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RELIABILITY ANALYSIS OF A PILE FOUNDATION AND CONTRIBUTION OF THE UNCERTAINTIES INVOLVED

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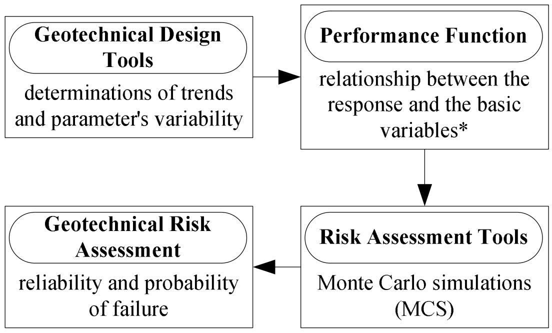
pile, axial load, reliability, uncertainties, influence of the uncertainties, model, soil, SPT

EXTENDED ABSTRACT

The work present in this paper was developed under the PhD thesis entitled "Reliability and Cost Models of Pile Foundations". The main goals of this study are: (1) to give technical and scientific bases about the use of reliability analysis in pile design, (2) compare levels of safety obtained by the traditional design methods, the Eurocode method (using partial factors) and the reliability based design method, (3) determine partial factors and give some recommendations for Portuguese Annex of Eurocode and also (4) obtain costs linear functions with statistics base that will assist to determine which costs are associated to a certain level of safety. Thus, in this paper is integrated in topic (1) where one way that geotechnical uncertainties can be treated in a simple way is shown.

All civil engineers are aware of the uncertainties in the design and their importance. But in some areas, as in geotechnics, the uncertainties are mostly unknown or really difficult to measure. That is why, unlike in structural design, the traditional way that geotechnical engineers have to introduce the uncertainties on the design is using a high global safety factor (based on past experience). But, of course, this way of treating the uncertainties does not give a rational base to understand their influence on the design. That being said this paper show one way that geotechnical uncertainties can be treated in a simple way. The methodology used aims to eliminate the possible confusions and difficulties that traditional reliability methodologies used in structures can cause to geotechnical designers in practice. A series of calculations of the probability of failure for a single pile foundation with axial load were done, in order to investigate the influence of each uncertainty source. It was found, as expected, that the most important uncertainty comes from model error, not from the soil.

The methodology used for the reliability analyses in this paper, differs from the typical employed in structural analysis, and was proposed by Honjo (2010) – see Figure 1. Here, the "Geotechnical Design Tools" and the "Risk Assessment Tools" are separated as much as possible, allowing a better understanding of the different steps and responses obtained. Also the assessment of the risk is done by the simplest method, Monte Carlos simulations.



*When this relationship is too complex (e.g. FEM), response surface method or neural networks can be used

Figure 1: Diagram of the methodology used in the reliability analysis (adapted from Honjo, 2010)

The methodology will be applied to a pile from the FEUP (Faculdade de Engenharia da Universidade do Porto) experimental site. The pile was bored in residual soil and has 0.6 meters of diameter, 4 SPT tests of the area are available and different lengths are analysed. The measurement error was not considered in this study. In the first step, when determining the trends (e.g. SPT), the spatial variability and statistical estimation error are considered together. After, one needs to gather the uncertainties for other necessary parameters (basic variables), like loads, by statistical analysis or bibliography (for e.g. Phoon 2008) – see Table 1. The values of the loads were considered as $G_k=Q_k=463$ kN. Then, the performance function (M = Resistance – Loads) is determined. This is a simple case since an empirical method based on SPT N values, SHB (2001), is used to determine the resistances (side R_f and tip R_t):

$$M = (R_f + R_t) - (G + Q)$$
$$M = (\delta_f \times F + \delta_t \times Q_t) - (\delta_g \times G_k + \delta_q \times Q_k) \qquad (1)$$

The model uncertainty (factors δ_f and δ_t, error when transforming the test parameters or soil parameters into the resistance) was obtained in Okahara et al. 1991 – see Table 1. Finally, Monte Carlo Simulations are performed and the probability of failure and reliability indexes (β) are determined. The results are shown in Figure 2 and 3 (All uncertainties – continuous line). The value of the reliability index obtained for the actual length of the pile (6 meters – β=1.88) is lower than the recommended for this type of structures. According to the bibliography, the values of β should be between 3 and 4 (CEN 2002). This can be justified by the fact that this is an experimental pile, so the consequences of failure are low. For a target β=3 the length of the pile should be around 8.5 meters.

Table 1: Uncertainties for the application example

variable	Mean	SD	Distribution	Reference
N_{SPT}	10.3 + 1.9z	4.6	Normal	-
G_k factor (δ_g)	1.0	0.10	Normal	Holicky et al. 2007
Q_k factor (δ_q)	0.6	0.21	Gumbel	Holicky et al. 2007
F factor (δ_f)	1.07	0.49 2	LogNormal	Okahara et al. 1991
Q_t factor (δ_t)	1.12	0.70 6	LogNormal	Okahara et al. 1991

MAIN RESULTS AND CONCLUSIONS

For analysing the uncertainties the calculation above was repeated, but removing the:

1. uncertainties in the side resistance (δ_f, N_{side}),
2. uncertainties in the tip resistance (δ_t, N_{tip}),
3. soil uncertainty (N_{side}, N_{tip}),
4. and model uncertainty (δ_f, δ_t).

The following results were obtained:

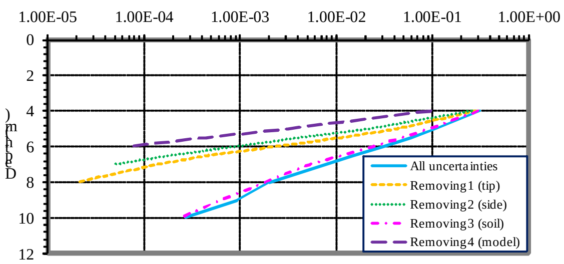


Figure 2: Probability of failure (lognormal scale)

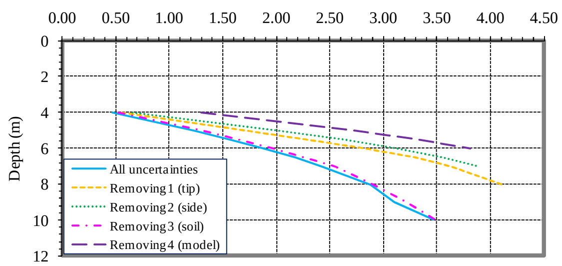


Figure 3: Reliability index

From the 2 graphs above, one can realize that the pile length of 8.5 meters determined for β=3 (considering all uncertainties) drops down to around 6 meters when removing uncertainties 1 or 2 (side or tip) and to 5 meters when removing uncertainty 4 (model). The methodology proposed by Honjo (2010) helps the geotechnical engineer to do a full reliability analysis without losing the intuitive understanding of the problem, important to make decisions during the design process. Five analyses were carried out for a single pile, with all uncertainties, and removing, at each time the side, tip, soil and model uncertainties. The results show that the contribution of the side and tip uncertainties, in this case, is the same, the side resistance is dominant (R_f/R_t around 2) but the uncertainties on the tip are bigger. Concerning to the soil and model uncertainties, it is shown, as expected, that the model error is much more important in the reliability of the pile. When removing the uncertainties of the soil, one can see that the results are almost the same as the ones obtained when considering all uncertainties. This way, for code calibration and recommendation for reliability design one can take into account this conclusion.

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