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INTERPRETATION OF SCREW PILE LOAD TEST DATA USING EXTRAPOLATION METHOD IN DENSE SAND

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ABSTRACT: The basic definition of ultimate pile capacity is the load at which pile penetration keep on increasing without increasing the applied load (plunging resistance state). The plunging resistance state is often not achieved due to the limitation of the loading system, especially under dense ground conditions. Therefore, extrapolation methods were proposed to estimate the ultimate state of the ground (plunging resistance). However, in case of screw piles, helix deformation can reduce the end bearing capacity and should be kept in mind while interpreting load test data. In the present study, the extrapolation methods such as Chin-Kondner and Decourt were used to check the indication of helix plate deformation from the screw pile load test data. The prediction capability of the ultimate end bearing capacity was also checked at settlement equals to 10% of helix diameter and at plunging resistance state. Model scale of pile load testing under dense ground condition was selected to achieve the plunging resistance state. It was observed from the test results that the Decourt method of plotting could indicate the helix plate deformation. A modified approach was proposed in Decourt method of plotting to estimate the helix limit load. It was also observed from the prediction analysis that it would be better to select the ultimate end bearing capacity from the predicted model curve at settlement equals to 10% of helix diameter. A reduction factor based on load test results is proposed so that the prediction of extrapolation methods at 10% of helix diameter can be controlled.

Keywords: Extrapolation Method, Screw Pile, Model Pile Load Test, Helix Deformation

1. INTRODUCTION

The basic definition of ultimate pile capacity is the highest load that can be applied to a pile until pile settlement continues without application of additional load (plunging resistance state). This basic definition is strength based and does not limit the pile head settlement (Perko, 2009). In case of helical piles, engineers preferred modified Davisson method in which, the ultimate end bearing capacity is defined at settlement equals to 10% of helix diameter (Perko, 2009). It is due to the fact that the end bearing capacity is fully mobilized at settlement equals to 10% of pile tip diameter (fine grained soils) or 20% of pile tip diameter for coarse-grained soils (Fleming et. al., 1985). However, it is very difficult to reach the plunging resistance state or even settlement equals to 10% of pile tip diameter in full-scale pile load test due to the limitation of the loading system, especially under dense ground conditions. In such a situation, simple extrapolation methods such as Chin-Kondner and Decourt can be used to predict the plunging resistance state (Perko, 2009). The approach of both methods is similar but their plotting procedure is opposite to each other. In Chin-Kondner method the settlement divided by load is plotted against the settlement and linear regression is applied on the straight portion of the curve to obtain the parameters of hyperbola. Whereas, In Decourt method the load divided by settlement is plotted against the load and linear regression is applied on the straight portion of the curve. The ultimate pile capacities that define the plunging resistance state and the model load settlement curves can be estimated by using the following equations.

$$Q_{UCK} = \frac{1}{C_1} \quad (1)$$

$$P_{CK} = \frac{\sqrt{S}}{(C_1 \times S + C_2)} \quad (2)$$

$$Q_{UD} = -\frac{C_2}{C_1} \quad (3)$$

$$P_D = \frac{C_2 \times S}{1 - (C_1 \times S)} \quad (4)$$

Where Q_{UCK} (Chin-Kondner) and Q_{UD} (Decourt) are ultimate pile capacities (plunging resistance state); C_1 is slope of liner regression; C_2 is the intercept of linear regression on y-axis; P_{CK} (Chin-Kondner) and P_D (Decourt) are the applied loads for model curve and S is the pile settlement.

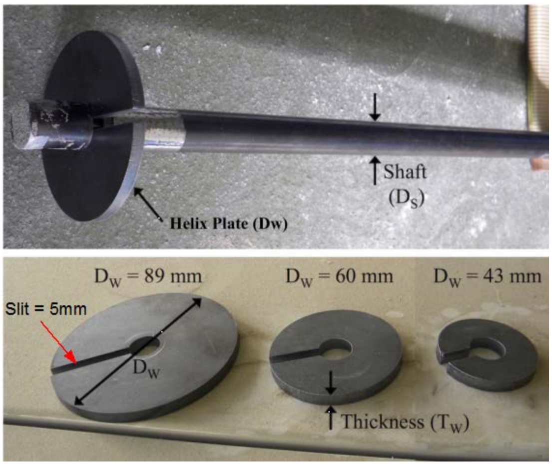
According to Fleming (1992) the evidence given by Chin (1970, 1972) for the prediction of load settlement curve is true of piles that carry majority of the structural load through friction or end bearing. However, both methods overestimate the plunging resistance state of the pile (Fellenius 1980; Fleming 1992; Perko 2009).

