Pile capacity in calcareous high plasticity clay

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ABSTRACT: In case of a small subset of the hundreds of static pile load tests carried out in the past few years we noticed that the standard CPT based calculation tend to overestimate the bearing capacity of the CFA piles. In these cases, high plasticity calcareous clay was present in the soil profile. Besides the overestimation of the bearing capacities a uniquely brittle behaviour was also common in these tests. An initial shaft resistance dominated stiff behaviour to a reasonably high resistance was followed by a sudden failure as if the increase of the toe resistance could not exceed the unusual drop of the shaft resistance. Continuously increasing or accelerating settlements were recorded at constant load levels.
A database was compiled from load test results for piles installed in various highway projects in Hungary showing the abovementioned phenomena. Data of CPT soundings and borehole records were processed and correlated with the pile load test results, to allow a deeper insight into the performance of piles.

Keywords: pile capacity; calcareous clay; cementation

1. Introduction

The most pronounced difference between the expected and experienced behaviour of piles was observed on sites where the soil profiles included high plasticity calcareous clay. The analysed piles showed an unusual phenomenon, their resistance dropped significantly presumably following the exhaustion of the shaft resistance. This process taken place alongside with continuously increasing settlements at constant load levels, which resulted in a sudden failure. The effect of calcareous clay on the bearing capacity of the piles is different in each case. While in some cases the measured capacity was only 70-80% of capacity calculated on the bases of CPT results, in other cases the difference was negligible. Apparently, the bearing capacities of the piles in calcareous clay soil environment cannot be calculated safely and statistically well-founded based on the CPT results. The brittle failure characterizing these piles together with the lower than usual reliability of the otherwise highly reliable CPT based dimensioning increases the associated risks.

2. The observed behaviour of the piles

2.1. General description

In the past 4-5 years hundreds of static pile load tests were carried out by our team throughout Hungary. In the cases when calcareous clay -especially if it was associated with high plasticity- was present in the soil profile the behaviour of the pile was significantly different compared to piles in non-calcareous clayey soil environment.

Presumably after the shaft resistance exhausted, the rate of settlement started to increase quickly sometimes to values only limited by the maximum rate of advance of the hydraulic loading system. It resulted in a sudden failure in most cases at lower than calculated resistance levels. The experienced behaviour could be interpreted as if the piles had no toe resistance, especially as the difference between the calculated and the measured resistance approximately agreed with the calculated toe resistance. But the results of the soil tests, of the load tests and of the pile driving reports did not explain the missing resistance on the pile toe. That led to assumption of the decreasing shaft resistance.

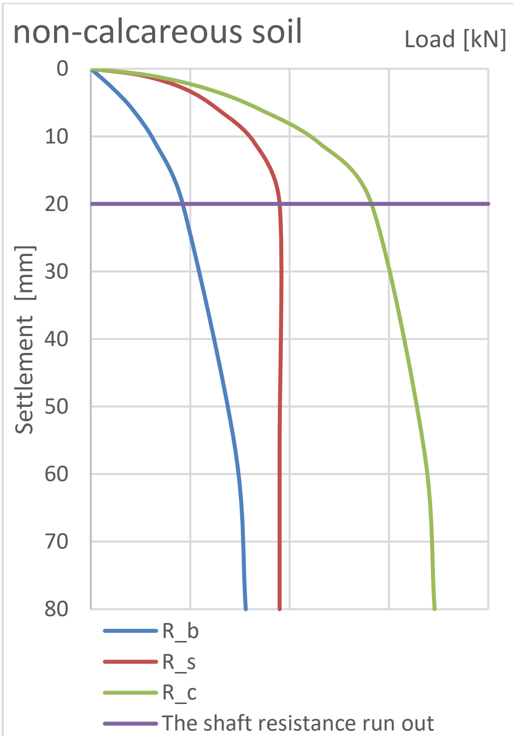

Figure 1. Generalized load-settlement curves of piles in non-calcareous soils

In non-calcareous soil environments, the load-settlement curves for shaft resistance component show nearly constant values once the shaft resistance is fully mobilized. This together with the increasing toe resistance, yields to an increasing total pile resistance as shown in Fig. 1. In contrast, when the soil profiles include calcareous clay layers, it may happen that the reduction of the shaft resistance reaches or exceeds the increment of the toe resistance, resulting in a constant or even decreasing total resistance.

