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COMMON GROUND 07

Numerical simulation of defective piles subjected to axial loads

Mohamed Shahin
Department of Civil Engineering, Curtin University of Technology, Perth, WA, Australia
Mohamed Sakr
Department of Structural Engineering, Tanta University, Tanta, Egypt

Keywords: finite element, pile foundations, pile defects

ABSTRACT

For heavy load structures on poor subsoil conditions, concrete piles are extensively used. The two main types of concrete piles are the precast driven piles and cast in-situ bored piles. During construction, it is common that cast in-situ bored piles experience some defects that may influence pile carrying capacity and structural safety. This paper aims to investigate the bearing capacity characteristics of defective piles using the finite element method (FEM). The defects considered are: improper end bearing; pile discontinuities; pile necking and poor concreting. It is concluded that numerical modelling using the finite element method is capable of simulating the behaviour of defective piles and that pile defects reduce the load carrying capacity of piles.

1 INTRODUCTION

It is common practice during the construction of cast in-situ reinforced concrete bored piles to encounter pile defects that endanger pile integrity and structural safety. Pile defects and associated problems have been reported and discussed by many investigators. For example, Hobbs (1957) reported a case of failure of cast in-situ pile that developed necking during installation which has occurred as a result of prevailing artesian ground water conditions. Peck (1965) described a case of building that suffered large differential settlements due to discontinuities in piling concrete with peaty soil gaps. Leonards (1982) reported a foundation failure of an oil tank at Fawley, England because of the presence of many gaps and discontinuities in the piles used. Xu (1999) carried out a nonlinear finite element analysis to study the load transfer characteristics of piles defected by breaks or gaps, and by the increase or decrease of pile diameter. Baker and Khan (1971) reported a case of failure where concrete was poured over a weak layer of sand and gravel that was accumulated at the bottom of borehole due to improper cleaning. Li (2007) conducted a statistical analysis on the rate of occurrence of pile defects as a result of poor concreting due to errors in handling slurry, casings and reinforcement cages. Olson and Thompson (1985) reported a case of five storey building that failed during the construction phase as a result of a considerable cracking of superstructure which occurred due to significant irregularity and voids in the pier shaft used for foundations. Anwar (1996) analysed the concrete strength of bridge piles concreted with interrupted tremie malfunction. Jung et al. (2006) evaluated the capacity of four full-sized cast-in-place piles that have artificial defects of soft bottom, concrete segregation and contractions of pile cross section. Sakr and Rao (2000) experimentally examined in the laboratory the impact of various defects on the load carrying capacity of piles.

Based on the aforementioned studies and reported cases of failures, the major pile defects may be summarised as: improper end bearing; pile discontinuity; pile necking and reduced pile strength as a result of poor concreting. In this paper, the influence of these defects on the bearing capacity characteristics of piles is investigated using the finite element analysis. A finite element model that simulates the behaviour of axially loaded piles is developed and used for the current study. Different defects are introduced to the developed finite element model and the results are presented and discussed.

2 DESCRIPTION OF FINITE ELEMENT MODEL

In this study, an axisymmetric finite element model for a concrete pile that is axially loaded is developed using PLAXIS (2004). A sound concrete pile is firstly simulated and used as a basis for comparisons against defective piles. The simulated pile has a diameter of 400 mm and length of 10

m. The surrounding soil covers an area extending to 30-pile diameter laterally and 3-pile length vertically, which most of the stress variations are expected to occur. The model is discretised utilising 15 node triangular elements (Figure 1). Due to symmetry, only one half of the pile and surrounding soil is considered in the numerical model. Roller boundaries are used in the vertical direction to warrant symmetry and to simulate end of soil, and fixed boundaries are chosen at the bottom of the model. Interface elements are considered between the pile and surrounding soil to allow for relative displacements. The axial load is simulated by applying prescribed displacements on the pile head and the corresponding loads are obtained (i.e. strain controlled). The minimum required mesh dicretisation is determined by carrying out a sensitivity analysis on various mesh dimensions until an optimal mesh is obtained. Details of the material properties used in the finite element simulations are given in Table 1 (columns 2 and 3), unless otherwise stated. Since the purpose of the present study is not to accurately predict the bearing capacity of piles but rather to investigate the bearing capacity characteristics of defective piles compared to those of the sound pile, arbitrarily material properties are used and exact bearing capacity predictions are not necessary.