Another important factor that should be kept in mind while interpreting the screw pile load test data is the deformation of helix. The previous studies indicated that the helix deformation alter the load settlement curve and reduce the end bearing capacity of screw pile (Yttrup & Abramsson, 2003; Malik et al., 2013). However, the change in the shape of load settlement curve is hard to identify from the load test data. Hence, the interpreted ultimate pile capacity will include the effect of helix deformation on the ground bearing capacity, which is not true representation of actual ground failure. Therefore, it is very important to identify the deformation of helix during the pile load test so that suitable remedial measures (increase in helix thickness or decrease in helix diameter) can be done for the working piles. Fellenius (2001b) stated that the weakness in the pile during the pile load test could be seen if the load test data is plotted according to Chin-Kondner method.

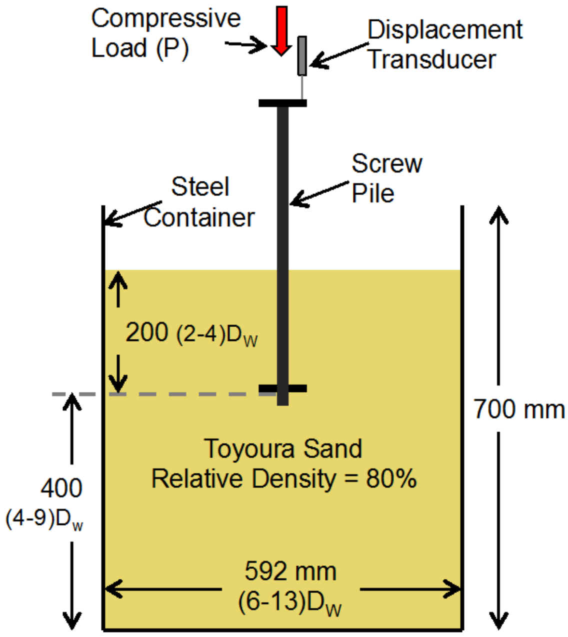
In the present study, the pile load test data of deformed and non-deformed screw piles were evaluated through extrapolation methods such as Chin-Kondner and Decourt to observe any indication of helix deformation. The prediction capability of both methods had also been evaluated at settlement equals to 10% of helix plate diameter and at plunging resistance state.

2. TESTING EQUIPMENT

Model steel screw piles having single helix with closed shaft tip were used in this study. The properties of pile shaft and helix were according to STK400 and SS400 steel standards (tensile strength 400MPa, yield strength 235MPa and elongation 20%). Helices were modeled as a flat circular plate because the objective of the study was to check the load settlement behavior of screw piles after installation of pile. A slit was provided (5mm) on the helix plate so that helix plates of different diameter and thickness can be inserted into the central shaft. The helices with different diameter and thickness are shown in Fig.1(a). The model steel container having diameter of 592mm and depth of 700mm was used to prepare the model ground as shown in Fig.1(b). The container size was selected according to previous study in which it was suggested that the container size should be 3 to 8 times the pile tip diameter (Kishida, 1963). Yang (2006) suggested that the influence zone in clean sand above the pile tip is between 1.5 to 2.5 times the pile diameter and influence zone below the pile tip is between 3.5 to 5.5 times the pile diameter. The container used in this study is within the suggested limits. The settlement (S) of the pile due to compressive load (P) was measured with the help of displacement transducer placed at the pile head as shown in Fig.1(b).



(a)



(b)

Fig.1 (a) Screw pile with helices of various sizes (b) Model container (units in mm)

The dimensions of the screw piles that were used in the present study are shown in Table 1. Toyoura sand (dry, fine grained) having specific gravity 2.645, D_{50} 0.19, e_{max} 0.973 and e_{min} 0.609 was used to prepare the model ground.

