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ENERGY AND ENVIRONMENTAL LOAD REDUCTION, OPTIMIZATION ON PILE FOUNDATION DESIGN

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Abstract: *Design methods must also be improved in order to reduce energy costs and environmental impact. When designing pile foundations, the costs and environmental impact of construction are far from being irrelevant.*
At present, the most widely accepted method for determining the load capacity is the pile load test, which is considered the most realistic result, and therefore great emphasis should be placed on ensuring that these are evaluated as effectively as possible. By replacing the pile load test, its environmental impact and cost could be avoided. The aim of our research is to estimate a mathematical function that, from the wide range of soil physical and/or mechanical parameters, gives a formula that can be used to plot the curve without the need to produce a pile load test. By showing the relationship between different soil parameters and load capacities. In order for this to be possible later with a new theory, we examined the feasibility of this by evaluating the results of several measurements.
Climate change will also bring a transformation in the course of planning, because there may be changes in the load capacity on the soil and the use of materials. Soil composition and structure will also be affected by warming. The environmental impact of building materials and increased costs demands also bring about changes in the design of pile foundations.

Keywords: *ultimate pile bearing capacity, curve, analysis, pile load test, comparison*

INTRODUCTION

The most accurate pile load capacity state estimate is the fracture pile load test, from which is determined the pile load test curve. The very costly pile load test is produced by loading the test piles in steps, waiting for them to consolidate in settlement.

It is difficult to carry out the pile load test until fracture, which is why these curves must be extended later.

Difficulty in the research is that not only the parameters of the prepared piles, but also the soil and groundwater environment play a role in their behaviour under load. There are even quite extraordinary soil types, but for now let's look at soils with average properties. [1]

We investigated as a research objective how a pile load test curve can be used and how its results can be calculated more accurately/easily. We want to compare our fitting method, previously function fitting methods and some computational methods that use CPT probe data.

Accurate extension or estimation of the pile load test curves may allow for a more accurate determination of the ultimate load capacity and its optimum utilisation, which is more sustainable or allows for a settlement-tuned design, which also helps in design practice.

1. Pile bearing capacity

The calculation of the bearing capacity of deep foundations and especially, of pile foundations, was developed from the calculation of the bearing capacity of shallow foundations, but a very important difference between the two is that, piles transfer the resulting load to the soil as a double combination at the base and on the shaft surface.

The relationship is not a constant ratio, but also varies with increasing load, as Professor Kézdi has shown. [2]

In general, the sum of the base resistance (R_b) and the shaft resistance (R_s) gives the pile bearing capacity (R_c).

$$R_c=R_b+R_s \quad (1)$$

The pile load test curves are generated using a function of soil physical parameters with the aim of making them feasible without to make a pile load test. The relationship of the different parameters are not really clear and the result of the calculation is not enough accurate. The aim of the research is how the pile bearing capacity could be done with a smaller deviation and a more realistic result.

Several methods are available to estimate the pile bearing capacity. We examined the most frequently used methods. Test load curve fitting methods: Engineering Handbook, Hooke's law and Our method. Pile bearing capacity calculation methods: DIN method, Eurocode method. We examined 20 piles made with CFA technology.

1.1. Fitting methods

Several methods are available to estimate the pile load test curve. [3]

Method 1: In the relevant chapter of the Engineering Handbook [4], a formula is given which estimates the shaft resistance in hyperbolic and the base resistance in linear (2-3) (Figure 1).

$$R_s=\frac{s}{s+s_H}(D\pi\Sigma l_i f_i) \quad (2)$$

where s- is the settlement, s_H- is the limited settlement (variable), D- is the pile diameter, l- is the pile length and f- is the coefficient of friction.

$$R_b=4DE_s s \quad (3)$$

where D-is the pile diameter, Es-is the soil compressional modulus and s-is the settlement.