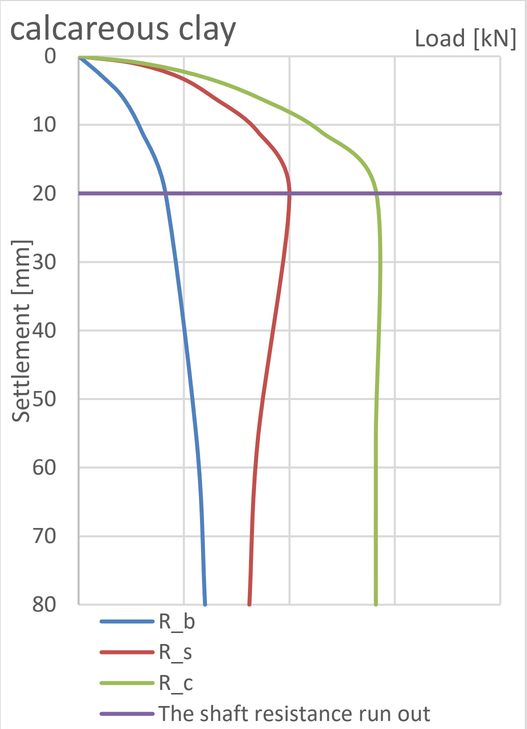

Figure 2. Load-settlement curves in calcareous clay soil environment

2.2. The analysed piles and load test results

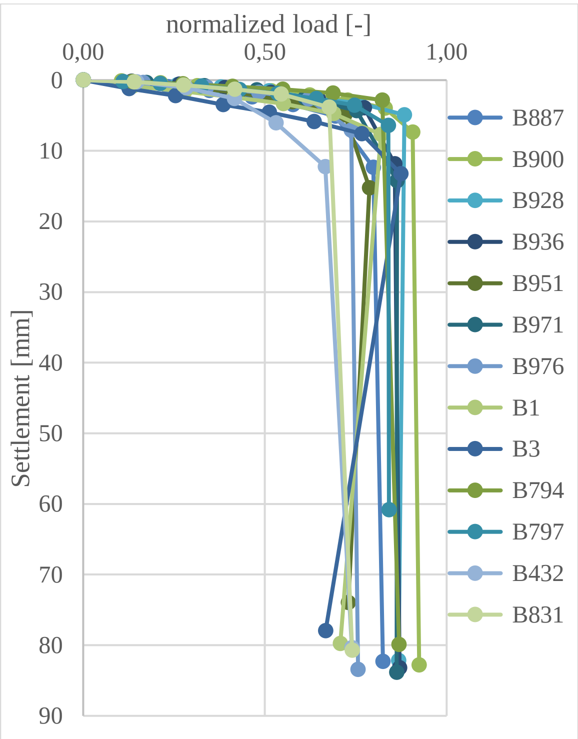

Figure 3. Normalized load-settlements curves of the pile load tests

Altogether 13 static pile load tests that shown the aforementioned behaviour were analysed. The results were from tests carried out in four different regions of Hungary. The soil profiles were similar at these sites in the following respects:

- The pile toe level was in cohesive layers,
- clayey soils were dominant along the pile, sometimes with relative thin coarse-grained inlays,
- the results of the soil classification based on the CPT sounding shown major differences compared to the lab identification results,
- the clayey layers were identified according to Robertson (1986) as clayey silt / silty clay in the most cases, and occasionally as sandy silt / silty sand.

The bearing capacities were calculated according to Szepesházi (2011). In his thesis Szepesházi suggested slight modifications to the formula suggested in Eurocode 7.2 and provided technological constants more relevant for piles made in Hungary based on the back analysis of about 100 high quality pile load tests carried out within the country. His method is widely used in the Hungarian pile design practice and since its introduction it proved to provide very accurate predictions of bearing capacities of piles in general soil profiles.