Table 1 Model screw pile dimensions

Shaft Diameter (D_s)	Helix Plate Diameter (D_w)	D_w/D_s	Shaft Length (L_s)	Helix Plate Thickness (T_w)		
(mm)	(mm)	-	(mm)	(mm)		
21.7	43	2.0	500	2	-	-
21.7	60	2.8	500	0.8	2	3
21.7	89	4.1	500	2	3	4

3. TESTING PROCEDURE

The dry Toyoura sand (fine grain) was compacted inside the model container in six layers, each of 100mm thickness. The relative density of the sand in each layer was approximately 80%. The screw pile was placed after the compaction of fourth layer instead of pushing force and torque. The remaining two layers were carefully compacted around the screw pile. The screw pile was kept vertical with the help of holding system during the compaction of the last two layers. The applied compressive load (P) was measured with the help of load cell.

4. TEST RESULTS AND DISCUSSIONS

The model pile load tests were performed on screw piles with helix plates of different diameter and thickness. The screw piles were removed from the model ground after the pile load tests and helix plate deformation was recorded. The screw piles having helix diameter of 60 and 89mm with thickness of 0.8, 2 and 3mm were deformed as shown in Fig.2.

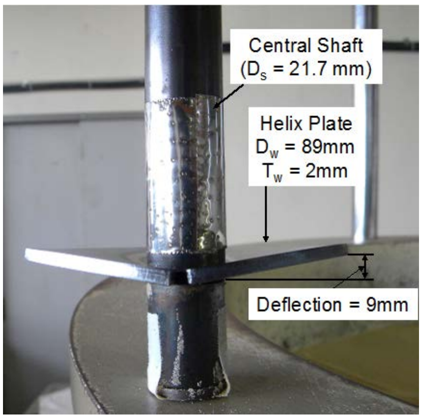


Fig.2 Deformed screw pile during load test

However, the load settlement curve had not shown any clear indication of helix deformation, except screw pile having helix diameter 60 and 89mm with thickness of 0.8 and 2mm respectively, in which helix deformation is too large with respect to helix thickness as shown in Fig.3.

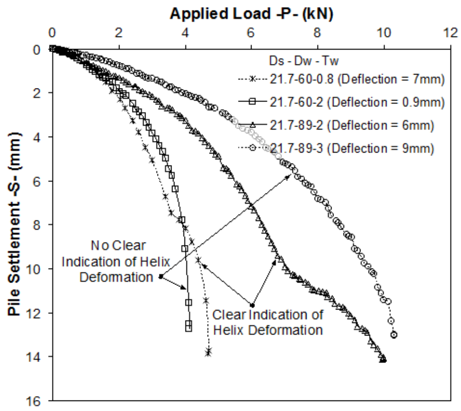


Fig.3 Load settlement curves of deformed piles

The serious effect of helix deformation on the reduction of end bearing capacity of the ground can only be found when the load settlement curves of deformed and non-deformed screw piles were overlapped as shown in Fig.4. However, in real field, it is not possible to perform pile load tests on various dimensions of screw piles as it considerably increases the cost of the project. Therefore, it will be helpful if Chin-Kondner or Decourt method can indicate the deformation of helix plate, so that helix thickness can be increased before the construction of working piles. The point at which load settlement curves of deformed and non-deformed screw piles starting to deviate from each other was considered as helix plate limit load (Q_W) because any further increase will affect the actual bearing capacity of the ground as shown in Fig.4. The ultimate pile capacities at plunging resistance (Q_U) and at settlement equals to 10% of helix plate diameter (representing the full mobilization of end bearing capacity, $Q_{U10\%}$) were measured from the load settlement curves of screw piles as shown in Fig.4. These pile capacities were taken as reference values and were used to evaluate the prediction capability of Chin-Kondner and Decourt methods.

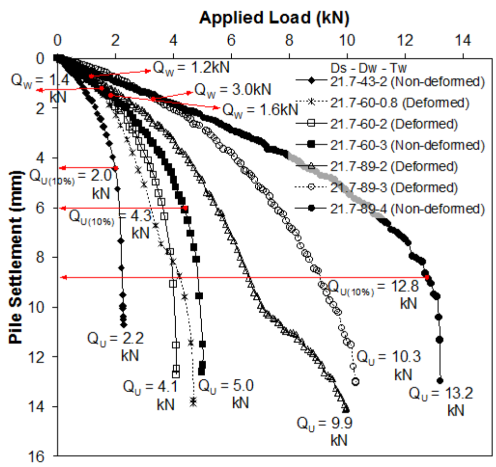


Fig.4 Comparison of load settlement curves of deformed and non-deformed screw piles

