

The Impact Analysis of Pile and Soil Parameters on Compressive Capacity of Long Pile

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Abstract. Using Finite-element Method to simulate prototype piles and then drawing the Load-settlement curves in order to calibrate the analysis software. When the simulation was consistent with the measured piles, taking it as the benchmark and then eight parameters were varied respectively so that the impacts on pile compressive capacity could be investigated. These parameters were soil's effective unit weight, lateral pressure coefficient, elasticity modulus, Poisson's ratio, cohesion, internal friction angle, pile's elasticity modulus and Poisson's ratio. Especially, soil's internal friction angle and pile's elastic modulus were deeply studied. The derived conclusions ranked the parameters by their influencing abilities. Furthermore, pile's elasticity modulus was emphasized to be paid high attention in long pile designing.

Introduction

Although pile is a very common foundation component, the research for it is often done and often new. Pile compressive capacity is finally embodied in the reaction of pile and soil, so knowing the contributions of pile-soil parameters is very necessary. Researching parameters of soil around and below the pile, some scholars back deduced from data getting from experiments [1,2] and some used Finite-Element-Method(shorted as "FEM") [3-6]. This paper mainly imitated the second way, thus the main work is to vary parameters' values to investigate their impacts on pile capacity on the platform of FEM. If the impact trends of pile-soil parameters on pile capacity were known, then the foundation scheme comparison would be easier and more effective on the situation of lacking measured pile data.

Study Method

Because of the lower cost and flexible parameters variety, FEM is a good tool for studying. For the sake of using this tool reliable, calibrating the simulation is necessary. That is to say, virtual simulation must be checked against actual prototype. Only if the results were agreed the followed up researches were dependable.

The prototype included two measured piles, which were bored piles with 61m of length and 1m of diameter. The measuring system was comprised of anchor piles, beam counterforce device, jack and dial indicator. Load was slowly added to complete tests. The parameters of soil layers were shown in Table 1

FEM software was ABAQUS. Modeling methods were referred to document [7]. Under vertical load the pile's geometrical shape and compression are symmetric, so two-dimensional plane model was established as shown in Fig. 1. Pile body was simplified as elastomer. The elasticity modulus -- $E_p = 3.15 \times 10^7 \text{ kPa}$, and Poisson's ratio -- $\nu_p = 0.2$, were equivalent to C35 concrete. Geological exploration report only provided compression modulus of soil, but ABAQUS needed elasticity modulus, so based on the conclusion of document [8], the compression modulus timed 15 to act as elasticity modulus. Soil's plasticity was assumed to agree with Mohr-Coulomb Model [9], and effective unit weight 13 kN/m^3 . Pile-soil tangential frictional coefficient was assumed as $\mu = \frac{\sin \varphi \cdot \cos \varphi}{1 + \sin^2 \varphi}$ [10], and normal contact was "hard". The element type of pile and soil was CAX4I – 4-Node quadrilateral bilinear incompatible axisymmetric element.

Tab. 1 Parameters of Soil Layers

No.	Soil Layer	Depth [m]	Unit Weight [kN/m ³]	Modulus of Compressibility [kPa]	Cohesion [kPa]	Internal Frictional Angle[°]
②-1	Muck	14.4	15.85	1500	18.9	10
②-2	Muck	12.9	16.11	1700	21.2	11
③-1	Mucky Clay	1.6	16.81	3500	26.2	12.4
③-2	Silty-Fine Sand	4.2	19.01	5000	14.6	23.8
③-3	Mucky Clay	8.3	19.11	6100	29.5	17.5
④-1	Silty Sand	2.6	19.22	8100	15	23.8
④-2	Silty Clay	2.6	18.87	6700	32.6	17.7
⑤-1	Round Gravel	2.4	19.01	11000	—	40
⑥-1	Silty Clay	7.9	18.79	7400	50.8	11.4
⑥-2	Silty Clay	3.1	19.42	11700	48.2	14.7
⑦	Round Gravel	4.1	19.6	12000	—	40
⑧	Silty Clay	unpenetrated	18.54	7000	—	17.3

The comparison between simulation and prototypes were shown in Fig. 2.

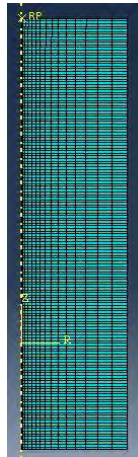
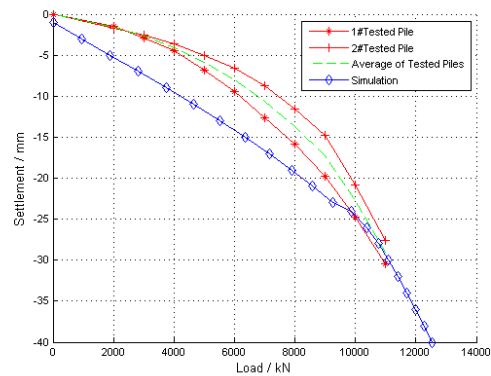


Fig. 1 Meshed FEM Model

Fig. 2 Q - S Curves of Measured Piles and Simulation

The simulation was fit worse with measured piles in the first half of Q - S curve but better in the second half. Especially in the stage of determining ultimate compressive capacity, the simulative curve appeared inflection point which was almost identical with measured value. Basically, researchers cared less about the first half of Q - S curve unless intending to find defects of pile, but they cared more about the second half of the curve because they were interested in the ultimate state, so the simulation was feasible.