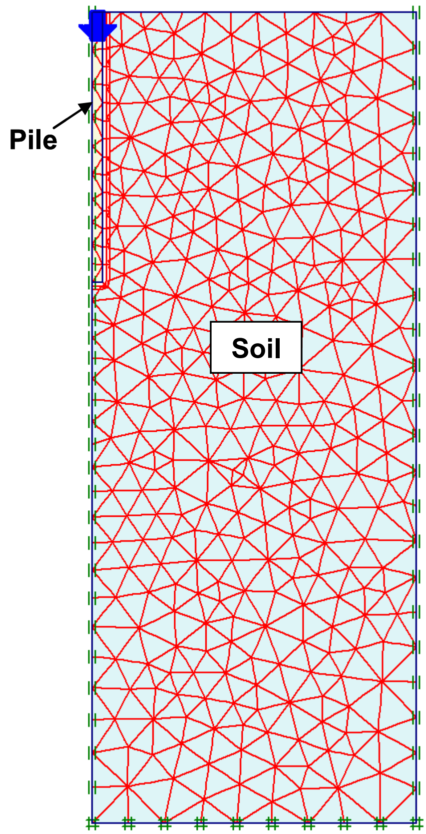

Figure 1: Finite element configurations used in PLAXIS

Table 1: Material properties used in the finite element simulations

Parameter	Pile	Surrounding soil	Soft base	Poor concrete
Material model	Elastic	Mohr-Coulomb	Mohr-Coulomb	Elastic
Density, γ (kN/m^3)	24	16	16	24
Young's modulus, *E* (MPa)	35000	15	2	5000
Poisson's ratio, *v*	0.15	0.35	0.30	0.15
Cohesion, *C* (kN/m^2)	–	30	6	–
Friction angle, Φ	–	24^o	5^o	–
Interface strength reduction factor	1.0	0.7	0.7	1.0

3 FINITE ELEMENT OF DEFECTIVE PILES

The finite element model of the sound pile developed in Section 2 is used to investigate the impact of pile defects on the bearing capacity behaviour of piles. Different pile defects (i.e. improper end bearing; pile discontinuity; pile necking and poor concreting) are introduced to the pile at a time, and the results are compared with those of the sound pile. It should be noted that all load-settlement finite element simulations are carried out up to pile displacement equal to 20% of pile diameter.

The improper end bearing is simulated by providing a soft soil layer (soft base) at the pile tip. The properties of the soft base used are given in Table 1 (column 4) and the load-settlement curve obtained is shown in Figure 2(a), which also contains the load-settlement curve of the sound pile. It can be seen from Figure 2(a) that due to the absence of proper end bearing, the ultimate pile load of defective pile is reduced by almost 21% compared with that of the sound pile. This emphasises the importance of embedding piles into proper end bearing for a sufficient length. It is not surprising that this type of pile foundation failures is common in several coastal areas where soft clay deposits are found, as reported by Baker and Khan (1971) and Fleming and Sliwinski (1977).