5. INDICATION OF HELIX PLATE DEFORMATION THROUGH CHIN-KONDNER AND DECOURT METHODS

The load test data of deformed and non-deformed screw piles were plotted according to Chin-Kondner method to check any indication of helix plate deformation. It was observed that Chin-Kondner method could not show any clear indication of helix plate deformation as shown in Fig.5. The slope of the straight-line portion changed with the increase in helix plate deformation as shown in Fig.5. However, such change in the slope of the straight-line is not enough to identify helix deformation if only the deformed screw pile load test data is available.

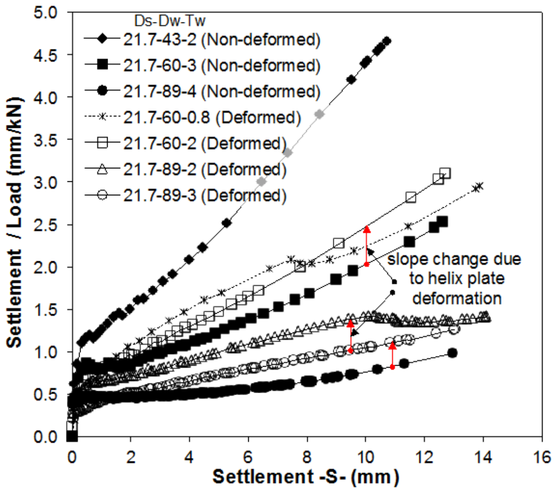


Fig.5 Chin-Kondner method of plotting screw pile load test data

The same load test data of deformed and non-deformed screw piles were also plotted according to Decourt method to check the indication of helix plate deformation. It was observed that this method could show the indication of helix plate deformation as shown in Fig.6. The straight-line portion of the test data was transformed to convex downward curve as the helix plate deformation started affecting the load settlement behavior of the ground as shown in Fig.6. This change is quite clear and can be observed even only deformed screw pile load test data is available.

Therefore, it is concluded that Decourt method of plotting can indicate the helix plate deformation, which reduce the end bearing capacity of screw pile.

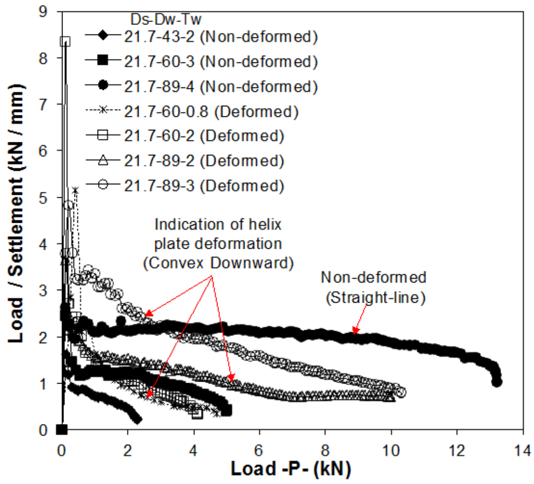
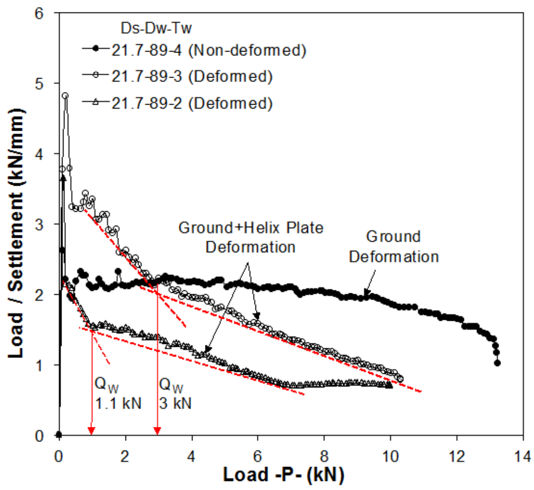