The shaft- to toe resistance ratio was about 7:3 – 8:2 in case of the piles of the current investigation, the measured resistances were approximately 20 % lower than the calculated values as shown by the normalized load-settlement curves in Fig. 3. The settlement when the shaft resistance exhausted was between 3 and 15 mm. This is less than the typical values of 0,02-0,03*D. The trend of the curves are very similar to each other. They are all close to vertical after the shaft resistance had no further reserves.

3. The calcareous high plasticity clay

Clearly the presence of calcareous clay in the soil profile has an undoubted effect on the bearing capacity of the piles. In this section a collection of observations that may lead to the experienced behaviour are provided.

3.1. Misleading identification based on the CPT

The results of the CPT soundings were analysed. The friction ratio (R_f) in these clayey layers is around 3, it shows a difference compared to the clays (the typical value: 4). The reason of this difference is that the recorded cone resistance (q_c) is higher because of the cementation in the calcareous clay. The higher than typical cone resistance in itself also pushes the points upwards in the Robertson chart, away from the clay segment, towards soils with considerable amount of coarser fraction. The cementation results in larger strength (real cohesion), which will disappear at small strains. On the other hand, the measured sleeve friction (f_s) is correlated with the lower residual value of the shear strength, therefore these q_c and f_s values result in smaller friction ratio. This and the high cone resistance together explain also the previously described differences in the soil classification.

3.2. Shear box tests

To confirm the decreasing shear strength that may lead to decreasing shaft resistance shear box tests were carried out. The behaviour of the pile-soil interface was analysed by shearing heterogenous blocks made of concrete cast over calcareous clay samples in a mould of the same size as the shear box following a curing time of 20 days.

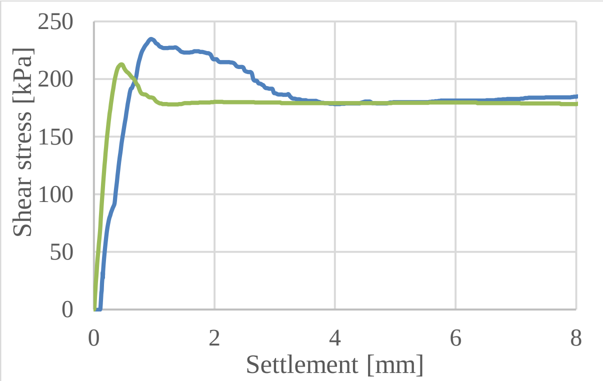

Figure 4. The shear box test results

From peak to residual the drop of the shear strength is about 20 %, this value is about identical with the assumed reduction of the shaft resistance experienced in the pile load tests (on average 25 %). This finding seems to support our hypothesis about the characteristics of the displacement - shaft resistance function. For the tests reconstructed samples from disturbed material taken from the CFA spiral used. The sample was taken when the structural piles were constructed at a site where we have seen the behaviour discussed.

3.3. Analysis of correlation between the soil parameters and the observed behaviour

It was hoped that by differentiating between sites where the behaviour was observed and those where not simple suggestion can be provided to help future designs. For the differentiation, 4 parameters of the clayey layers were collected from sites where the phenomenon was observed and from those where despite the similar soil environment, pile geometry etc. no brittle failure was observed. The parameters involved in the investigation were the plasticity index, the consistency index, the cone resistance from the CPT tests and the soil behaviour index. These come from the clayey layers, which presumably seeded the observed behaviour of the piles and in case of the control group from the representative clayey soil of the profile.

It was concluded that based on the current dataset and picking a single reference soil in the profile (however grounded the selection of layer seems) neither combination of the above parameters can split the piles into two easily distinguishable groups, susceptible and not susceptible to brittle failure and underestimation of the bearing capacity. See Fig. 5.