Method 2: Based on the Hooke's law (4) a soil model still used in soil mechanics (Figure 1). Shaft resistance and markings are the same as in the previous method. The calculation of the base resistance (4-8) is quite different, with a simplified result that is about one tenth of the formula given by method 1.

$$\sigma = E_s * \varepsilon \quad (4)$$

which is the Hooke's law, σ-is the vertical stress, Es- is the soil compressional modulus and ε- is the relative deformation.

$$R_b = \frac{E_s\left(\frac{D^2\pi}{4}\right)}{2D} s \quad (5)$$

where the

$$\varepsilon = \frac{s}{2D},\ A = \frac{D^2\pi}{4}. \quad (6\text{-}7)$$

The 2D compression limit depth under individual piles is generally used in Hungary.

$$R_b \approx 0{,}4DE_s s \quad (8)$$

is our simplified formula.
The methods are illustrated through a selected pile load test (Figures 1).

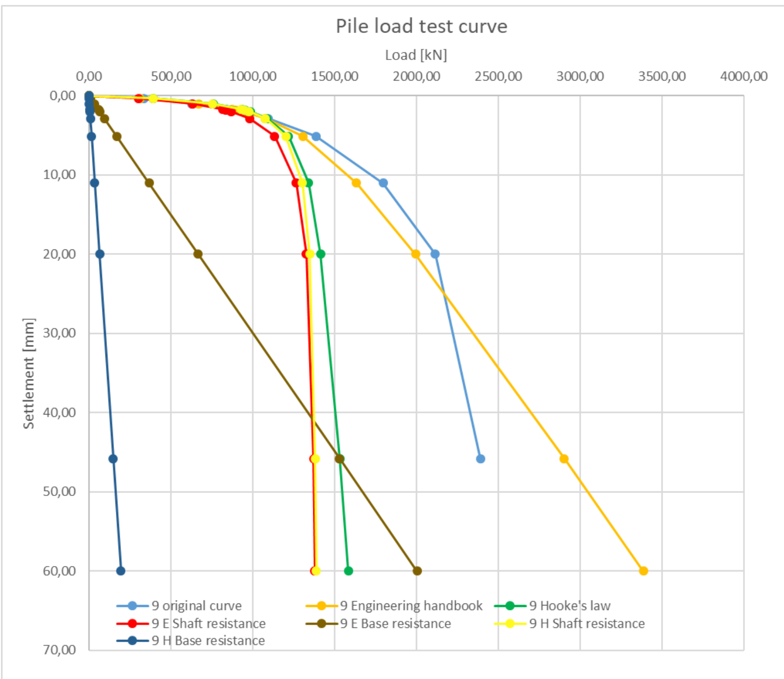

Figure 1. Example of curves calculated using the two methods. [light blue - original curve, orange - based on Engineering handbook (Base resistance-khaki, Shaft resistance-red), light green - based on Hooke's law (Base resistance-dark blue, Shaft resistance-yellow)] Source: own

We have focused of the difference between the two methods. The handbook formula is not given good result in all type of piles. Therefore, our results have to be seen in the light of the fact that all the piles we investigated were made with CFA technology.

Method 3: The fitting method developed by the authors, presented in previous publications [3][5], was written up on the basis of the function being written up by square roots. [6] (Figure 2)
Finally, the proposed formula, which estimates both the shaft resistance and the base resistance as root hyperbolic (9-10).

As a result of our many attempts, we have formulated our method:

$$R_s = \sqrt{\frac{s}{s+s_H}}(D\pi\Sigma l_i f_i) \quad (9)$$

$$R_b = \sqrt{\frac{s}{s+s_H}}(kDE_s) \quad (10),$$

where the notations have already been presented in Methods 1 and 2, but s_H-constant, k-variable.

Since we have already presented these fits in our previous paper [5], we will just say that our method can be used to fit a variable with the smallest mean standard deviation.