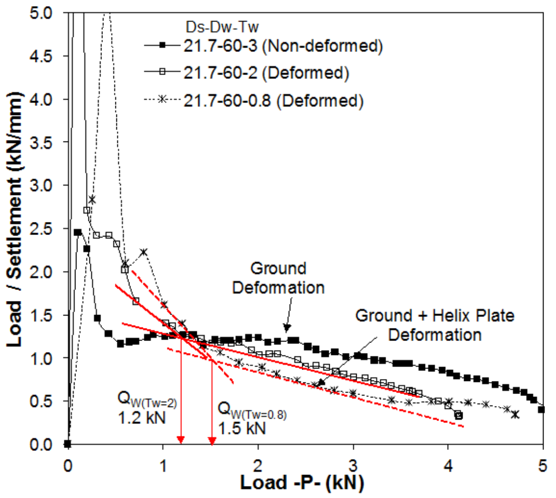
Fig.6 Decourt method of plotting screw pile load test data

5.1 Estimation of Helix Plate Limit Load (Q_W) through Modified Approach in Decourt Method

The helix plate limit load (Q_W) can only be estimated if deformed and non-deformed screw pile load test data is available (by overlapping load settlement curves) because it is hard to identify the helix plate deformation from deformed load settlement curve only. However, It was observed that Decourt method of plotting the load test data showed clear indication of helix plate deformation as shown in Fig.7(a, b). It was observed that the straight-line portion of the load test data transformed to convex downward curve with the increase in helix plate deformation that affect the actual load settlement behavior of the ground as shown in Fig.7(a, b). Therefore, it is possible to estimate the helix plate limit load (Q_W) by plotting the tangents on the convex downward curve or by selecting the point where the change of slope is started as shown in Fig.7(a, b).



(a)



(b)

Fig.7 Proposed modification to estimate the helix plate limit load (a) D_W = 89mm (b) D_W = 60mm

The estimation of helix plate limit load (Q_W) through proposed modification showed close agreement with helix plate limit load that was calculated by overlapping deformed and non-deformed screw piles load settlement curves (shown in Fig.4) as indicated in Fig.8.

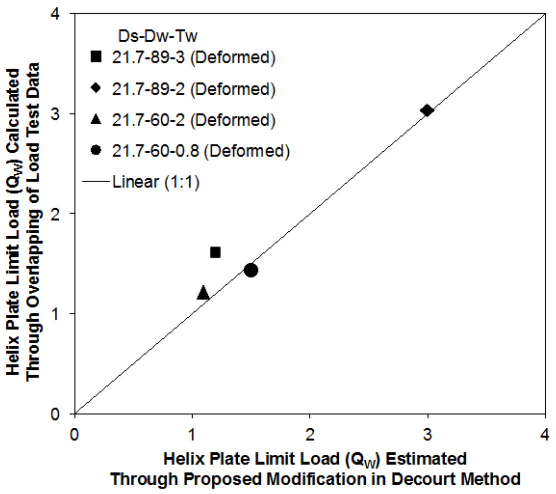


Fig.8 Comparison of estimated and calculated helix plate limit load

6. ULTIMATE SCREW PILE CAPACITY PREDICTION ANALYSIS

The reference ultimate end bearing capacities (at plunging resistance state and at 10% of helix plate diameter) from the load test data of non-deformed screw piles were compared with prediction of Chin-Kondner and Decourt methods through five load test data scenarios, which are as follows.

Scenario 1: Load test data used up to settlement equals to 2.5% of helix plate diameter (D_W).

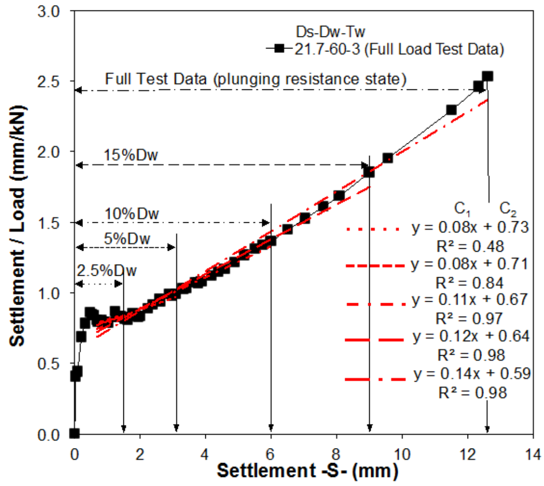
Scenario 2: Load test data used up to settlement equals to 5% of (D_W).

Scenario 3: Load test data used up to settlement equals to 10% of (D_W).

