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Smart Geotechnics for Smart Societies – Zhussupbekov, Sarsembayeva & Kaliakin (Eds)

Preliminary study of ultimate load prediction using the DINGO database

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ABSTRACT: Chin's analysis method can be employed to interpret the ultimate capacity of pile load tests. Using maintained pile load test data from the DINGO database, consisting of axial compressive loading, the performance of Chin's method was investigated for piles in various UK soil deposits. It is shown that Chin's method tends to be unconservative when predicting ultimate pile capacity regardless of how 'failure' is defined (e.g. head settlement over 10% of pile diameter). The results are compared with test data from Ireland where similar trends were observed.

1 INTRODUCTION

Chin's method is a procedure for predicting the ultimate load a pile can carry without reaching 'failure' during testing (Chin 1970, 1972). In this method, the recorded settlements from load/settlement data are divided by the corresponding load for the same set of data and then plotted against only the settlements from the same load/settlement dataset, and a linear regression in the form of Equation (1) fitted. The ultimate load of the pile is then calculated as the inverse of the slope of the fitted line (Equation 1):

$$\Delta/P = M\Delta + B \tag{1}$$

where Δ = pile head settlement; P = applied load at the pile head; $1/M$ = ultimate pile head load; and B = constant. Chin's method is essentially an extrapolation method (cf. Galbraith et al. 2014).

Other methods have been developed based on forms of Equation (1) (e.g. Fleming 1992, Fellenius 1980, Comodromos *et al.* 2003, Topacio *et al.* 2022) with various modifications proposed. Fleming (1992) suggested that Chin's method may overestimate the ultimate load. In this study, Equation (1) is employed to analyse data extracted from the DINGO database (see Vardanega *et al.* 2021a, 2021b, Voyagaki *et al.* 2022). The DINGO database contains pile load-settlement data (alongside ground investigation data) for 551 piles of various types constructed in different soil deposits in the United Kingdom. The DINGO database data were obtained from various resources in which some of the data were hand digitised from figures and tables.

This study assesses the reliability of Equation (1) for predicting the ultimate load of a pile when a load-test does not reach 'failure' compared to measured ultimate loads in testing based on pile head settlement exceeding 10% of the pile diameter (BSI 2004, Frank *et al.* 2004). Although Equation (1) can be used for different pile loading methods (Chin 1972), this study focusses on compression Maintained Load (ML) tests.

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2 DATA SELECTION & FILTERING

It was determined that for 378 piles from the DINGO database a compression ML test had been carried out. Load-settlement tables for each pile were constructed and datapoints from any unloading phases (if present) were excluded. All piles reported with less than 3 load-settlement datapoints were not considered in this analysis (40 piles). The remaining 338 piles were analysed using Equation (1) as shown in the example illustrated in Figure 1. Figure 2 presents the load-settlement datapoints distribution in DINGO database. Confidence interval (CI) analyses were performed on the resulting R^2 values of the Equation (1) fittings to the test data combined with the number of load-settlement datapoints (e.g. Paradine & Rivett 1953, Johnson 1978). The pile tests were then divided into three categories based on the aforementioned analyses. The first category (CI 98%) contains all the piles that have R^2 values equal or higher than for 98% confidence interval for the same number of load-settlement datapoints (degrees of freedom). The number of piles in this category was 296 piles. The second category (CI 90%) presents all the piles with R^2 values equal or higher than that found for the 90% confidence interval but less than for the 98% confidence interval for the same degrees of freedom (17 piles). The third category presents piles with R^2 less than for 90% confidence interval for the same degrees of freedom (25 piles). This analysis indicates that Equation (1) generally provides a robust statistical fit to the pile load test data.

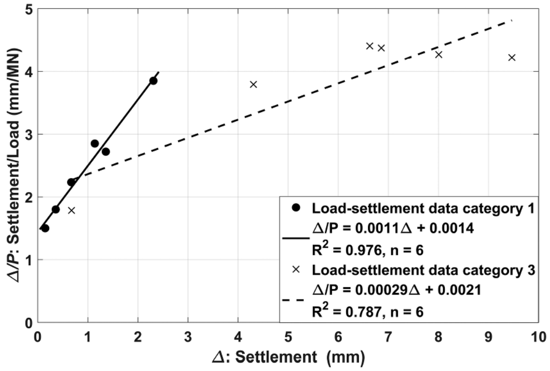

Figure 1. Example of fitting data using Equation (1); for a pile with R^2 higher than that for 98% confidence interval and for a pile from the group with R^2 less than that for 90% confidence interval.