Analysis

Since the simulation was agreed with measured piles, it was set as datum, and eight parameters – soil's effective unit weight, lateral pressure coefficient, elasticity modulus, Poisson's ration, cohesion, internal friction angle, pile's elasticity modulus and Poisson's ratio – were varied respectively to show the impacts on pile compressive capacity, and the variation range was 0.5, 0.75, 1.25 and 1.5 times of the original values. It must be pointed out that, the variation range was just set in the unified intervals, whether or not the values were rational was not considered.

Impact on Compressive Capacity. The impact curves of each parameter on pile compressive capacity were shown in Fig. 3.

Fig. 3 showed soil's internal friction angle influenced pile compressive capacity strongest, and the impact curve was nearly linear. Internal friction angle was coupled with pile-soil frictional coefficient, so the impact was a coaction result. Long pile was friction-type, so the higher frictional coefficient, the more advantageous the development of pile capacity.

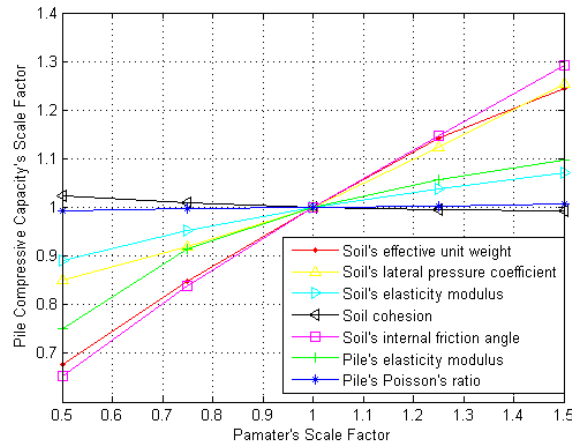


Fig. 3 Impact Curves of Each Parameter on Pile Compressive Capacity

The second strongest parameter was soil's effective unit weight. Effective unit weight generated effective gravity stress, and then effective gravity stress generated normal pressure to pile side, after that normal pressure and frictional coefficient together generated pile shaft resistance, so the effective unit weight was a very important parameter.

The third strongest parameter was pile's elasticity modulus. When the modulus was greater than datum, pile's compressive capacity ascended slowly; when the modulus was smaller than datum, pile's compressive capacity descended rapidly. When elasticity modulus was greater, pile's self compression was smaller and the pile could be regarded as nearly rigid, so the compressive capacity depended on soil properties mostly. On the contrary, when elasticity modulus was smaller, pile's self compression was greater, so the impact of the modulus became more and more important.

The datum of soil's lateral pressure coefficient was 0.53. Since the greater value was out of rational range, the lateral pressure coefficient curve was effective only if the value was smaller than datum. The curve showed its impact power was smaller than pile's elasticity modulus.

Soil's elasticity modulus, or compression modulus, had moderate impact on pile compressive capacity. The efficiency was lower than the above parameters.

Soil cohesion, Poisson's ratio of pile and soil hardly had impacts on long pile (or friction-type pile) compressive capacity.

Further Study About Internal Friction Angle and Frictional Coefficient. As simulation assumed, soil's internal friction angle was coupled with pile-soil frictional coefficient, but the coefficient might change independently by material surface treatment. The innovations of pile, such as lateral jet grouting, planting kernel pile into soil-cement, etc., very likely improved the pile-soil frictional coefficient by means of cement slurry and then promoted shaft resistance, meanwhile the internal friction angle was not changed. So made the frictional coefficient and internal friction angle separation, and then observed their impacts on pile compressive capacity respectively. The calculating results showed in Fig. 4.

It could be seen in Fig. 4, if soil's internal friction angle was not coupled with frictional coefficient, the impact of internal friction angle could be ignored. In other words, the impact of frictional coefficient on pile compressive capacity was far more strong than internal friction angle.

The two main parameters in Mohr-Coulomb Theory, cohesion and internal friction angle, nearly had no influence on pile compressive capacity, it seemed like strange, but for long pile it was reasonable. Long pile is friction-type, empirically, although pile compressive capacity reaches ultimate, the stress of soils around pile will not reach the limitation, so the pile failure mode will not include shear failure of soils around the pile. This is the reason why cohesion and internal friction angle seemed not important. Were pile end-bearing-type, tip resistance became main part of pile compressive capacity, situation would be

totally different. At that time, pile compressive capacity depended on tip resistance, tip resistance depended on soil strength, and soil strength depended on soil cohesion and internal friction angle, so the two parameters would definitely play very important roles.

