

Influence of constitutive model on soil structure interface interaction under axisymmetric condition

Binbin Xu^{1,2,3,4*}

¹Tianjin Port Engineering Institute Co. Ltd. of CCCC First Harbor Engineering Co. Ltd., Tianjin, 300222, China

²CCCC First Harbor Engineering Co. Ltd., Tianjin, 300461, China

³Key Lab. of Geotechnical Engineering of Tianjin, Tianjin, 300222, China

⁴Key Lab. of Geotechnical Engineering, Ministry of Communication, Tianjin, 300222, China

Abstract. This paper mainly studies the performance of axisymmetric radial interaction between soil and structure under radial stress. One of the key points is the research on the mechanical properties of the interface. The latter is now the frontier field, and also the focus of this paper's theoretical analysis. Based on FEM, a large-scale international finite element software, this paper attempts to establish a general comprehensive model with comparative function through the advantages of numerical simulation. After obtaining the results, the analysis focuses on the influence of different materials on the interaction, and summarizes the stress field, strain field, displacement field and stress-strain relationship of the model under different materials.

1 Research background

This paper mainly studies the performance of axisymmetric radial interaction between soil and structure under radial stress. One of the key points is the research on the mechanical properties of the interface. The latter is now the frontier field, and also the focus of this paper's theoretical analysis^[1-3]. Based on FEM, a large-scale international finite element software, this paper attempts to establish a general comprehensive model with comparative function through the advantages of numerical simulation. After obtaining the results, the analysis focuses on the influence of different materials on the interaction, and summarizes the stress field, strain field, displacement field and stress-strain relationship of the model under different materials^[4-6].

The interaction between soil and structure is an important research direction, which involves a wide range of aspects, including energy, transportation, construction and aviation. For a single soil or a single structure under a given stress, its radial interaction or tangential interaction has been very mature. Research fruit industry has been very fruitful, but in the contact surface of the two the research of radial interaction is very few. This paper based on this point discusses how to correctly study the interaction between soil and structure in order to have a certain guiding significance for the actual engineering. Through changing the constitutive model, the reaction on the contact face is studied.

In civil engineering and water conservancy engineering, soil structure interaction is very common. Pile soil, wall soil, soil nail soil interaction mechanism in pile foundation, retaining wall, dam cutoff wall, deep

foundation pit and other projects all belong to this kind of problem. Due to the large difference in stiffness and strength between soil and structure, the structural surface with large deformation modulus restrains the soil near the structural surface, resulting in great changes in its mechanical properties, which is different from the single soil and structural materials. Therefore, the correct description of the mechanical properties of the interface between soil and structure under radial and tangential action is one of the core problems to reasonably evaluate and judge the mechanical and deformation behavior of soil structure interaction in practical engineering, which also makes the research of soil mechanics and geotechnical problems to a new level.

2 Research method

2.1 Interface interaction

The interface interaction includes tangential interaction and normal interaction. The tangential action includes the relative motion (sliding) of the contact surface and the possible frictional shear stress. Each contact interaction can represent a contact characteristic, which defines the model of interaction between contact surfaces. In this paper, the influence of tangential interaction is not considered, but the interaction of normal stress is considered.

The contact of normal interaction includes hard contact and soft contact. The distance between the two surfaces is called the gap. When the gap between the two surfaces becomes zero, a contact constraint is imposed on the contact surface. In the formula of the contact

* Corresponding author: 109930595@qq.com

problem, there is no restriction on the value of the contact pressure that can be transferred between the contact surfaces. When the contact pressure between the contact surfaces becomes zero or negative, the two contact surfaces separate and the constraint is removed. This behavior represents "hard" contact.

For soft contact, it does not have a simple expression like hard contact, it needs a compound equation expression, because the influence of the stiffness of power exponential function related to soft contact may lead to the decrease of the convergence speed of the model, or excessive contact strain may lead to non convergence.

3 Model establishment and its influencing factors

At present, the research on the interaction between soil and structure at home and abroad mainly focuses on the shear behavior of the interface, while the research on the radial behavior is not much. However, according to the discussion on the failure causes of shaft lining, the radial interaction still plays an important role in the failure of axisymmetric structure, Radial interaction is also an indispensable key problem in the study of interaction.

3.1 Model description

As shown in Figure 1, there is an infinite wellbore structure in uniform stratum. Its supporting conditions are considered to be invariable in the vertical direction, and its stress is considered to be vertical invariable. The influence range of disturbance on surrounding soil after shaft excavation can be approximately expressed by the following formula:

$$R=20r \quad (1)$$

Where r is the radius of the shaft and R is the range of soil affected.

