Parametric study simulation of axially loaded bored pile using finite element Code — Plaxis Software on subsurface soils Khartoum area-Sudan

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The diversity and complexity of subsurface soil in studied area consisting of alluvial deposits cause many difficulties for foundation engineering. Therefore, a solution is needed for foundation in this problematic soil. In Sudan, raft foundation represents the basic and most widespread shallow foundation method for engineering structure except for bridges where the pile foundation is used.

In recent years, after the discovery of petroleum in Sudan, a major advance in piling technology is needed due to intensive building of large numbers of precast high-rise tower. This paper used Plaxis software to understand the behavior of axially loaded bored pile using different loads, lengths and diameters of piles. In this paper a comprehensive analytical study using finite element analysis is presented and parametric study of pile under vertical load is performed. The analytical and quantitative analysis in this study shows useful understanding of the behavior of bored pile.

Keywords: bored pile, finite code, plaxis software.

Introduction

In the situation when the soil at shallow layers is poor, in order to transmit the load safely, the depth of foundation has to be increased till a suitable soil stratum is found.

Pile foundations are an example of deep foundations. Pile is a relatively small in diameter shaft, which is driven or installed into the ground by suitable means. Piles are usually driven in groups to provide foundations for structures. Pile group, may be subjected to vertical loads, horizontal loads or a combination of these two. Piles are useful in transferring load through poor soil or water to a suitable bearing stratum or through friction along the length of piles in soft soils.

Piles are also used to resist horizontal loads as in the case of foundations for retaining walls, bridge abutments and wharves. In the case of large lateral loads, piles are driven at an angle, these are found to serve better than vertical piles.

Shorts piles are sometimes used for compacting loose sand deposits which get densified by the vibration set up on driving, such piles are known as compaction piles. Piles are sometimes used to resist uplift loads and thus under tension. They are called tension piles. Piles can also be used to provide anchorage against horizontal pull as in the case of anchor bulkhead and termed as anchor piles.

Ottaviani [1] used three-dimensional finite element method for analysis of vertically loaded pile with or without pile caps. Due to the complexity of the single element stiffness computation and large number of elements, the piles and the soil were assumed as weightless linearly elastic homogenous media for examination of the load transfer mechanism [2]. Chow [3] presented a method based on elasticity theory for the analysis of axially and laterally loaded pile embedded in isotropic non-homogenous soils. Zhang and Small [4] proposed two methods based on the finite layer theory to analysis axially and laterally loaded pile embedded in the homogeneous and non-homogeneous soils. The principal of the methods is similar to that used by Lee and Small [5]. The effluence matrices of piles and the soil layered were obtained from the interaction method presented by Zhang and Small [6].

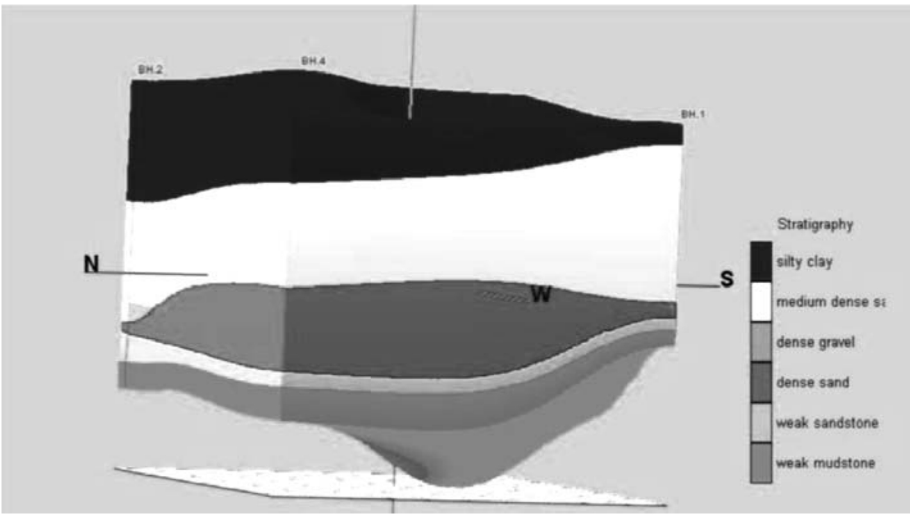

Fig. 1. Geo-electrical model of subsurface soil in the study area.