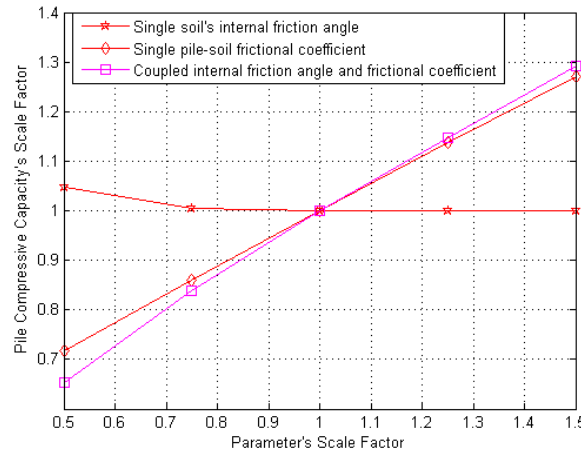


Fig. 4 Impacts of Soil's Internal Friction Angle and Frictional Coefficient on Pile Compressive Capacity

Further Study about Pile Elasticity Modulus. Engineers might take more care about pile's strength in designing. As far as strength was greater demands, engineers would like to use low strength concrete so that economical efficiency could be promoted, but they took less care about pile stiffness. This sort of designing idea was suitable for short or moderate long pile but was not for long pile. Pile stiffness was mainly manifested by elasticity modulus. As mentioned above, pile's compressive capacity descended rapidly along with elasticity modulus, so it was necessary to take further study for pile's elasticity modulus. As pile's elasticity modulus varied, pile's body deformation was shown in Fig. 5, and Mises stress in Fig. 6.

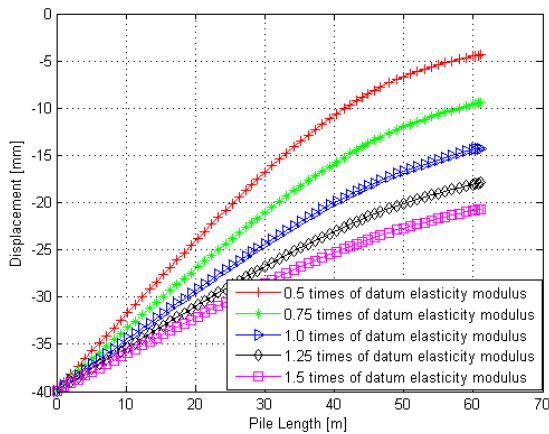


Fig. 5 Deformations of Pile Body Segments

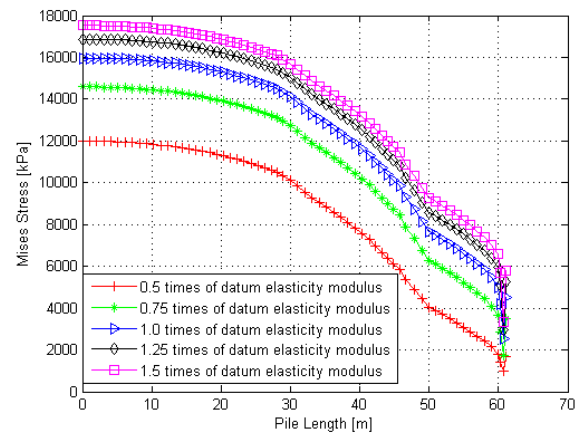


Fig. 6 Mises Stresses of Pile Body Segments

The pile top settlement was set as 40mm in simulation. When the pile elasticity modulus varied, toe settlements differentiated greatly, -- the softest pile's toe settlement was only 4.4mm. That meant pile body compression was up to 35.6mm and accounted for most of the deformation. At that time, the pile compressive capacity was 9413kN only. The datum pile's compressive capacity was 12539kN and the largest stress was 15960kPa on the top of the pile, so if the design was given priority to strength, concrete would be confirmed as soon as its strength greater than stress under the most unfavorable conditions, that meant concrete grade C25 was confirmed (Specification stipulates the minimum concrete grade is C25 for pile)[11]. But the elasticity modulus of C25 was 2.8×10^7 kPa which 0.93 times of datum modulus only, so concluding from Fig. 3, pile compressive capacity might not meet predetermined standards. Specification requires determining pile ultimate capacity by testing for high-class foundation, so piles were often given higher concrete grade for testing in order to be not destroyed during the process of static

load, but were given lower concrete grade in designing if the strength met the largest stress among tested results. At that time, the phenomenon of elasticity modulus might change pile compressive capacity must be paid very much attention, especially when the testing pile is long and concrete grades is high.

Summary

By FEM simulation and analysis, some conclusions suiting for concrete long pile were drawn out:

1. Pile-soil frictional coefficient, soil effective unit weight influenced pile compressive capacity mostly, and soil's lateral pressure coefficient influenced greatly. Soil cohesion, Poisson's ratio of pile and soil had little influence on pile compressive capacity.
2. Concrete long pile's elasticity modulus had very important impact on pile compressive capacity. It determined pile section stiffness and body compression, so did not low the concrete grade just because stress was small, it should be aware that concrete grade coupled with elasticity modulus, elasticity modulus coupled with pile body compression, and finally compression coupled with compressive capacity.

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