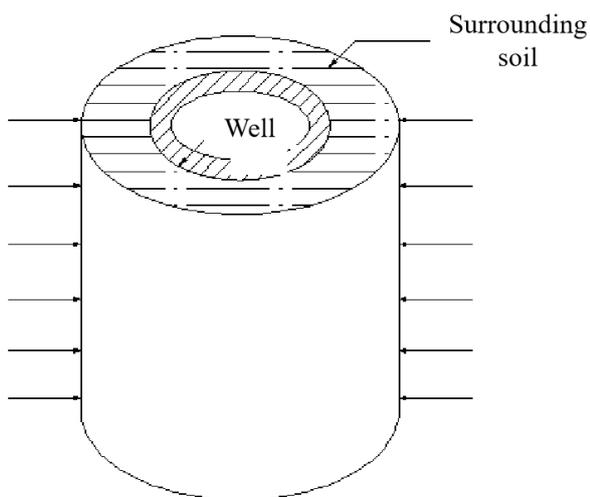


Fig. 1 Model prototype

As shown in Figure 1, after the soil mass in the affected range is obtained, the significance of the model is explained by comparing the excavated wellbore. The

first step is to set up the support, while the consideration factor of selecting the support is the load it bears. It is generally believed that the load comes from the surrounding soil and has an influence range. For simplification, the drawing shows the shaft, supporting structure and affected soil after excavation.

Considering the stress balance in the stratum, if the soil in the affected area is taken out from the stratum alone, there will be confining pressure acting on the surrounding soil. Because of the axisymmetric composition of the model, and considering the soil as isotropic material, the confining pressure can also be considered as axisymmetric radial stress. In order to simplify the analysis, for a specific area, the variation range of soil properties is not too large, so the material of confining soil is selected from a specific deep soil layer, and the mechanical properties of soil remain unchanged in the numerical analysis, considering the influence of the change of structural material mode on the radial interaction behavior on the interface.

Considering that the longitudinal dimension of the model will be much larger than the transverse dimension, it can be assumed that it is a plane strain problem, and the longitudinal strain is approximately zero. The simplified figure is shown in Figure 2.

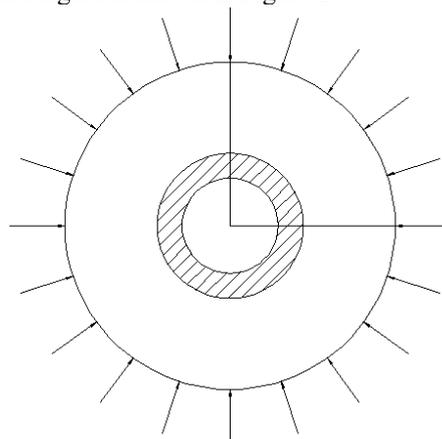


Fig. 2 Simplified plane strain model

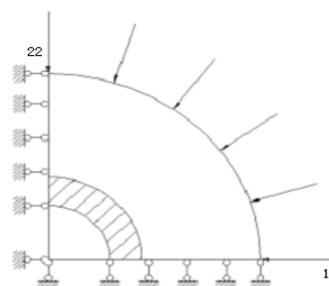


Fig. 3 1/4 model

Under the action of positive symmetrical load, the angle and horizontal displacement of the positive symmetric structure cannot occur. Figure 2 calculates that the model structure and load have two symmetrical axes, so only one quarter of the structure can be taken for analysis, as shown in Figure 3.

3.2 Different materials influence

The most fundamental influence of interaction is produced by two or several different materials. The change of materials will lead to different mechanical properties on the interface. In order to qualitatively analyze the role of material change in the process of interaction, several typical materials will be used in numerical analysis. The effects of structures with different material properties on the radial interaction at the interface between soil and structure are obtained by comparative analysis. The last section is the ideal elastic model, ideal elastic-plastic model, linear strain-hardening model, elastic power strengthening model and absolute rigid model.