Subsurface soil in the study area

The study area covers part of Khartoum basin, which is one of the major central Sudan rift basins. The sedimentary sub-basin is elongated in NW_SE trend, where the Pan-African Basement complex bounds it on the northeast and southwest, and forms its bottom limit at the depth of 500 m. The sub-surface geology belongs to three Formations, which are regionally interconnected. These Formations are the (upper recent) superficial deposits and river alluvium, which rest unconformable on the Gezira Formation (quaternary-tertiary) and the upper part of Omdurman Formation (upper cretaceous) [7]. Most of the surface is cover by clay soils, which varies in thickness. consists of unconsolidated clay, silts, sand and gravel. Its rests unconformable on the Cretaceous sandstone formation and is overlain by blown sand and other superficial deposits [8]. Ibrahim [7] suggested that it comprise the area between white and blue Nile. Abdelsalam [9] divided Gezira formation into three members lower Mungata Member, Lower sandy Member and upper clay Member. Awad [10] considered Wad Medani Member as part of Gezira formation.

Engineering properties of subsurface soil

Intensive field site characterization and laboratories investigation have been conducted. Using rock work program the soil layers have been presented in three dimension model in Fig. 1.

Soil profile

The boreholes revealed existence of alternating layers of very stiff low to high plasticity silty clays (CL to CH) and very stiff low to high plasticity silts (ML to MH) in the upper 10 m. This is underlain by medium dense sand (SM or SP-SM) layer extended down to 20 m and this layer overlain a very dense sand layer extend 25 depth. The alternating layers of weak mud-stone and weak sand stone extended down to the bottom of the boreholes at about 35 m. These weak mud-stone and weak sandstone are belong to Omdurman formation which are extended to deepest depth.

Figures 2 and 3 show the particle size characterization and activity of the soil, respectively.

End Bearing Capacity of piles in Clay Soils

Driven piles: the widely used equation for driven piles proposed by Skempton defines the end bearing capacity in clay soils as follows Skempton [11]:

$$q = 9 \times Cu \quad (1)$$

where: q — end bearing capacity,
C_u — cohesion of soil at the tip of the pile

Martin et al. [12]:

$$q = c \times N \text{ MN/m} \quad (2)$$

where: c — 0.20,
N — SPT value at pile tip

Bored Piles: Shioi and Fukui [13] suggested the following Eq.

$$q = c \times N \text{ MN/m}^2 \quad (3)$$

where: c — 0.15,
N — SPT value at pile tip.

Skin Friction in Clay Soils. The equations are based on undrain shear strength (cohesion):

$$f_{ult} = \alpha \bullet S_u \quad (4)$$

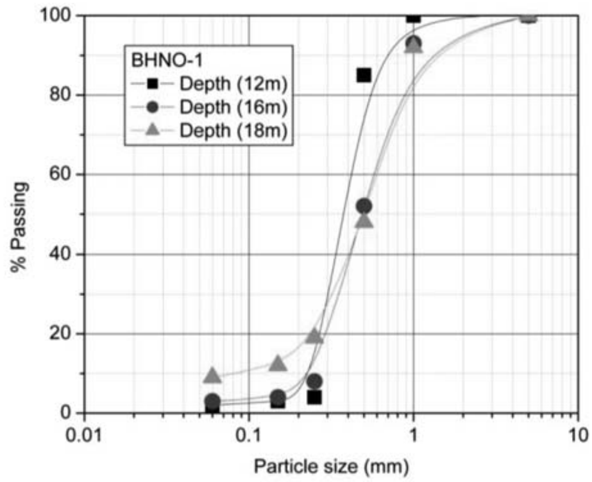

Fig. 2. Particle size of soil in the study area.