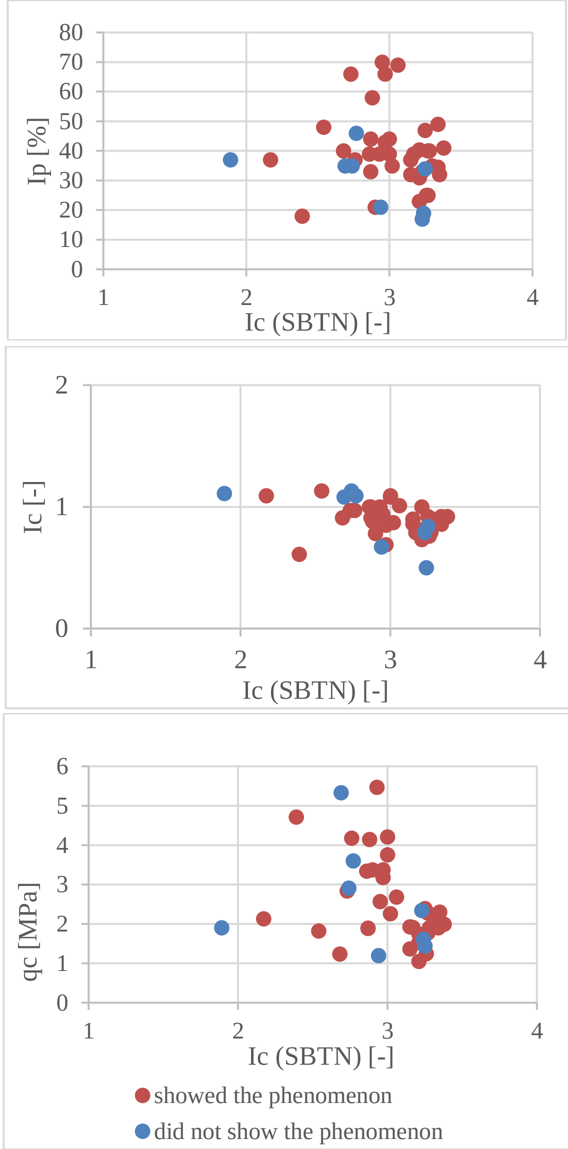

Figure 5. The analysed parameters

4. Associated design methods

The measured resistances were only 80 % of the calculated values. This difference is approximately equal to the toe resistance. So, the first method of considering the described phenomenon in the early phase of the design is to neglect of the toe resistance.

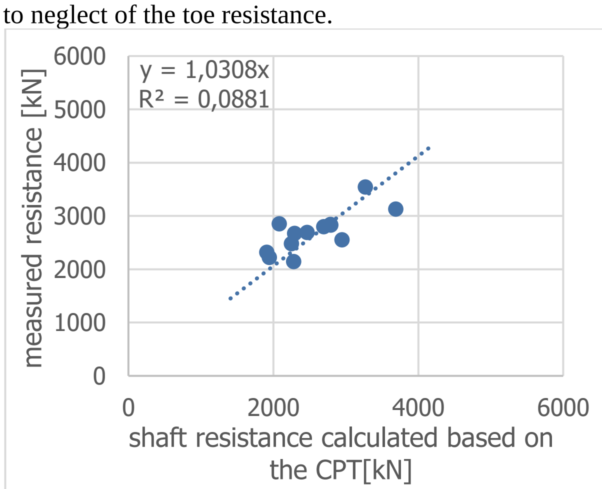

Figure 6. The correlation of measured resistance and calculated shaft resistance

This method in the light of the current dataset give a good agreement, but this estimation can yield to conservative estimation of the bearing capacity in case of larger toe resistances. In addition, this method does not represent the physical reality therefore despite the currently good agreement e.g. for piles with different dimensions it may fail to provide reasonable predictions.

The other way is the reduction of the calculated resistance with 20%, which proceed from the pile test results. Considering this as a calibration of the results it feels to be somewhat more reliable than method 1. Although the dataset is limited which reduces the reliability on the positive side it must be mentioned that the elements of the datasets belong to different locations several hundred kilometres apart.

