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桩土摩擦粘着特性及分析方法

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摘 要 同一土层的桩侧摩阻力在不同条件下取值会有很大区别,因此有必要对桩侧摩阻力的影响因素进行分析。分析了桩土的摩擦粘着机理,指出影响侧摩阻力的因素主要为桩土界面强度及土层强度,其中桩土界面强度包括界面摩擦力和界面粘着力两部分。根据机理分析提出使用有限元法配合试验结果进行分析应包括两方面的内容:(1)根据试验实测结果通过试算确定侧摩阻力极值由桩土界面强度决定还是由土层强度决定;(2)若侧摩阻力由界面强度决定则根据土层特性进行摩擦系数假定,进而确定界面摩擦力及粘着力。介绍了ADINA建模及计算过程。通过应用一组混凝土短桩的静载试验结果进行计算分析来说明分析过程。

关键词 桩 桩侧摩阻力 ADINA 有限元分析 摩擦

中图法分类号 TU473.21; **文献标志码** A

Engineering experience showed when the soil and pile style is determined, the bottom condition, the direction of force applied on pile, the characters of nearby soil, the depth of soil can also influence the value of utmost shaft soil resistance[1—3]. For the variation reason of shaft soil resistance of pile, some researches have carried out from different aspects such as the performance of soil[4], the interact of pile and soil[5], the depth of pile[6], the influence of bottom resistance[7,8] and so on. Because the essence influence factors are the strength and stiffness of pile-soil system, the analysis study should be carried out.

Load test is a wide used method to test the shaft soil resistance of pile. But how to use the field data and the testing result to analyze the determining factors of shaft soil resistance of pile is an unsolved problem. A procedure of such analysis is introduced using ADINA software.

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1 Crucial influence factors of shaft soil resistance

There are many factors influencing on the shaft soil resistance, but only two of them are crucial. One is the strength of the pile-soil interface, the other is the strength of the soil. The value of the utmost shaft soil resistance is determined by the relatively weak one. The strength of the pile-soil interface and the strength of the soil have something in common, but actually deferent. Testing results show that the strength of the pile-soil interface can expressed as[9]

$$Q = a + \mu P \tag{1}$$

in which, a is the adhesive force of the pile-soil interface, μ is the coefficient of friction. This expression is similar to the expression of shearing strength of soil, but the meaning are different. The expression of soil shearing strength is[10]

$$\tau = c + \sigma \tan \varphi \tag{2}$$

in which, c is the coherence of soil, φ is the angle of internal friction of soil. In the expression of the pile-soil strength the adhesive force is determined by the coherence of the soil and the microcosmic constitution of

the pile surface. The coefficient of the friction is correlative to the coarseness of the pile surface and the material speciality. Analyzing with the theory of contact mechanics and fractal, the expression can be get[11]

$$\mu = f(D, G, \varphi, \upsilon, K, A_r) \tag{3}$$

in which, D is the fractal dimension of surface outline, G is the scale coefficient reflecting the range of outline, A_r is the actual contact area, υ is the poisson ratio of material, φ is the character parameter of material which can be regarded as the yield strain of material, K is the correlation coefficient of the rigidity and yield stress.

D, G and A_r are the parameters reflecting the coarseness of pile-soil interface, υ, φ and K are the parameters reflecting the characteristic of material. From above expression it can be seen that the friction coefficient is a value related to the coarseness of the interface and the characters of the contact material. Analyzing with the above expression is very complexity. There are differences in the pile-soil interface strength and the soil shearing strength. The soil shearing strength is correlative with the contact force between soil particles, while the pile-soil interface strength is correlative with the contact force between pile particles and soil particles.

When the strength of the pile-soil interface is high enough, the destroy will happen in the soil. It is not to considered that the side soil resistant of a pile is completely determined by the soil strength. Because the soil is not barely bear the shearing force, there are original vertical and side direction pressures, which made the soil under three direction forces. Soil stress around pile is axial symmetry, a hexahedral element (fig. 1) is chosen to be analysed. In fig. 1, shearing stress τ is caused by shaft soil resistance of pile, other stresses are determined by original soil stress and the constrict condition of nearby soil when soil being deforming. Based on the strength rule of soil, the strength condition is determined by all stresses of the hexahedral element. The shearing stress τ is not a certain value when the element reaches its strength condition, this means the shaft soil resistance of pile is not certain also.

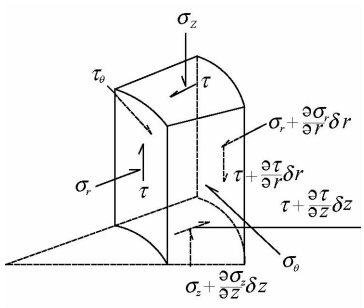

fig. 1　Hexahedral element and its stress

The influence factors can be summed up in three aspects: (1) the original vertical and side pressures of soil and the changes of them caused by the displacement of pile; (2) the strength parameters of the pile-soil interface (c, μ); (3) the material characteristics of a pile and soil. The main reasons that cause the different of the shaft soil resistance of a pile are the original value and changes of vertical and side pressures, especially of side pressure, because the side pressure can influent not only the maximum and minimum value of principle stress, but also the value of interface friction.