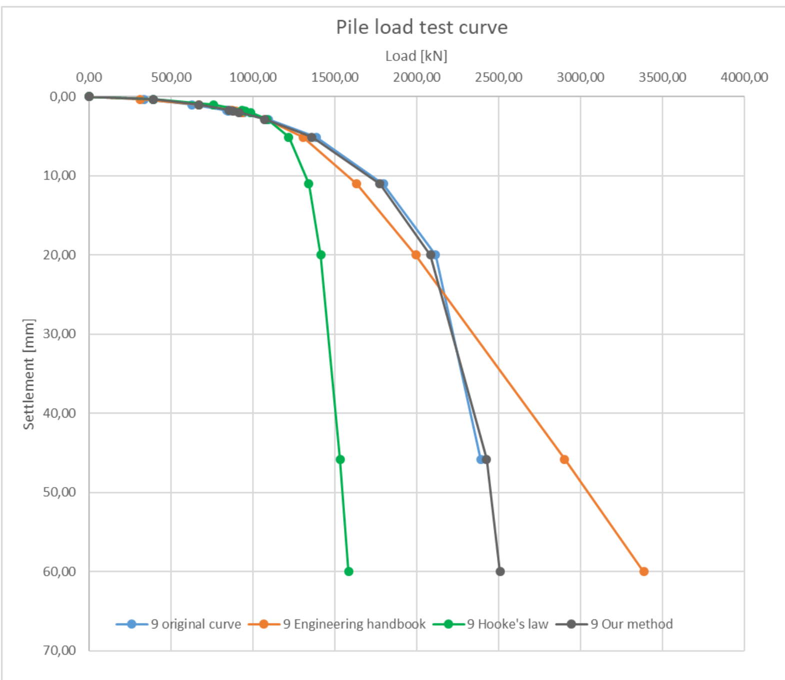

Figure 2. Example comparing the three methods with the original. (light blue - original curve, orange – based on Engineering handbook, light green - based on Hooke's law, grey - based on Our method)
Source: own

1.2. DIN method

The German DIN standard differs from the known methods in its concept. Instead of the breaking force, it estimates the pile load test curve. When estimating the pile load test curve from a static probe, DIN divides the curve into linear sections. (Figure3.) The shaft resistance - settlement function is divided into two linear sections: an elastic section and a perfectly ductile section. The base resistance - settlement function is divided into four linear sections, the last section being a perfectly ductile section with three breakpoints. [7] The concept of trying to estimate the pile bearing capacity and the pile load test curve too is sympathetic.

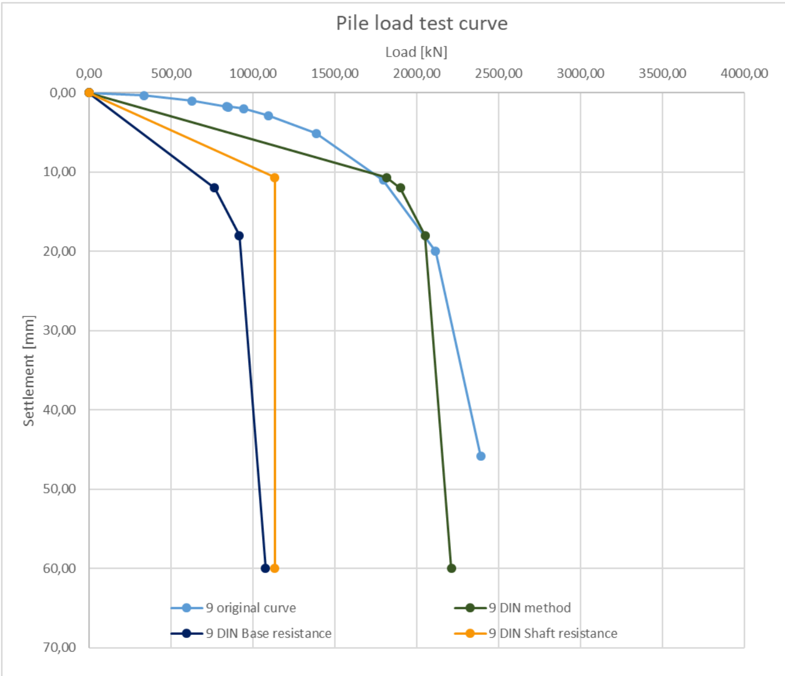

Figure 3. Example for determining the load capacity of piles using the DIN method [light blue - original curve, green - based on DIN method (Base resistance-dark blue, Shaft resistance-orange)]
Source: own