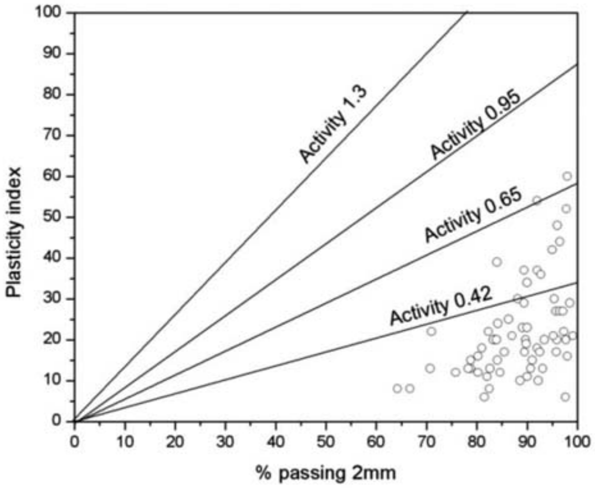

Fig. 3. Activity chart shows the activity of clayey soil.

where: f_{ult} — ultimate skin friction,
α — skin friction coefficient,
S_u — undrain shear strength or cohesion; $S_u = Q_u/2$,
Q_u — unconfined compressive strength

Driven Piles: American Petroleum Institute (API). API [14] provides the following equation to find the skin friction in clay soils.

$$f = \alpha \times C_u \quad (5)$$

where: f — unit skin friction,
C_u — cohesion,
α — 1.0 for clays with Cu < 25 kN/m^2 (522 psf)
— 0.5 for clays with Cu > 70 kN/m^2 (1,460 psf).

Interpolate for the α value for cohesion values between 25 kN/m and 70 kN/m^2. Per the API method, the skin friction is solely dependent on cohesion. Effective stress changes with the depth and the API method disregard the effective stress effects in soil.

Bored Piles: Fleming et al. [15] proposed this Eq. For this skin friction.

$$f = \alpha \times C_u \quad (6)$$

where: f — unit skin friction,
C_u — cohesion,
α — 0.7 for clays with Cu < 25 kN/m^2 (522 psf),
— 0.35 for clays with Cu > 70 kN/m^2 (1,460 psf).

Kolk and Van der Velde [16] method considers both cohesion and effective stress.

$$f_{ult} = \alpha \times S_u \quad (8)$$

where: f_{ult} — ultimate skin friction,
α — skin friction coefficient,
S_u — undrained shear strength (cohesion).

In this case, the skin friction coefficient, α, is obtained using the correlations provided by Kolk and Van der Velde [16]. The parameter α is based on both cohesion and effective stress.

The parameter α in the Kolk and Van der Velde equation is based on the ratio of undrained shear strength and effective stress.

Bored pile modeling

Finite elements have been used intensively in recent years for foundation purposes. Plaxis software was used in this study to evaluate the effect of pile length, diameter, soil models, load intensity on the shear stress and settlement of the foundation on axially loaded pile. In order to simulate the behavior of the soil and the structures, a suitable material model and appropriate material parameters were assigned to the geometry, Plaxis [17]. The parameters used in this study were taken from results of different type of tests conducted in the Geo-technical institute, University of Khartoum. The following tests are included: classification tests such as sieve analysis, liquid and plastic limits, water content, shear test to obtain the cohesion and friction angles of the soil, odometer test to gain the modulus of elastically and triaxial test. The parameters of the pile were taken from the literature. Values used for bored pile modeling are listed in Table 1.

Table 1. Material properties for the soil layers and pile.