The destroy mechanics can be simulated by finite element analysis. Commonly finite element calculation will set contact elements in the interface of a pile and soil. The contact element has its particular strength condition and stress-stain rules, which are independent to the material parameters of soil. For different parameters of soil or the interface strength, destroying may happen in soil or in the pile-soil interface. In the calculation, parameters of soil can refer to geologic examination report, parameters of the pile-soil interface can be obtained from test data. For more accurate calcula-

tion, the parameter choosing is important.

2 Analysis of shaft soil resistance

Pile calculation method can be concluded as follows; (1) methods basing on mechanics, such as load-transfer method, elastic method, shearing distortion transfer method etc; (2) methods basing on experience, such as statistics methods; (3) numerical methods. Finite element theory is the representative method of numerical method. Pile testing results indicates that the shaft soil resistance of pile is influenced by pile style, pile length, side soil and their position, bottom condition and so on. For the complex interaction of pile and soil, to add up the statistic value of shaft soil resistance of pile only according to the soil characteristic can not get the accurate total value. Using finite element method can take the interact of pile and soil into account, so it is more suitable for the study of the mechanism of shaft soil resistance of pile,

ADINA is a common finite element program, the steps to forming a ADINA program for pile calculation are as follows. (1) For pile-soil calculation, axial symmetry model can be used. The range of calculation is shown in fig. 2 (2) The surface according the position of point and the boundary condition are defined. (3) The material characteristic and element group are defined. For pile elastic model can be used. For rock or soil Mohr-Coulumnb model or Drucker-Prager model etc can be used. (4) The original stress is calculated. A "transfer" method can be used to apply the original soil stress. Firstly several temporary soil elements are set up, for convenience to apply original stress, the position of temporary soil element can be same as the position of pile element, their characteristics is same as nearby soil. After applying gravitation, calculation can be fulfilled and the soil stress from the result can be drawn out. In this step of calculation the soil pressure parameter need not be imported because all condition are clear the stress of every nodes can be calculated directly. The calculated stress of this step is the original stress. (5) The actual model of pile-soil system is established. The temporarily soil element set in the original stress calculation is deleted, and the element is replaced with pile element. (6) The contact group and contact pair are defined. (7) The original stress in the new model is applied and the pile load is applied. (9) The calculation is carried out.

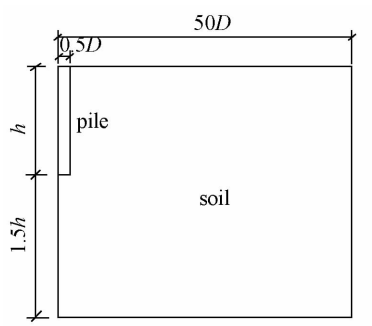

fig. 2 the sketch map of griding area in finite element analysis

To judge the destroying happened in soil or in the pile-soil interface, ADINA interface order "tied" is used to make the interface unbreakable. The calculated result is determined by the strength of soil. Comparing with the calculation results with the testing results, the actual destroying position can be known. If the interface is set to be unbreakable and the shaft soil resistance of testing values is smaller than calculating one, it indicates that destroying position is in the pile-soil interface. In equation (1) the value of Q is the testing value of shaft soil resistance, the value of P is side soil pressure, which can be calculated with the ADINA program. One of the value c and μ should be determined firstly according to the different soil characters, then the other one can be calculated. By analyzing the destroy position and interface parameters of pile-soil system, the influence factors of shaft soil resistance of

pile can be clear. Because the friction force is affected distinctly by the side soil pressure, when estimating the shaft soil resistance which is determined by the friction of pile-soil interface the depth of soil should be taken into account.

3 Analysis example

An analysis example for compressive test of short pile in middle weathered rock is given. The test was conducted in haizhu District, Guangzhou city. The test piles are all 0.5 meters in diameter and 0.5 meters in length. The geologic data and the position of short piles are shown in fig. 3.

Because the geologic situation and the depth of each pile is almost same, it can be calculated using a single one model. The calculated depth is 25 m. The geologic situation and values of parameters for calculation is shown in table 1. For medium weathered rock Mohr-Coulomb model is used, for weak weathered rock elastic model is used.

