2 CPT-1a through TP2 CPT-4a at TP2, and TP3 CPT-1a through TP3 CPT-4a at TP3). The records of TP2 CPT-3 were inconsistent and were therefore discarded. No new boreholes were drilled after the pile installation. Figure 3

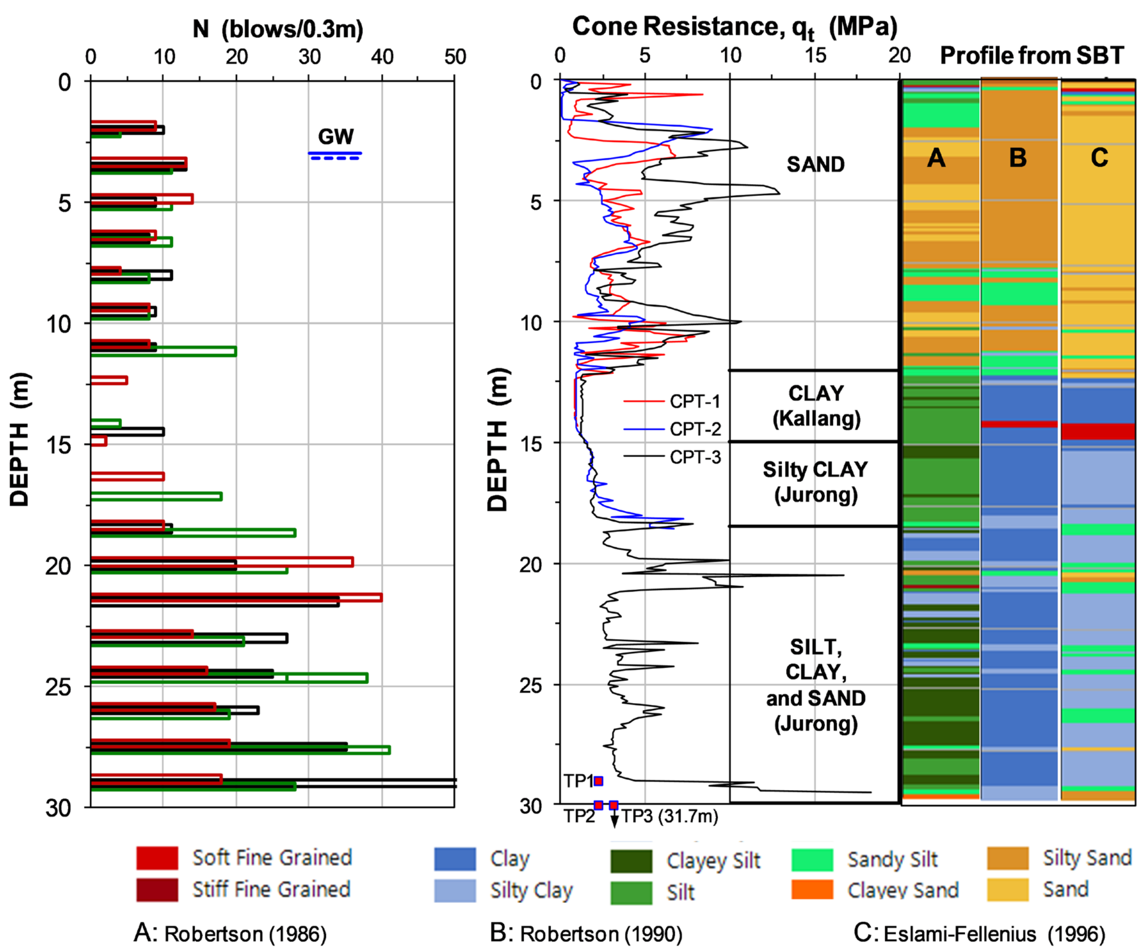

Figure 2. Soil profile and distribution of SPT N-indices and CPTU cone resistances, q_t, with SBT soil layering charts