Parameter	Name	Silty clay	Medium dense sand	Pile	Units
Material model	Model	Mohr-Coulomb	Mohr-Coulomb	Linear-elastic	—
Material behavior	Type	Un-drained	Drained	Nonporous	—
Unsaturated soil weight	γ unsaturated	14	17	24	kN/m^3
Saturated soil weight	γ saturated	18.2	22.3	—	kN/m^3
Young's modulus	*E*	9500	14300	$2.10.0^7$	kN/m^2
Poisson's ratio	ν	0.3	0.2	0.25	—
Cohesion	c	25.3	8	—	kN/m^2
Friction angle	ϕ	4	28	—	°
Dilatancy angle	ψ	0	0	—	°
Interface reduction factor	R_{inter}	1	1	1	—

Simulation of pile modeling

Different lengths and diameters with different load intensity were assigned to the pile foundation in this study Table 2.

Table 2. Load, pile length and diameter.

Force [kN]	Pile length [m]	Pile diameter [m]
300, 350, 400, 450, 500, 550, 600, 652, 650	8, 12, 15	0.3
300, 350, 400, 450, 500, 550, 600, 650	10	0.3, 0.4, 0.5

Create the model

The well-known Mohr-Coulomb Model model is usually used as a first approximation of soil behavior. Due to its simplicity, it is highly popular and gives reasonable results. The model involves five parameters, i.e. Young's modulus, E, Poisson's ratio, ν, cohesion, c, internal friction angle, ø, and dilatation angle, ψ.

Pile model

The piles were model as Linear Elastic Model This model represents Hooke's law of isotropic linear elasticity.

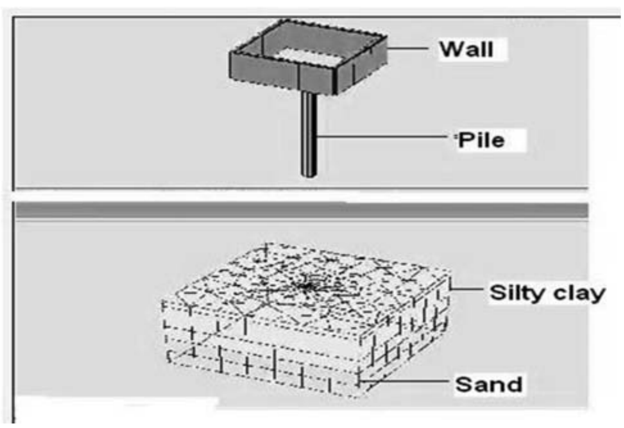

Fig. 4. Pile and soil model.

The model involves two elastic stiffness parameters, i.e. Young's modulus, E, and Poisson's ratio, ν. The linear elastic model is seldom used to simulate soil behavior. It is primarily used for stiff massive structural systems installed in soil, such as the test piles in this paper.

The model was drown sufficiently large so that the boundaries do not influence the results of the problem to be studied. Figure 4 shows the soil model.

Result and Discussion

The results of pile foundation modeling using plaxis software are shown in Fig. 5. Figure 5 shows the total displacement and type of failure within acceptable deformation limit.

The load settlement curves provided in this study show good understanding of the effect of pile lengths and diameters on piled foundation behavior. The increase in length of pile, causes an increase in its load carrying capacity, shear stresses, shear strain and hence helps the pile in undergoing lesser settlement, Fig. 6. There is limiting value of pile length beyond which further increase in length does not help in increasing load carrying capacity nor reducing settlement, these study agree with results presented by Dilip Kumar Maharai [18]. Referring to the stress-settlement relation, it can be clearly seen that there is any break point. So the stresses make 25 mm deformation are used for all pile length as failure point.

Future research

The paper presented the behavior of vertically loaded bored pile with different thicknesses and lengths supporting vertical load using finite element code- Plaxis software. The research presented here will be extended to analysis the following

- Pile supporting vertical and inclined load.
- The effect of applying load from structure on the soil and changing of the soil modulus due to compression.