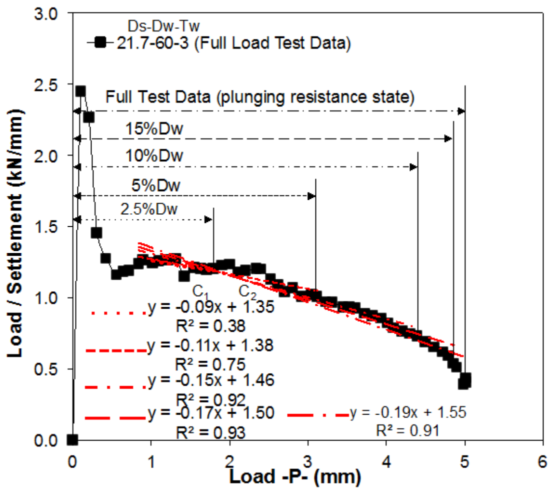
Scenario 4: Load test data used up to settlement equals to 15% of (D_W).

Scenario 5: Load test data used up to plunging resistance state.

The plotting procedure of Chin-Kondner and Decourt methods was applied for all the scenarios of screw piles. However, screw pile having helix plate diameter (D_W) of 60mm are presented here as shown in Fig.9(a, b).



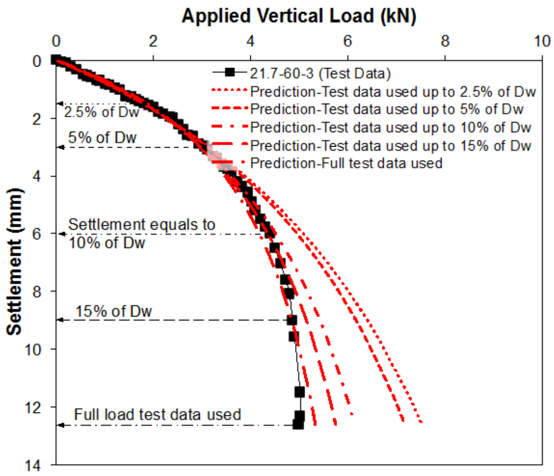
(a)



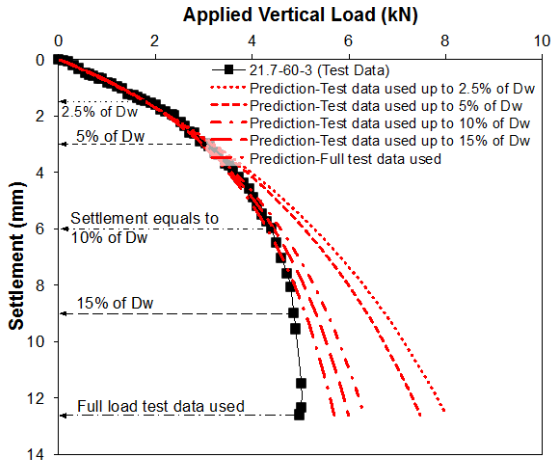
(b)

Fig.9 Load test data plotting for all scenarios (a) Chin-Kondner method (b) Decourt method

The model curves of Chin-Kondner (P_{CK}) and Decourt (P_D) methods for all the load test data scenarios were calculated using Eq. (2) and (4). It was observed from the comparison of model and load test data curves that the prediction of both methods showed better agreement up to settlement equals to 10% of helix plate diameter than at plunging resistance state as shown in Fig.10(a, b). It was also observed that the load settlement curves prediction of both methods were close to each other. Similar results were obtained for screw piles having helix plate diameter of 43 and 89mm.



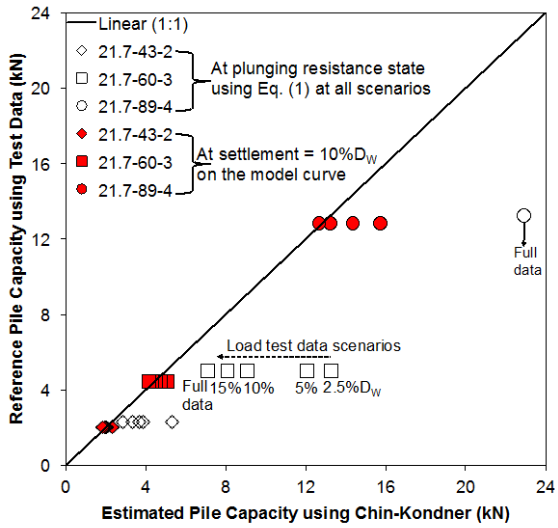
(a)