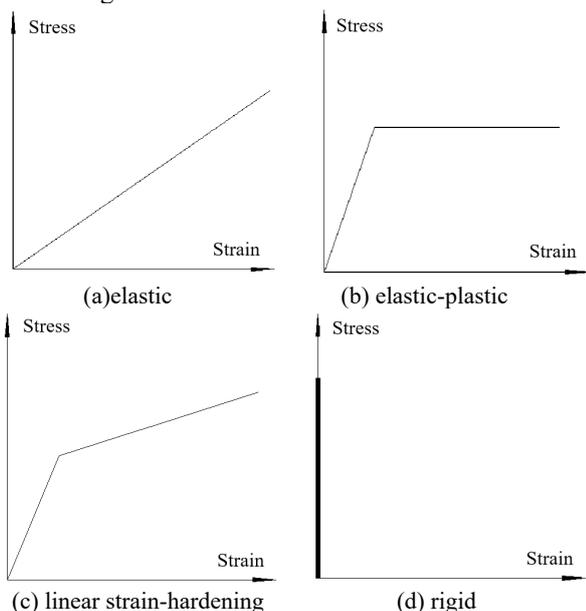


Fig. 4 Different constitutive models

Structural materials with different stress-strain relationships have different effects on the interaction between soil and structure. However, the focus of this paper is on what kind of influence the change of various material modes will have on the contact surface and its vicinity, what degree it is, and what factors it is related to.

4 Numerical simulation

In order to make the research results have certain practical reference significance, the selection of specific parameters should be as close to the reality as possible.

Table 1 Common parameters of structural materials

Density (kg/m ³)	Elastic modulus (Pa)	Yield strength (Pa)
2500	2e10	2e7

After defining the elastic parameters of materials such as elastic modulus and Poisson's ratio, the ideal elastic-plastic model enters the definition of plasticity. According to the characteristics of the model, when the

stress reaches yield, the stress remains unchanged and the strain increases. So a straight line is determined by two points, and the yield stress and plastic strain of two points are given at least. The yield stress of these two points should be the same, 30 MPa, and the plastic strain is different.

Linear hardening, that is, elastic linear hardening model, also determines the straight line according to two points, and the yield stress and plastic strain of two points must be given. Because the elastic modulus in the hardening stage is much smaller than that in the elastic stage, it is necessary to determine the stress-strain increment in the hardening stage reasonably. In order to make the strengthening slope smaller and close to the change mode of the ideal elastic-plastic model, the plastic strain increases by 0.05 for every 1MPa increase in yield stress.

Figure 5 describes the distribution of displacement field and the change along the radial direction of soil mass under the condition of confining pressure of 20MPa in five different material models, in which the horizontal coordinate means from the center of the shaft to the edge of the surrounding soil, and the vertical coordinate represents displacement.

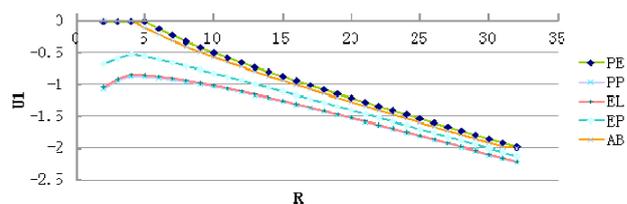


Fig. 5 U1 comparison of different materials

From the graph, we can get the following results intuitively. 1) For the five different material models, the displacement is approximately linear along the radial direction, the closer the model center is, the smaller the displacement is, and the maximum displacement in the structure is about one meter. 2) In the ideal elastic model, there is a very small radial displacement inside the structure, while in the absolute rigid model, the radial displacement is completely zero; In the models of ideal elastoplasticity, elastic linear strengthening and elastic power strengthening which can produce plastic strain, there are large radial displacements in the structure. 3) From the ideal elastic-plastic model to the elastic linear strengthening model and then to the elastic power strengthening model, although they all have radial displacement in the structure, they are different from each other. In order to more accurately compare the differences between them, a part of the models on the left and right of the contact surface are taken out for analysis separately. The abscissa from Figures 6-8 is from the inner side of the structure to the outer side of the surrounding soil.

Comparing with Figures 6-8, the displacement of the structure in the ideal elastic-plastic model changes the most, because in the ideal elastic-plastic model, once the internal stress of the structure reaches yield, the plastic strain will increase sharply, resulting in irrecoverable deformation; For the model of power-law hardening, the

increasing rate of plastic strain is obviously much slower than that of ideal elastic-plastic, and its increase depends on the increasing rate of stress in the model to some extent, so the displacement is relatively small.