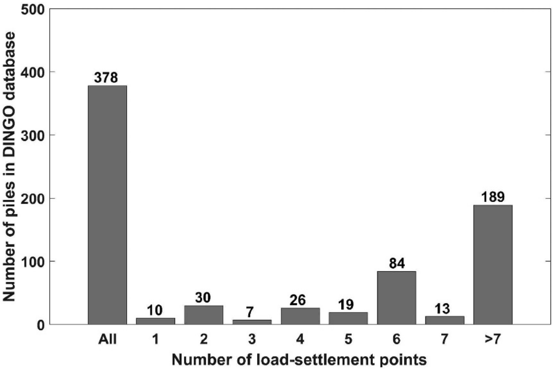

Figure 2. Load-settlement data point distribution for ML piles in the DINGO database.

3 DATA ANALYSIS

Piles from the first category (CI 98%) were used, as the low number of piles in the other categories did not (in the view of the authors) justify lowering the confidence level. The mean (μ) and standard deviation (σ) for the M and B parameters in Equation (1) were calculated and categorised based on the load-settlement datapoints available (Table 1). The values of μ and the σ of the fitting parameters for all the piles are mainly affected by that of piles with more than 7 datapoints (highest number of piles), with no obvious trend observed for μ of M and B with the increasing number of points. In Figure 3, a box plot is shown for coefficient of determination (R^2) values obtained from fitting the piles within CI 98%. Figure 4 shows the pile diameter distribution used in this study with the percent of piles in each diameter range reaching a settlement equal or greater than 10% of the diameter.

Table 1. Descriptive statistics for M and B from Equation (1) applied to pile tests from the CI 98% category.

		All	3	4	5	6	7	>7
Slope (M)	μ	0.86	0.70	1.30	0.78	0.91	1.30	0.75
[MN^{-1}]	σ	0.93	0.64	1.20	0.59	0.86	1.40	0.90
Intercept (B)	μ	3.50	1.50	3.50	1.70	1.50	2.40	4.80
[mm/MN]	σ	6.40	1.50	4.90	1.50	1.90	1.40	8.10

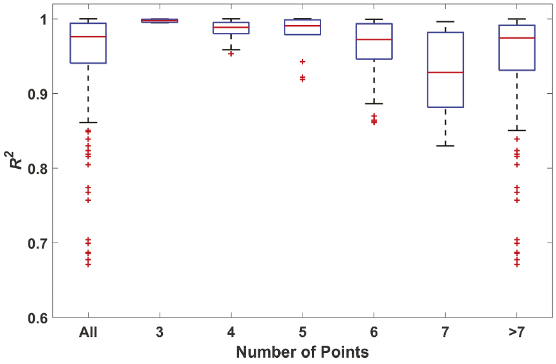

Figure 3. Boxplot of R^2 categorized based on the number of load-settlement data points for piles in CI 98%.

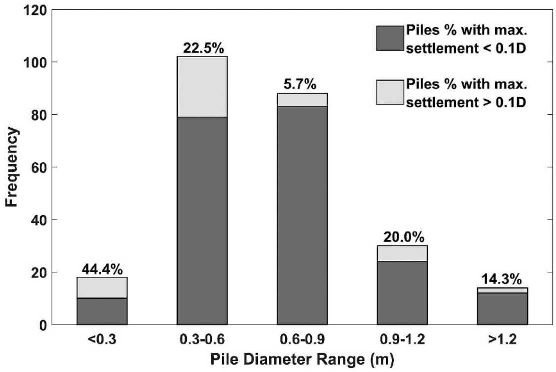

Figure 4. Pile diameter distribution of CI 98% presenting the percentage of piles in each range group with a maximum settlement equal or higher than 10% of the pile diameter.

Initially, piles with maximum test settlement reaching or exceeding 10% of the base diameter were selected (44 piles) and the load corresponding to 10% diameter settlement ($P_{ult,10\%}$) was recorded as the measured ultimate load for each test. This criterion was also used in Galbraith (2011) and Galbraith *et al.* (2014). Figure 5(a, b) shows that most of the predictions fall within the ± 50% bounds shown. However, Equation (1) tends to systematically overestimate the ultimate load. These trends were also observed for 10 pile load tests with recorded settlements greater than 10% of pile diameter hand digitised from Galbraith (2011). Then using the maximum recorded load from the pile testing ($P_{ult,max}$), the number of piles available for analysis increased from 44 to 252 tests. However, the maximum test settlement to diameter ratio, Δ_{max}/D, for this approach ranges from 0.1% to 108%.