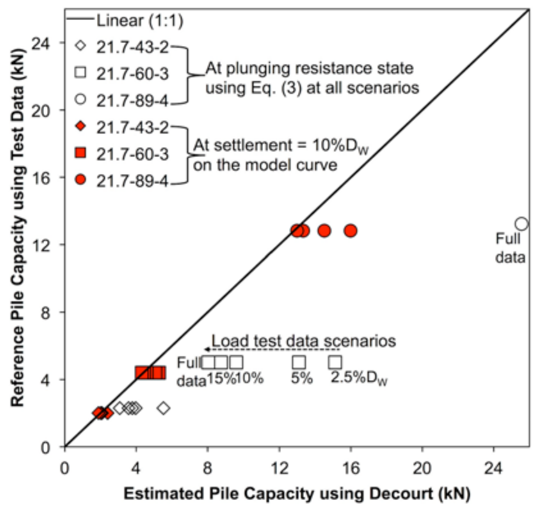
(b)

Fig.10 Load settlement curves comparison for all scenarios (a) Chin-Kondner method (b) Decourt method

As the lower part of the predicted curves had not shown good agreement with the load test data, therefore, the calculated end bearing capacity (at plunging resistance state) from Eqs. (1) and (3) was on higher side at all the scenarios as shown in Fig.11(a, b). However, if the ultimate end bearing capacity is considered at settlement equals to 10% of helix plate diameter and selected from the predicted model curve, it showed good agreement with the reference pile capacity as shown in Fig.11(a, b). Therefore, it is suggested that the ultimate pile capacity should be selected from the model curve at settlement equals to 10% of helix diameter (representing full mobilization of end bearing capacity in fine sand) instead of plunging resistance state by using Eqs. (1) and (3). The reason for selecting the ultimate pile capacity from the model curve at 10% of helix diameter is due to the fact that the shape of the load settlement curve can be plunging with or without increase in load, which depend on the surrounding condition of the ground. It was also observed that prediction of both methods were similar to each other.



(a)



(b)

Fig.11 Comparison of pile capacity at plunging resistance and at 10% of helix diameter (a) Chin-Kondner method (b) Decourt method

It is observed from the pile load test data that the shape of the load settlement curves showed very clear bilinear relationship, which is very difficult to predict through extrapolation if the load test data is less than 5% of helix diameter. That is the reason; the prediction of both methods is on the higher side (10-15% average) at settlement equals to 10% of helix diameter (refer Figs. 10 and 11). Therefore, a reduction factor (RF) is proposed to control the over prediction of Chin-Kondner and Decourt methods (at 10% of helix diameter) based on experimental load test data in dense fine sand.

$$RF_{CK} = \frac{Q_{U10\%}}{Q_{UCK10\%}} \tag{5}$$

$$RF_D = \frac{Q_{U10\%}}{Q_{UD10\%}} \tag{6}$$

Where RF_{CK} (Chin-Kondner) and RF_D (Decourt) are reduction factors; $Q_{U10\%}$ reference pile capacity from the load test data at 10% of helix diameter; $Q_{UCK10\%}$ (Chin-Kondner) and $Q_{UD10\%}$ (Decourt) are ultimate end bearing capacity selected from the model curve at 10% of helix diameter.

The relationship of reduction factor with respect to settlement equal to helix plate diameter (D_W) is shown in Fig.12. The calculated reduction factors using Eqs. (5) and (6) were almost similar to each other as shown in Fig.12.