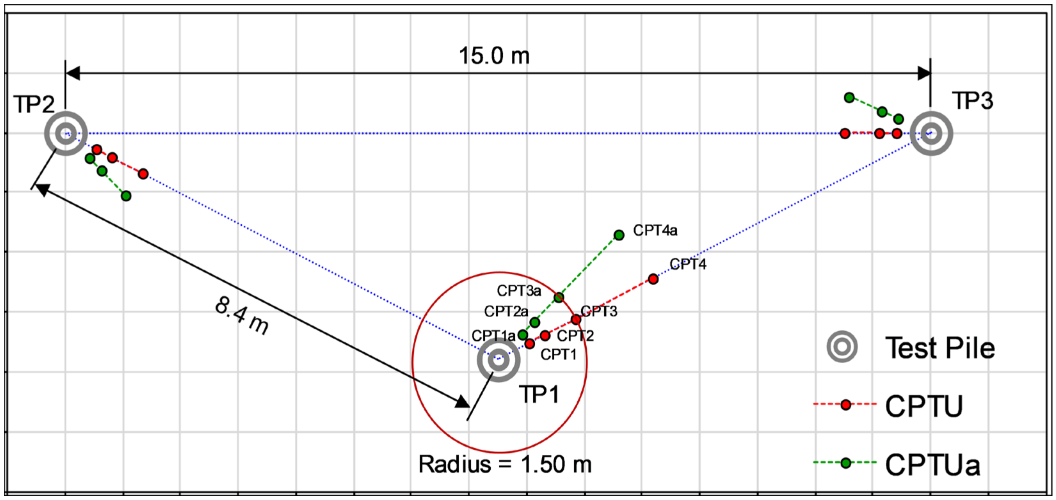

Figure 3. Plan view of locations of test piles and in-situ tests

shows the location of the test piles and the CPTU soundings. The pile size and CPT locations are to scale.

In mid-November, static loading tests were carried out on the test piles. The test results of the static tests were reported by Fellenius (2015).

Press-In Force

The distributions of press-in force recorded for the three test piles is compiled in Figure 4, showing the response to be quite similar for the piles. The press-in force increased rapidly above the groundwater table (3.7 m). It then became constant in the sand and underlying clay to about 20 m depth, from where it increased gradually until the pile toe encountered the coarse-grained Jurong formation.

CPTU Records

Figure 5 compiles the CPTU diagrams for the three test pile locations (TP1, TP-2, and TP-3) limited to the results to 12 m depth (the sand fill and the first 2 m of the clay below). All records of the TP2 CPT-3 sounding were erroneous (reasons are unknown) and are excluded from the figure. The U2-values of TP3 CPT-3 were erratic and have been excluded.

The values of cone resistance, q_t, and sleeve resistance, R_f, differ somewhat between the soundings with the q_t-values for CPT-1 being considerably smaller than for CPT-2, CPT-3, and CPT-4 soundings, which were a mere 600, 900, and 2,400 mm away. Although the prior drilling of the borehole 600 mm away from the CPT-1 locations could have had some effect, the differences are less likely due to differences in soil density of the fairly homogenous sand and more to small variations in the measuring precision.

The resistance ratio, R_f, and the TP-1 and TP2 pore pressure, U2, diagrams delineate quite clearly the boundary between the sand fill and the natural clay soil at about 10 m depth, as well as the 3.7-m depth to the groundwater table.

Figure 6 compiles the CPTU-soundings for the tests pushed “after” the installation of the press-in piles. Overall, the records are consistent, showing a spread between values

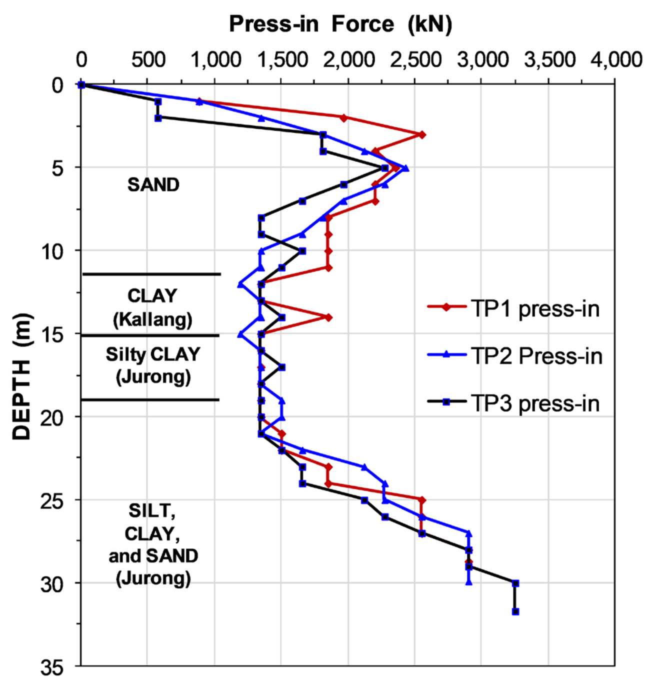

Figure 4. Distribution of press-in forces

similar to that of the “before” tests. The spread of values make it difficult to discern a trend. Moreover, the number of CPT-soundings being limited at each test pile location limits the weight of a statistical compilation.