1.3. Eurocode method

The pile load capacity calculation according to the European standard MSZ EN 1997-2:2008 annex D7 was adopted based on the Dutch standard. [8] We used this supplemented with the method recommended according to the MSZ EN 1997-2 design guide [9]. The specific value of the base resistance can be determined by examining the specially considered values of the cone resistance of the probe downwards and upwards from the base, depending on whether the soil is granular or cohesive. For the calculation of bound soils, we therefore calculated by introducing the undrained shear strength recommended in the standard's design guide. [10] The shaft resistance is given by the cone resistance of the probe measured along the shaft, and its value corrected as necessary.

2. Compare

We can compare the three pile load test curve fitting methods- Engineering handbook, Hooke's law and our own method - because only one variable was included in each of them. We experienced the smallest average standard deviation in our own method. [5] Comperation of the pile load capacity for D/10 settlement with different methods.

	Abs(Our m. - Eng h.) kN	Abs(Our m. - Hooke m.) kN	Abs(Our m. - DIN m.) kN	Abs(Our m. - EC m.) kN
	318,84	1069,89	282,77	534,97
	763,91	599,69	147,51	87,56
	1223,30	433,51	36,91	364,19
	4074,71	1778,61	1644,02	1557,11
	334,26	1660,68	1000,42	691,00
	6056,43	670,66	462,40	655,09
	576,62	1813,76	1488,64	1393,45
	625,79	1106,62	884,20	424,30
	877,08	923,65	298,28	71,05
	3549,61	901,61	711,53	677,29
	485,28	992,36	5,74	90,05
	1476,12	3180,68	2519,98	2086,27
	90,74	1027,25	962,06	701,68
	6052,89	706,21	639,81	560,10
	4916,90	1572,29	1616,88	1563,56
	839,40	1909,13	1759,36	1442,48
	645,18	1695,36	1465,67	1306,01
	536,20	1675,25	1005,80	907,31
	144,95	994,78	681,50	522,72
	4653,28	22,04	398,32	359,76
Avg difference:	**1912,08**	**1236,70**	**900,59**	**799,80**

Table 1. The absolute value of the difference between the calculated values Source: own

The average deviation also shows that the DIN and EC methods are the closest to our fitting results. (Table 1.)

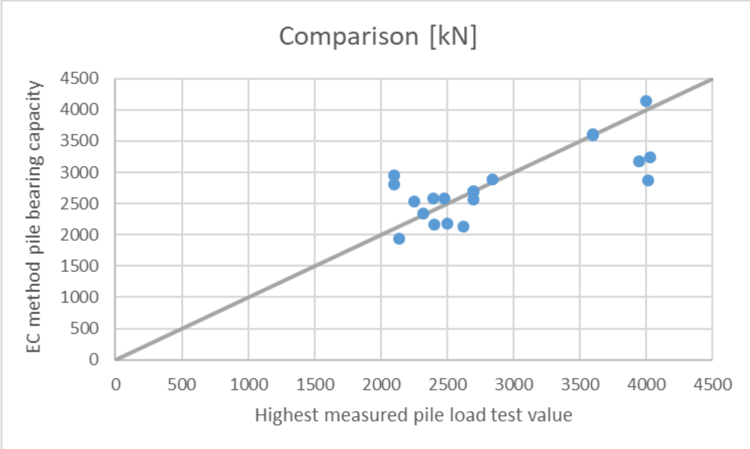

Figure 4. Comparison of the highest measured pile load test value with the EC method Source: own

We examined which one might be more realistic and found that many times the test load without wrecking took longer than the ultimate bearing capacity value calculated using the above EC method. (Figure 4.)

With a few exceptions, according to our method, the estimated pile capacity is therefore higher than EC method. (Figure 5.)