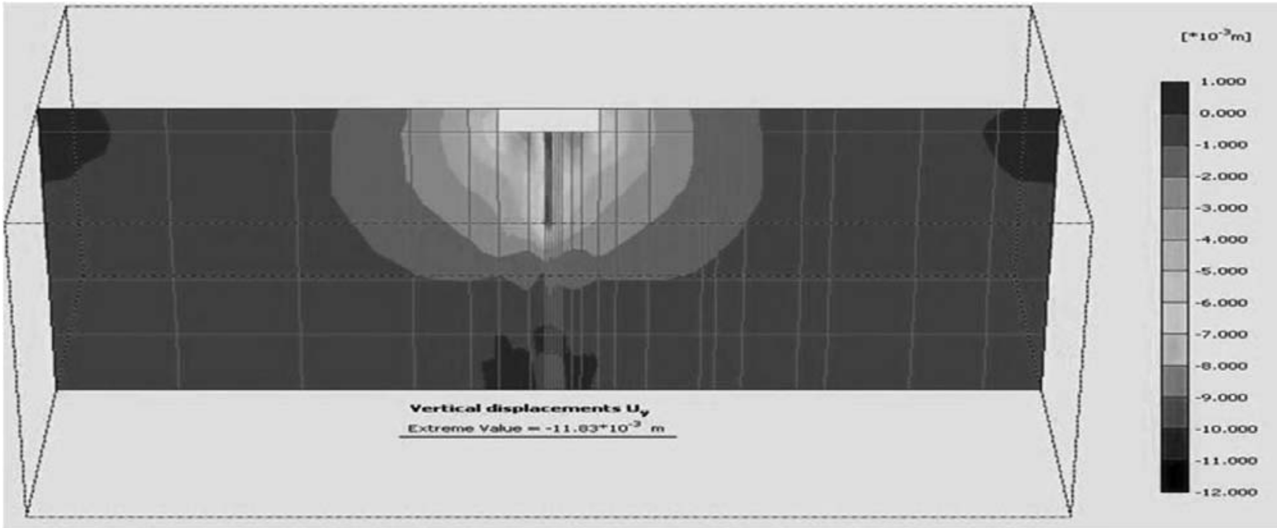

Fig. 5. The vertical displacement and type of failure of the pile foundation.

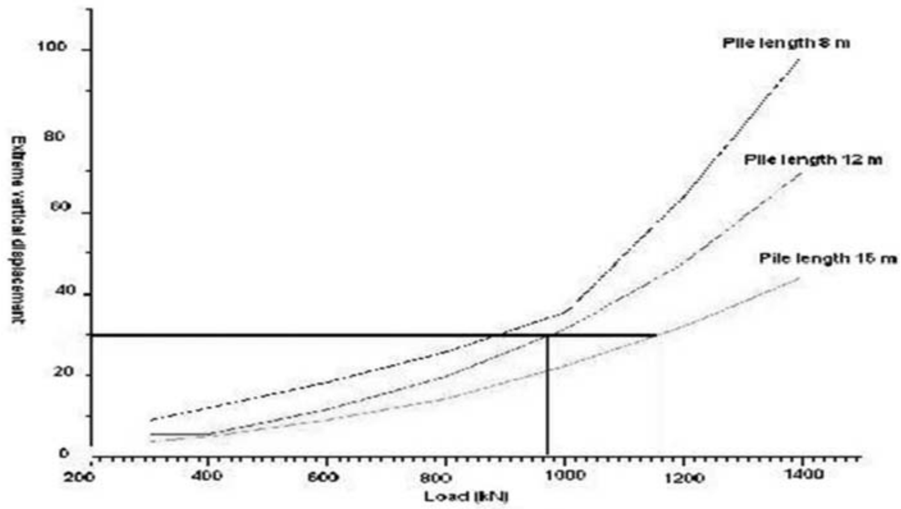

Fig. 6. The bearing capacity tend to increase with the increase of pile length.

- The effect of ground water fluctuation on the stability of the structure.
- Use of pile raft method instead of pile foundation.

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