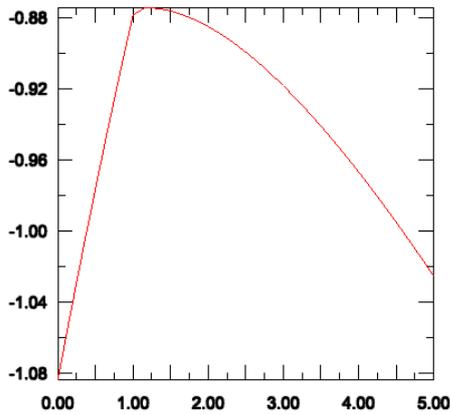


Fig. 6 Ideal elastoplasticity

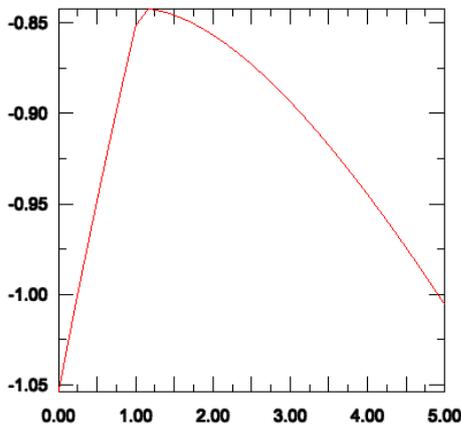


Fig. 7 Elastic linear strengthening

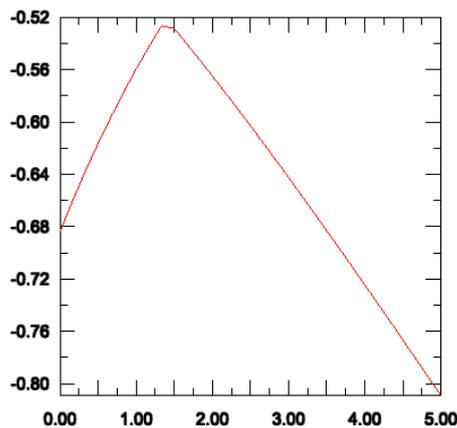


Fig. 8 Elastic power strengthening

It can also be seen from the figure that the displacement difference between ideal elastoplastic model and linear strengthening model is not very large, because the slope of reinforcement in material definition is too small:

$$k = \frac{2.1e7 - 2e7}{0.05} = 2 * 10^7 \quad (2)$$

It can be predicted that if the value of K is increased, that is, if the value of plastic strain is decreased, a smaller displacement will be obtained. In a word, if the plastic strain of the material itself is large enough, or the change rate of the plastic strain is large enough, the displacement of the contact surface and the structure will increase under the same stress.

5 Conclusions

In this paper, a general model is established by FEM, which can realize the change of material mode without re modeling. In the analysis of the influence of various factors on the results, we can see that:

(1) When the model materials are different, the stress, strain, displacement and change in the model are closely related to the stress level: if the stress level is too small, the structure is still in the elastic stage, and the performance of the materials that are not plastic is basically the same.

(2) If the stress level is large enough, the difference between different materials becomes very obvious, which can be divided into two kinds of cases. One is that plastic deformation is relatively "easy", that is, once the structure reaches the yield stress, the plastic strain will increase almost freely, such as the ideal elastic-plastic and the elastic linear strengthening with small slope in the strengthening stage, when the stress in the soil is transferred to the structure, there is no peak stress on the contact surface due to different plastic change rate, and the transition on the contact surface is very smooth; The other is the elastic and absolute rigid models which do not produce plastic strain. Although they can also produce deformation, the deformation depends on the elastic deformation of external force, so the stress change rate and strain change rate are always not synchronous on the contact surface, resulting in the peak stress.

(3) In the material simulation, we only choose the yield stress criterion which satisfies the metal plasticity. This is a yield stress criterion established by introducing material science into engineering practice. It is an idealized yield criterion, which obviously does not conform to the actual material selection. In fact, it is only concrete, There are about three kinds of yield criteria to describe, and the simulation results in this case are not particularly in line with the reality.

References

1. X.R. Zhu, J.C. Wang, *Rock and Soil Mechanics*, **25**, 2 (2004)
2. L.M. Hu, J.L. Pu, *Journal of Geotechnical Engineering*, **23**, 4 (2001)
3. M.Q. Qiu, Z.W. Ai, S.H. Luo, T.F. Deng, *Journal of Jiangxi University of Science and Technology*, 3 (2004)
4. D.J. Zhang, T.H. Lu, *Journal of Geotechnical Engineering*, **20**, 6 (1998)

5. S.F. Zhao, Z.G. Dai, X. Liu, X.Y. Liu, *Journal of Underground Space and Engineering*, **32** 4 (2018)
6. R. F. Goodman, R.L. Talor, *Journal of Soil Mechanics and Foundation Engineering Division, ASCE*, **94**, 3 (1968)