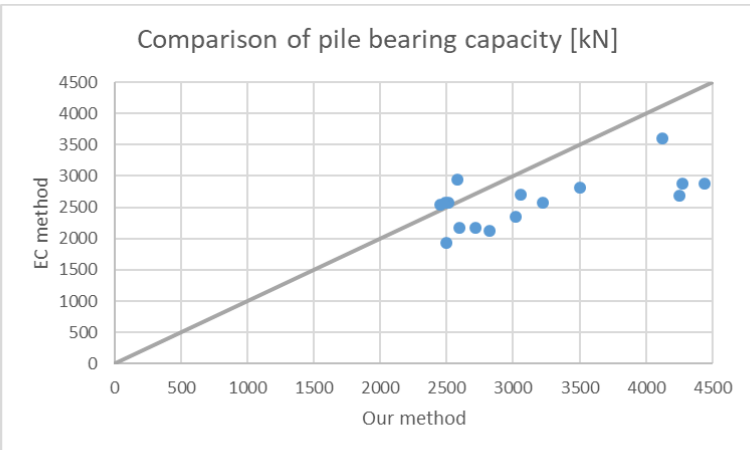

Figure 5. Comparison of our method with the EC method Source: own

3. Conclusion

After carrying out the tests, we came to the following conclusions:

• Among the methods fitted with the investigated function, our method gives the best fitting pile load test curve. Of course, many refinements are still needed in the method we have developed, but for a pile load test curve finished sooner, the curve fitted by our method is likely to give more realistic final results than the 1. and 2. methods we have studied. (Table 1.) (Figure 6.)

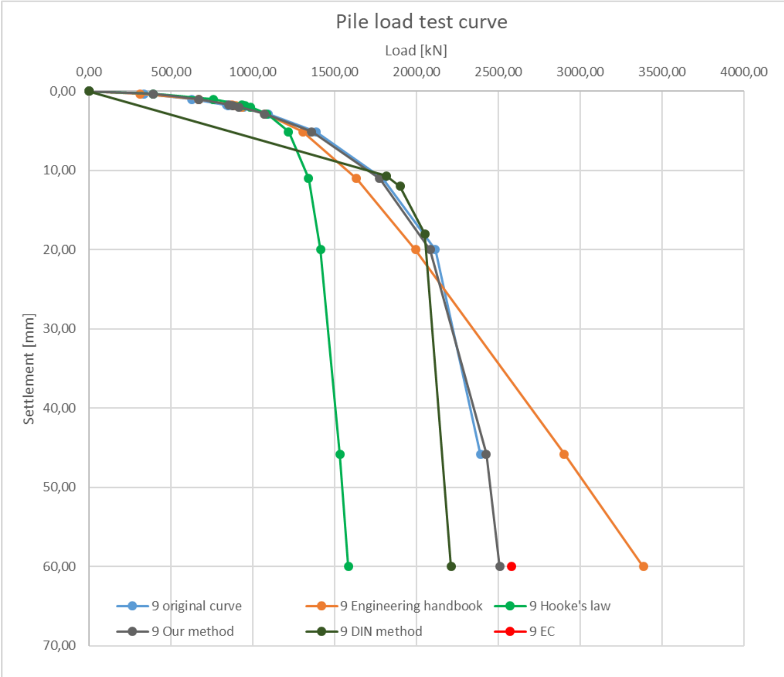

Figure 6. Examle comparing all described methods with the original (light blue - original curve, orange – based on Engineering handbook, light green - based on Hooke's law, grey - based on Our method, dark green - based on DIN method, red - based on EC method) Source: own

For comparison, we considered the load for D/10 settlement value as the ultimate bearing capacity.

• The ultimate load value calculated by the EC method is often less than the maximum load value measured during the unfinished test load. (Figure 4.)

• We compared the load for D/10 settlement value with the bearing capacity calculated using calculation methods. Among the examined methods, the value calculated by EC is the closest on average to our method. (Table 1.)

• It is clear from the pile load test data we generally use a conservative estimate for the DIN and EC method.

• Our method more realistically determines the bearing capacity of the pile above the last load value. (Figure 5.)

A later goal is to get to know/examine the literature even more thoroughly, which will include current and international results.

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