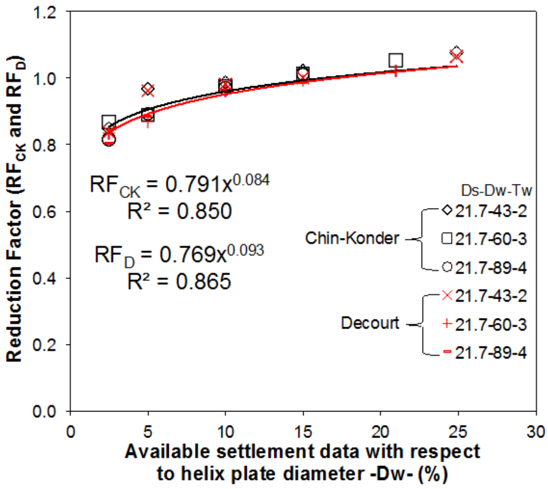


Fig.12 Relationship of reduction factor with respect to available load test data

The equations to calculate reduced ultimate end bearing capacity using proposed reduction factor for both methods are as follows.

$$Q_{UCK10\%}(Reduced) = Q_{UCK10\%} \times RF_{CK} \tag{7}$$

$$Q_{UD10\%}(Reduced) = Q_{UD10\%} \times RF_D \tag{8}$$

The comparison of reduced ultimate end bearing capacity using reduction factor (refer. Fig.12) with reference ultimate end bearing capacity showed very good agreement as shown in Fig.13.

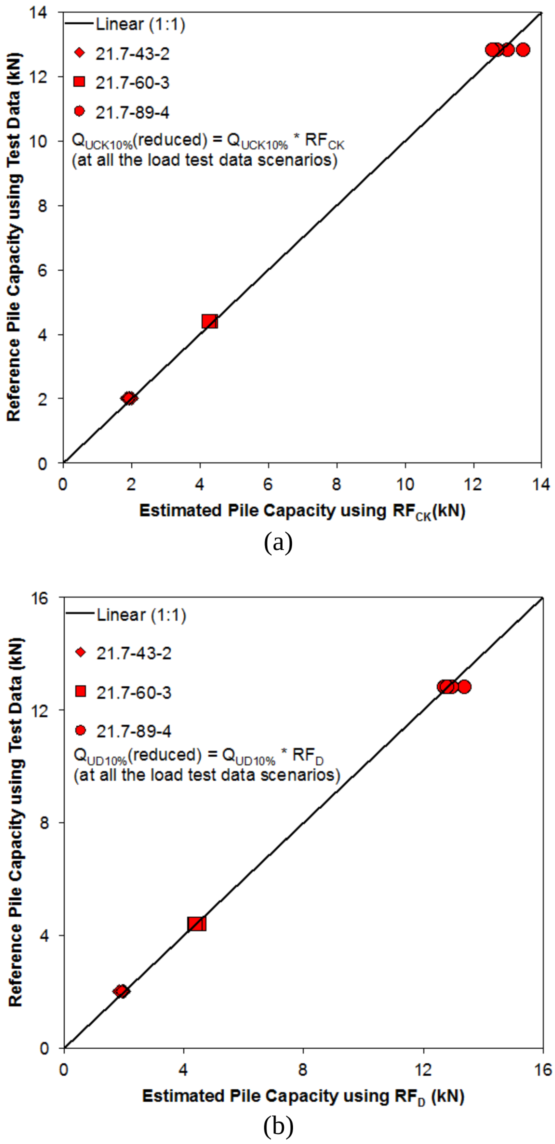


Fig.13 Comparison of reduced capacity with reference capacity (a) Chin-Kondner (b) Decourt

7. CONCLUSIONS

The extrapolation methods such Chin-Kondner and Decourt were used to check the indication of helix plate deformation from the screw pile load test data. The prediction capability of both methods was also checked when limited load test data is available. Based on test results and comparison analysis, following conclusions are drawn:

(1) The Decourt method of plotting can indicate the helix plate deformation during the pile load test that affects the ultimate pile capacity of the ground. It was observed from the test results that the straight-line portion transformed to convex downward curve as the deformation of the helix plate start affecting the load settlement behavior of the ground. The helix plate limit load that affects the load settlement behavior can be estimated if tangents are plotted on the convex downward curve.

(2) The prediction analysis indicated that both methods overestimate the ultimate pile capacity at plunging resistance state. However, the prediction analysis showed better agreement with the load test data if the ultimate pile capacity is selected from the predicted model curve at settlement equals to 10% of helix plate diameter (indicates full mobilization of end bearing). Therefore, it is better to consider the ultimate end bearing capacity at settlement equals to 10% of helix diameter from the model curve if limited load test data is available.

(3) A reduction factor based on pile load test results in dense fine sand is proposed to control the over prediction of Chin-Kondner and Decourt methods at settlement equals to 10% of helix diameter.

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