Nevertheless, as is shown in Figure 7, a comparison of the average of the three sounding at the site “before” press-in to the average of the three “after” press-in at the distances of 0.6, 0.9, and 1.5 mm away from each of the test piles, shows that the press-in installation has densified the sand and with a trend of decreasing cone resistance, q_t, with distance away, but an increase is still present at the 1.5 m distance.

As to sleeve resistance, the diagrams suggest that the sleeve resistance measured in the sand by at the “after” press-in soundings is about smaller than at the “before” soundings.

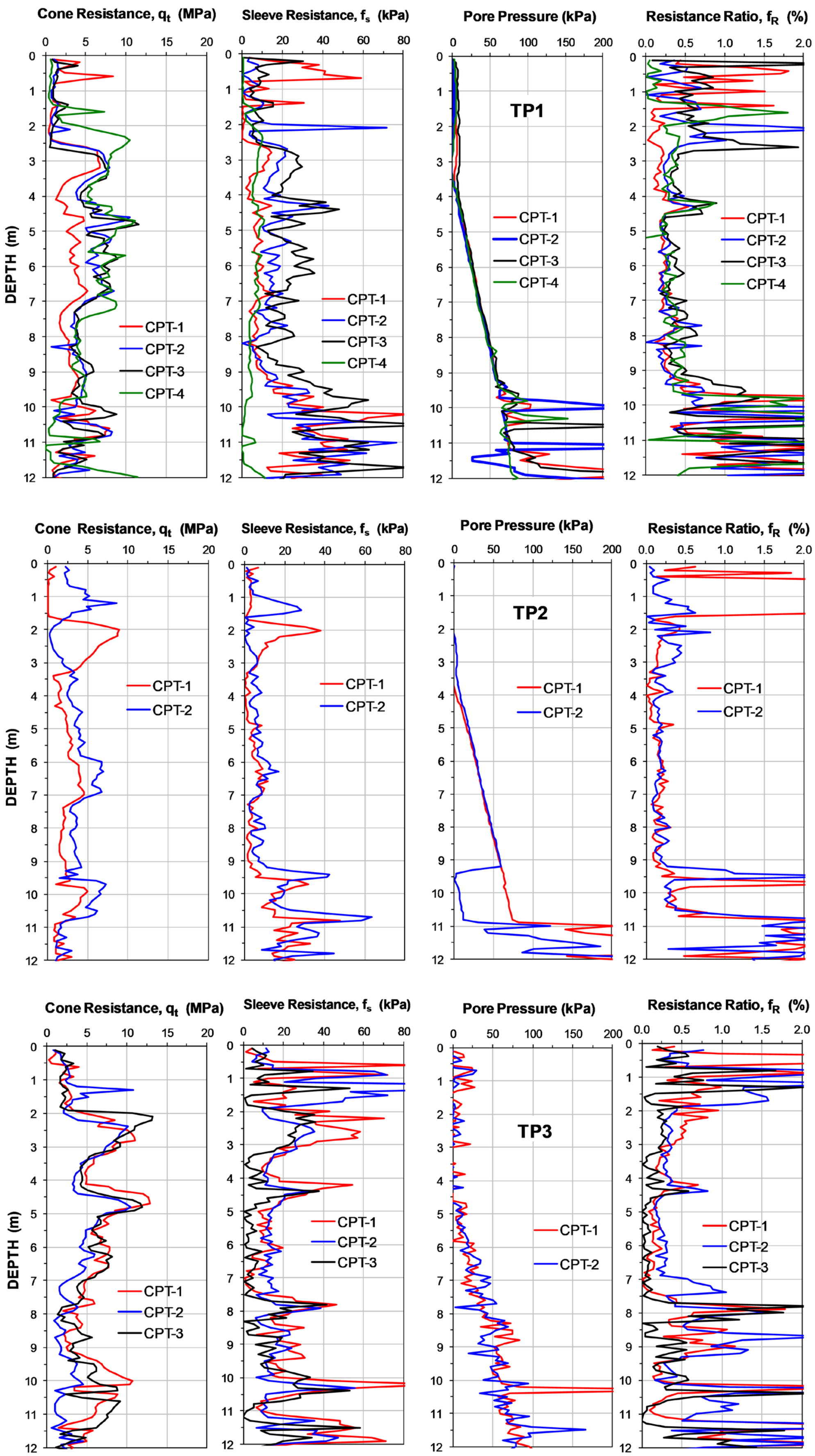

Figure 5. CPT diagram from soundings before installing the press-in piles

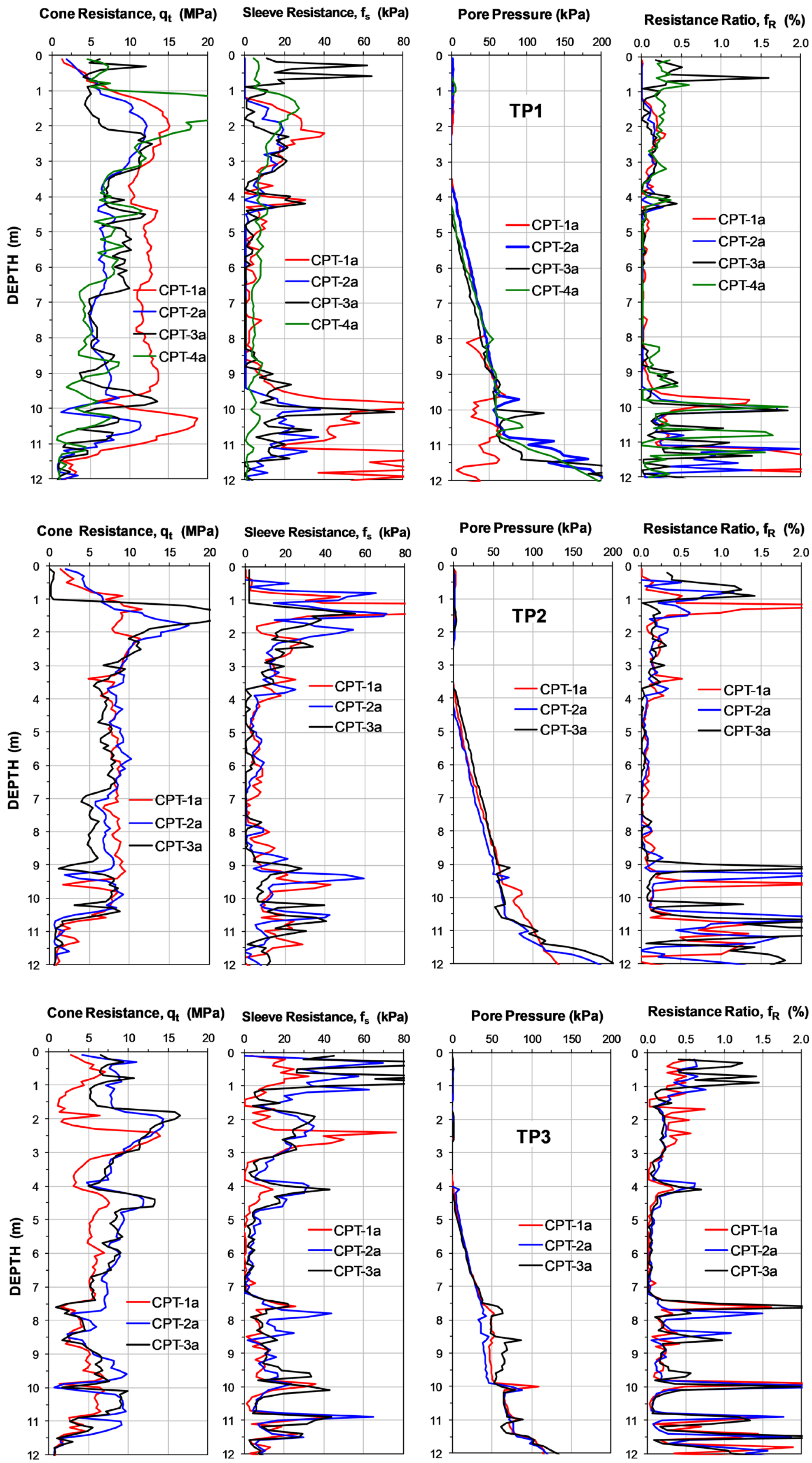

Figure 6. CPT diagram from soundings after installing the press-in piles