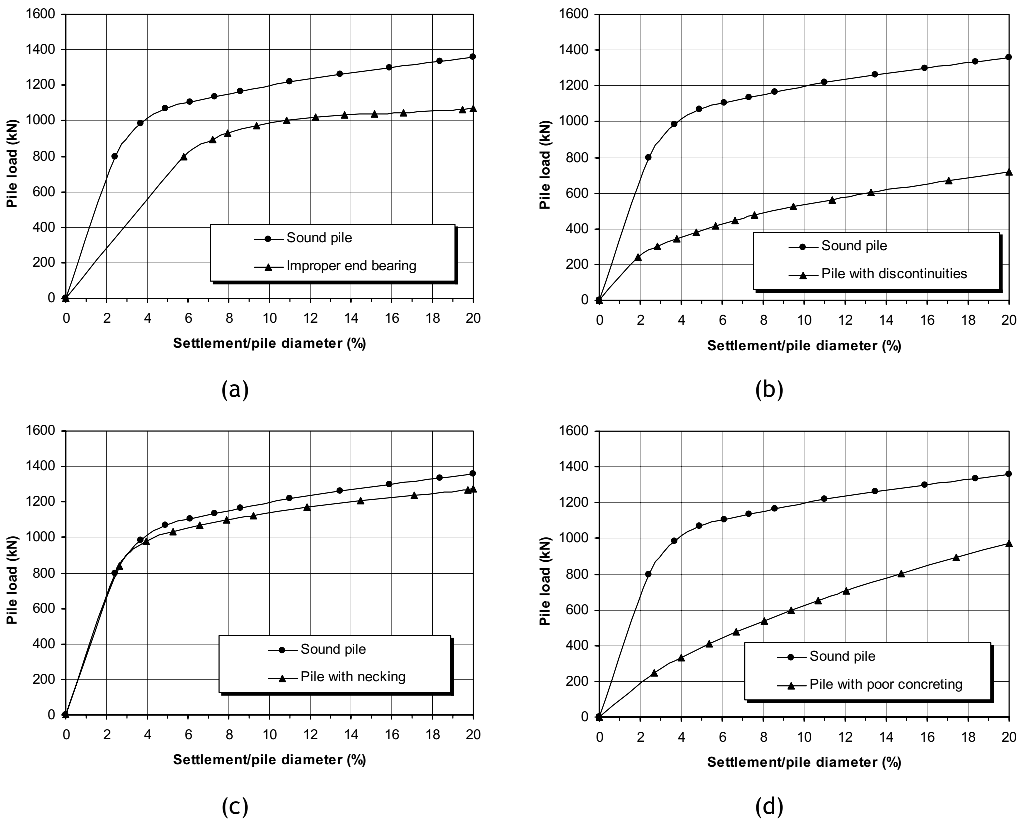

Figure 2: Influence of pile defects on pile bearing capacity: (a) improper end bearing; (b) pile discontinuities; (c) pile necking; and (d) poor concreting

The discontinuities in piles are modelled by introducing gaps of thin layers of similar clay of that of the surrounding soil at three different positions (i.e. 0.25 L, 0.5 L and 0.75 L, where L is the total length of pile). The results are shown in Figure 2(b) and illustrate that a significant reduction in pile load of 47% is occurred for defective pile compared with that of the sound pile. This is due to the compression of the clay gaps (discontinuities) introduced to the pile.

Necking is introduced to the finite element model by decreasing the pile diameter by 50% at three different locations (i.e. 0.25 *L*, 0.5 *L* and 0.75 *L*). The load-settlement curve obtained is shown in Figure 2(c), which shows a reduction in pile carrying capacity of defective pile of almost 7% compared with that of the sound pile. It should be noted that this reduction in pile capacity could be more if the structural failure of pile due to concrete crushing is allowed, which is not considered in the numerical analysis as pile concrete is assumed to behave as an elastic material.

In many situations, failure of pile foundations occur because of poor compaction of concrete; flushing of cement due to ground water flow or segregation of concrete, which result in reduced structural strength of piles. This condition is simulated by using poor concrete of low Young's modulus (Table 1, column 5). The load-settlement curve obtained for poor concreting is shown in Figure 2(d) and illustrates a reduction of almost 28% in the pile bearing capacity of defective pile compared with that of the sound pile. Again, as with necking, this reduction value could be even more if the pile was allowed to fail under concrete crushing. As mentioned previously, typical field cases of failure due to poor concreting have been reported by many researchers (e.g. Pandey 1967; Baker and Khan 1971; Olson and Thompson 1985).

4 CONCLUSIONS

It is evident from this study that the numerical modelling using the finite element analysis is capable of simulating the bearing capacity characteristics of defective piles. It was shown that improper end bearing can decrease the pile carrying capacity by almost 21%, and that pile discontinuities can significantly reduce the pile capacity by 47%. It was also illustrated that necking and poor concreting are capable of reducing the pile bearing capacity by 7% and 28%, respectively, provided that concrete crushing is not allowed. This study points out the importance of following strict quality assurance for cast in-situ bored piles so that possible defects can be avoided.

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