The third possibility for taking into account this special pile behaviour is the reduction of the calculated shaft resistance according to the correlation of the unit shaft resistance and the reduction of the shaft resistance (Fig. 7.)

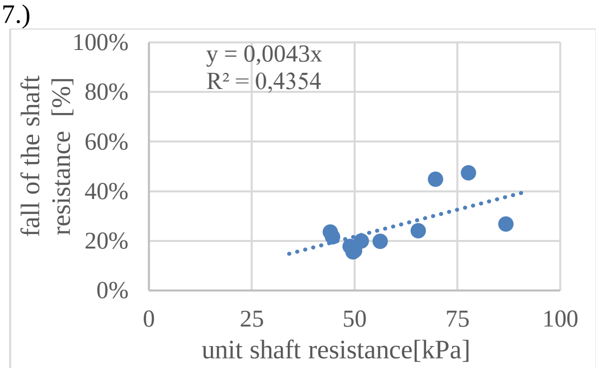

Figure 7. The correlation of the unit shaft resistance and the fall of the shaft resistance

The reduction of the shaft resistance is proportional to the unit shaft resistance, for example by the unit shaft resistance of 50 kPa the expected fall is about 22 %, in the case of 70 kPa is the fall about 30 %. This correlation is adaptable to an estimation in the early phase of the design.

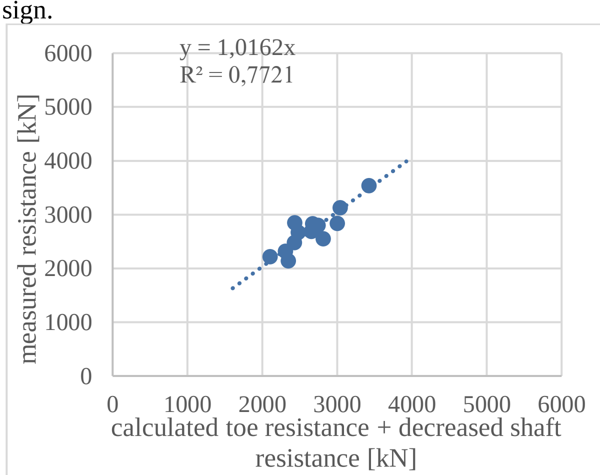

Figure 8. The correlation of measured resistance and with decreased shaft resistance calculated resistance

5. Conclusions

The results of the pile load tests draw attention to the unusual behaviour of piles built in calcareous clay soil environment. The described phenomenon was experienced throughout Hungary, it cannot be regarded as a local problem. It was found that when certain features of the soil profile are revealed by the soil investigation, such as significantly different CPT and lab identification, presence of high plasticity and calcareous clay in the profile special care is required when dimensioning piles. The investigations so far could not pinpoint a single parameter or pair of parameters that would allow a simplified and automatized decision making whether any special attention is required or not. In this respect the search for parameters and data filtering methods is still in progress. In the paper we proposed a hypothesis that the behaviour is associated with a major post failure reduction of the shaft resistance. The data so far seem to support this hypothesis however for certainty special pile load tests including measurement of force distribution within the pile should be carried out. Based on the current data available crude empirical design principles were presented, to be used especially until more sophisticated and integrated design methods become available. Leaving the presented effect out of consideration can result in additional costs, and increased risks, therefore it must be handled, even if only by using one of the proposed rough methods.

References

[1] Fellenius, B. H., Eslami, A.: Soil profile interpreted from CPTu data, In: „Year 2000 Geotechnics" Geotechnical Engineering Conference, Asian Institute of Technology, Bangkok, Thailand, November 27 - 30, 2000, 18 p.

[2] Szepesházi, R.: Dimensioning of piles according to Eurocode 7, PhD thesis, University of Miskolc 2011

[3] Szepesházi, R.: Geotechnical design based on Eurocode 7 and the associated European geotechnical standards, Business Média Magyarország, Budaörs, 2008