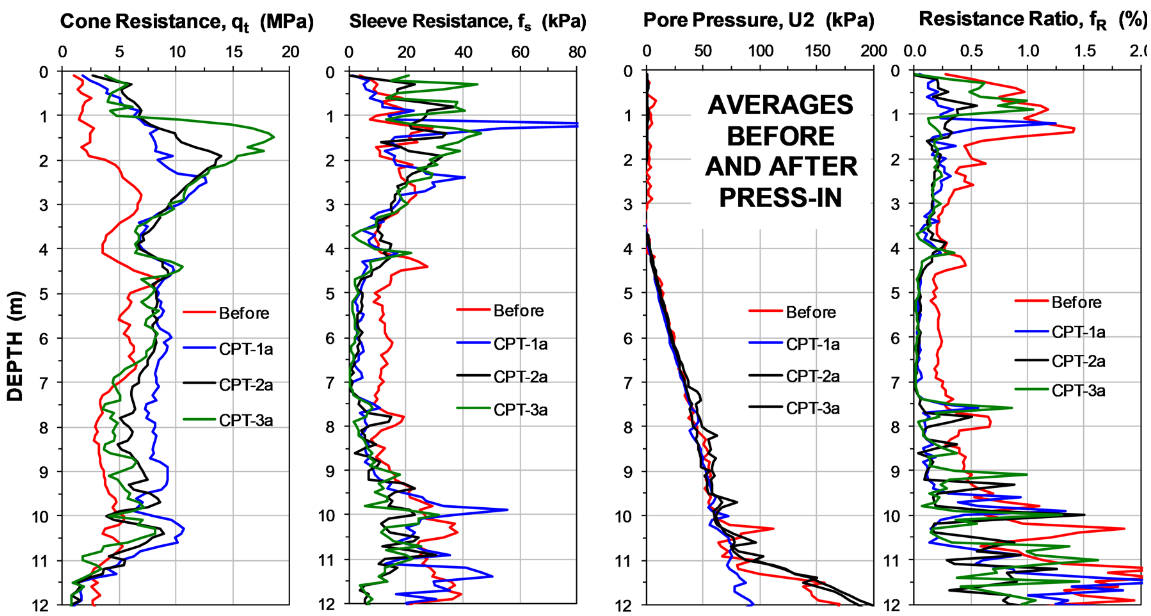

Figure 7. CPT diagrams from above 12 m depth before and after installing the press-in piles with averages of "after" soundings at each of the three distances away from the center of the test piles (0.6, 0.9, and 1.5 m, respectively, see Figure 3)

If taken at face value, the data would suggest that the resistance ratio, R_f, would have reduced by a factor of ten.

Figure 8 expands Figure 7 inasmuch that the depth scale (the ordinate) has been expanded to 30 m to include the full depth of all CPT soundings. To include the larger values at depth, the abscissa scales were expanded, too. First to note is that sleeve resistances below 12 m depth, although having quite a spread, are about the same "before" as "after" the pile installation. As to the cone resistance, the diagrams show that in the natural soils below the sand fill no effect of the press-in pile installation can be seen in the "before" and "after" CPT records. The three CPT-1a soundings at half a pile diameter, 300 mm, away from the pile surface all show a continued approximate absence of pore-pressure increase in pushing the cone, as opposed to the pore pressures measured further away. This could be a result of the press-in installation having moved sand downward for a few metre creating an at least 300 mm thick pervious layer nearest the pile in the upper 5 m of the clay layer.

Comments and Conclusions

Although twenty CPT soundings over the small area—ten "before" and ten "after" the installation of the press-in piles—may seem many, the number is not sufficient for any