To analyse the data using this approach, the piles were divided into three classes based on settlement diameter ratio: (i) Class 1: $\Delta_{max}/D \geq 10\%$ (44 tests); (ii) Class 2: $2\% \geq \Delta_{max}/D > 10\%$ (98 tests) and (iii) Class 3: $\Delta_{max}/D < 2\%$ (110 tests). Figure 6(a, b) shows the measured vs. calculated ultimate load plot with these three sub-groups highlighted. Similar results to those shown in Figures 5(a, b) are shown however, increasing Δ_{max}/D appears to improve the accuracy of Equation (1) to some extent.

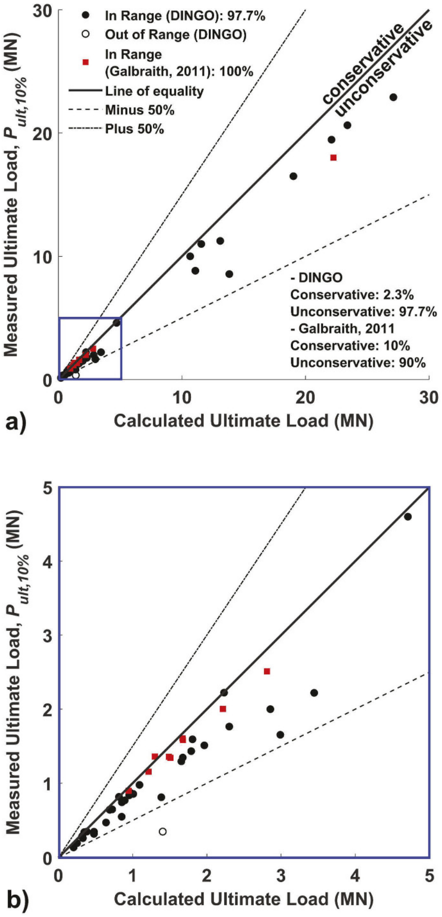

Figure 5. Measured $P_{ult,10\%}$ vs. calculated ultimate load using Equation (1): (a) all data (average over-prediction is about 19.2%), (b) plot for load range 0 to 5MN.

For those tests with recorded settlements equal or greater than 10% of the pile diameter, $P_{ult,10\%}$ and $P_{ult,max}$ have similar values (not shown here for the sake of brevity), which is likely as reaching this settlement threshold was the objective of the original testing. This may

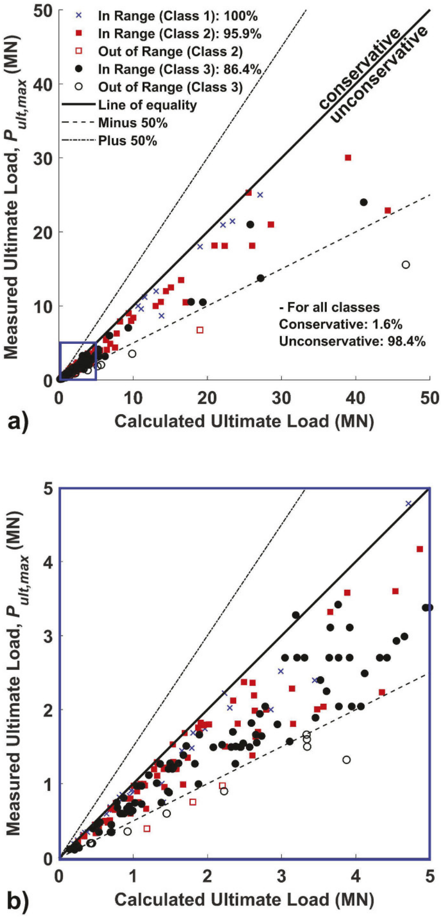

Figure 6. Measured $P_{ult,max}$ vs. calculated ultimate load using Equation (1): (a) all data plot (average overprediction is about 24.8%), (b) plot for load range 0 to 5MN.

explain why the trends observed comparing Figure 5(a, b) with Figure 6(a, b) are similar. In addition, it results in a slightly larger overprediction of $P_{ult,max}$ (24.8%) compared to $P_{ult,10\%}$ (19.2%) as, on average, the former is lower. These trends may not be the case for other datasets of pile-load tests.

4 SUMMARY & CONCLUSIONS

ML compression pile load tests from the DINGO database (along with data from Galbraith 2011) were analysed using Chin's method (Equation 1). The applicability of Equation (1) for prediction of ultimate pile capacity was assessed by comparing predicted ultimate load values against $P_{ult,10\%}$ and $P_{ult,max}$. For the unconservative predictions across the DINGO database (which equate to around 98% of the analysed pile tests) the Chin method tends to overpredict $P_{ult,10\%}$ by around 19.2% and $P_{ult,max}$ by around 24.8% on average.

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