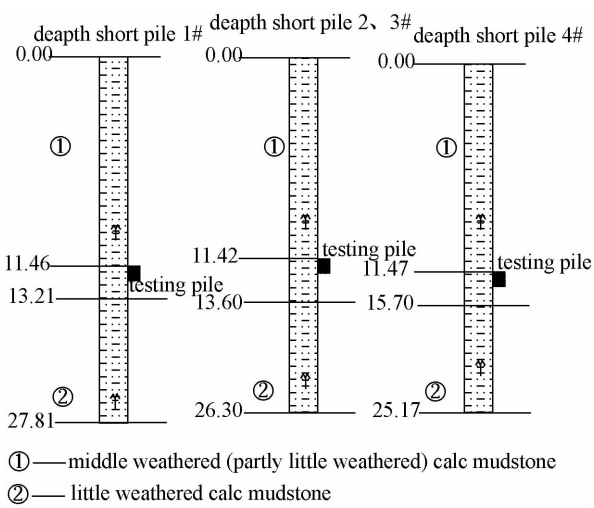

fig. 3　The geologic situation and the location of the test piles

Firstly, set the contact pair as tied, which make the interface unbreakable. The calculated ultimate shaft soil resistance is 5 661 kPa, which is much bigger than the testing value. So it can be presumed that the destroy happened in the pile-rock interface. After determining the destroying happened in the interface, the interface parameters can be calculated using testing data. From equation (1) it can be known that the interface condition is determined by the parameters a and μ and side soil pressure P. Side soil pressure P is difficult to be test, but can be easily calculated with ADINA software. From tests it was known that the μ value of medium weathered rock and concrete changes between 0.80 and 1.30[12]. When side pressure value is low, the error of μ value would not influent the result distinctly, so the μ value can take as 1.05. The adherence value can be gotten using testing value minus calculated friction value. The calculation value is shown in Table 2.

Table 1　The geologic situation and values of parameters for calculation

Soil horizon	Depth of soil horizon /m	Elastic modulus /MPa	density /kg · m^{-3}	Coherence /kPa	Internal friction angle/(°)	Friction coefficient
Middle weathered rock	15.7	4.0	2.0	1 046.0	48.0	1.05
Little weathered rock	25.2	18	2.2	/	/	/

Table 2　The comparing between the testing values and calculating values of side rock resistance of piles in compression testing

Pile number/(#)	Test value /kPa	Calculated value of interface friction/kPa	Interface adherence/kPa
1	2 866	769	2 097
2	2 548		1 779
3	2 229		1 460
4	2 229		1 460

From the analysis it can be presumed that for the testing short piles, the ultimate shaft rock resistance

will range from 1 460 kPa (when the original rock stress is zero) to 5 661 kPa (when the original rock stress is big enough and the shaft resistance is determined by rock strength) and the value between them is determined by the original rock stress.

5 Conclusions

(1) The influence factors to the shaft soil resistance of pile can be summed up in three aspects: First, the original vertical and side pressures of soil and the changes of them caused by the displacement of pile. Second, the strength parameters of the pile-soil interface (c, μ). Third, the material characteristics of a pile and soil.

(2) An analysis procedure of shaft soil resistance of pile using ADINA software should include three steps: First, judging the destroy position and using the testing value to calculate the interface parameters if the destroy happened in the interface. Second, determining the interface parameters a and μ consulting to the parameters c and tg ϕ of soil. Third, adjusting the parameters to make the result to be agree with the testing results and distinguish the friction force from the adherence force in pile-soil interface strength. Because the friction force is affected distinctly by the side soil pressure, when estimating the shaft soil resistance which is determined by the friction of pile-soil interface the depth of soil (or the original stress of soil) should be taken into account.

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织提供科学的依据。然而集装箱运输组织是一个比较复杂的优化问题,涉及的很多参数的标定也很困难,在此的研究也期待给集装箱运输的组织优化提供一定的理论支持。

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Research on the Optimization Model of Scheduling for Multimodal Transport of Containerized Cargo Problem

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[**Abstract**] The competition among the container transport companies grows more and more vehement, however, the management levels and methods of those companies have not been increased accordingly. Based on analyzing a lot of restrictions elements in the multimodal transport system, from the view of realizing profit-maximizing of the transport operators, a cargo container transport schedule optimization model is constructed, according to this kind of Integer programming model, a corresponding example to is also give verify the validity of the model.

[**Key words**] multimodal transport freight scheduling Integer programming model

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Characteristic and Analysis Method of Friction and Adherence of Pile and Soil

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[**Abstract**] The shaft soil resistance of pile may change in different situation. It is important to analyze the influence factors of it. The friction and adherence mechanics of shaft soil resistance of pile are analyzed. It is indicated that the main influence factors are the strength of pile-soil interface and the strength of soil. The strength of pile-soil interface include interface friction and interface adherence. Accordingly, finite element analysis of testing piles should include following content. First, to judge the destroy position in the pile-soil interface or in the soil by trial calculation. Second, if the destroy is judged to be in the pile-soil interface, a further calculate is needed to make clear the proportion of friction and adherence by presuming the friction coefficient. The ADINA program for pile analysis is introduced. A set of side friction testing results of a group of concrete short pile in middle weathered rock is analyzed using ADINA program to illuminate the analysis procedure.

[**Key words**] pile shaft soil resistance of pile ADINA finite element analysis friction