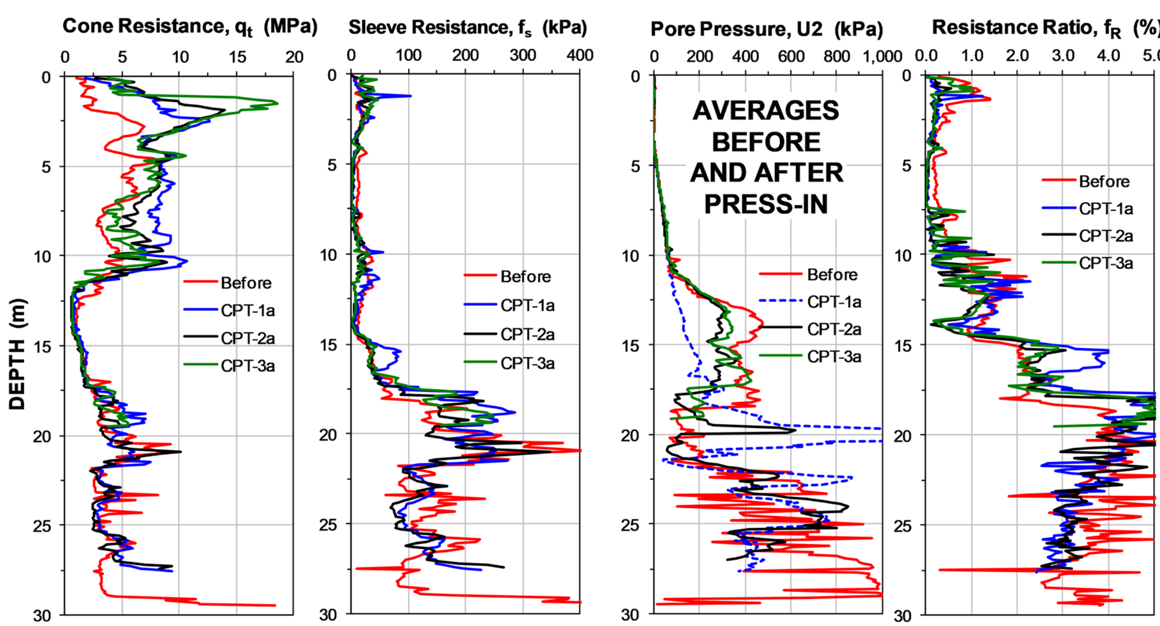

Figure 8. CPT diagrams from full depth before and after installing the press-in piles with averages of "after" soundings are at each of the three distances away from the test piles

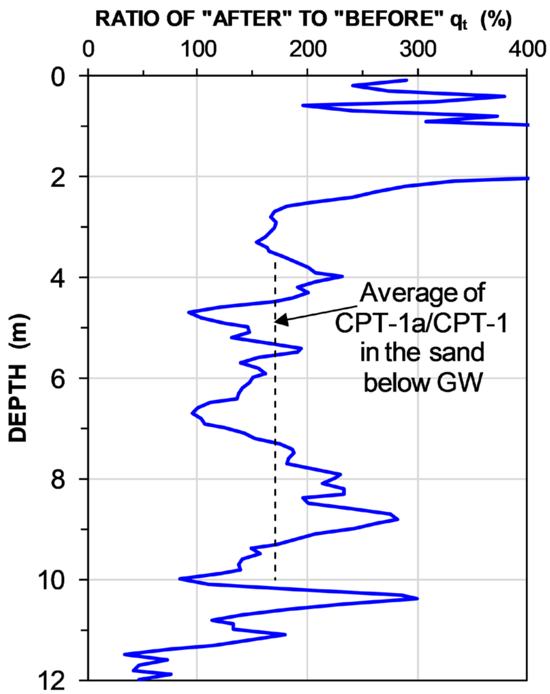

Figure 9. Distribution of the ratio of cone resistance determined "after" and "before".

detailed statistical analysis. Moreover, the "before" CPT measurements of cone resistance and sleeve resistance show a spread of values and there is no reason to expect that the "after" soundings would have any smaller spread. Therefore, some of the observed increase in cone resistance and sleeve resistance may be coincidental, only. Adding a few additional CPT soundings might well have given different averages—smaller or larger. Qualitatively, however, the records show that the installation of the single press-in piles significantly increased the density of the sand fill as registered by the cone resistance. Figure 9 shows that the average increase in cone resistance recorded in CPT-1 and CPT-1a amounted to a ratio of about 180% between the "after" to the "before" resistances.

The various methods for estimating pile response from a CPT sounding all correlate more or less linearly to the cone resistance. This raises the practical question of accuracy of back-calculated responses correlated to CPT soundings and other in-situ methods for estimating the response of a pile to a static load: usually such records are obtained before the pile installation (though, sometimes, e.g., for forensic purpose, they may be obtained afterward). Some calculation methods include very precise constants in the CPT-based calculation of the pile response. Much of that precision is obviously not justified.

It is reasonable to expect that had the pile been driven instead of press-in piles, an even more pronounced increase of cone resistance in the, originally, loose sand might have resulted. While the observed effect raises little concern, it does qualify applying in-situ tests to analysis of pile response. It would be of interest to see results of similar measurements on installation effect—for press-in piles as well as for other types of piles and in different types of soil.

Acknowledgements

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