Study on characteristics of pipe pile of insert board machine penetration into soil

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Abstract. Inserting plastic drainage board is commonly used in inserting machine, and the difficulty of inserting pipe pile into soil directly affects the efficiency of inserting construction. In this paper, CEL numerical method is used to study the relationship of penetration resistance with penetration depth and the influence of penetration velocity on penetration resistance. It is found that the stress of pile and pipe inserted into soil is symmetrical distribution. The curve of penetration resistance of clay layer with penetration depth has obvious turning point and limit value. The penetration resistance of sand layer increases with the increase of penetration depth, and there is no limit value. In addition, according to different construction conditions, the control of intubation speed in different soil layers is proposed.

Keywords: pipe pile; penetration velocity; penetration resistance; CEL method

1 Introduction

The plastic drainage plate consolidation method is a foundation treatment method developed on the basis of the sand well principle. Currently, the commonly used insertion machine in China is mainly the insertion machine. Due to its low cost and convenient operation, this device has a wide range of applications. When inserting and driving drainage boards, it is necessary to insert the pile barrel into the soil to a certain depth in order to leave the drainage board in the soil. At the same time, the resistance of the pile barrel inserted into the soil directly affects the construction efficiency of the drainage board.

Previous scholars have conducted relevant research on the resistance characteristics of pile structures penetrating into soil. Zhang Haipeng and Kou Hailei studied the change of pile driving resistance caused by the compression action of continuously inserted concrete pipe pile on surrounding soil through indoor model tests and analyzed the influence of different penetration rates on the penetration resistance of model pile[1][2]. In addition, Zou Changchun and Liu Junwei investigated the impact of the design form of the bottom structure of the pipe pile on the penetration re-

D. Li et al. (eds.), *Proceedings of the 2023 9th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2023)*, Advances in Engineering Research 228,
https://doi.org/10.2991/978-94-6463-336-8_54

sistance[3][4]. Li Jingpei also studied the variation rule of penetration resistance during the penetration of metal pipe piles and CPTU through centrifugal model tests[5]. Liu Zhibin et al. conducted on-site experiments to study the penetration resistance of concrete pipe piles during pile sinking, and analyzed the variation patterns of penetration resistance in different soil types[6-9].

Ye Mingge used ABAQUS finite element method to simulate the change rule of penetration resistance during the process of concrete pipe pile penetration into clay layers [10]. It is found that the thickness of upper soil, pile diameter and pile-soil friction coefficient have a significant impact on the penetration resistance of pile mold. It also summarized the relationship between the penetration resistance of the pile mold and the thickness of the upper soil layer, pile diameter, and pile soil friction coefficient. Wu Qunan et al. used the ALE (Arbitrary Euler Lagrangian) method and CEL (Coupled Euler Lagrangian) method to study the penetration resistance of rigid piles into soil, and conducted parameter analysis on the influencing factors of penetration resistance[11][12].

From the above, it can be seen that in previous research projects, the diameter of pipe piles were generally between 0.3 and 1.2 meters. However, the diameter of the pile barrel of the board inserting machine is generally 0.1-0.15 meters, and the research on the penetration of small diameter piles into soil is rare. Therefore, it is necessary to conduct research on the resistance of the pile barrel of the board inserting machine to the soil. This article intends to use the CEL method to study the penetration resistance of small diameter pipe pile when penetrating into soil. By elucidating the impact of changes in soil quality and penetration rate on the analysis results of penetration resistance, reference is provided for the efficient insertion construction of drainage boards on site in the future.

2 Materials and Methods

2.1 Method introduction

The CEL method can divide the soil that undergoes large deformation into Euler grids, and the soil material can freely flow between the Euler grids. Therefore, this method is suitable for simulating large deformation problems such as penetration and tooth cutting.

Operator splitting is a key step in the process of using CEL method. Operator splitting in CEL method is only carried out for solving Euler fields. The conservation equation in Euler form can be written in the following form.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0 \tag{1}$$

$$\frac{\partial \rho u}{\partial t} + \nabla \cdot (\rho u \otimes u) = \nabla \cdot \sigma + \rho b \tag{2}$$

$$\frac{\partial e}{\partial t} + \nabla \cdot \left(eu \right) = \sigma : D \tag{3}$$

It can be seen that the mass, momentum and energy conservation equations above have the same form as below.

$$\frac{\partial \psi}{\partial t} + \nabla \cdot \Phi = Q \tag{4}$$

Where, Φ can be regarded as the flux function, Q can be regarded as the source term. The operator splitting method can be applied to decompose the equation (4-13) into the following two formulas.

$$\frac{\partial \psi}{\partial t} = Q \tag{5}$$

$$\frac{\partial \psi}{\partial t} + \nabla \cdot \Phi = 0 \tag{6}$$

Equations (5) and (6) are called Lagrange and Euler steps respectively. The principle diagram of the operator splitting method is shown in the figure below. In the Lagrange step, the nodes are temporarily fixed to the material, and the units deform as the material deforms. In the Euler step, the material deformation is paused, the deformed mesh is moved back to the original mesh position, and the variable mapping is performed between the old and new mesh. It should be noted that time only advances in the Lagrange step, while in the Euler step, time is stagnant. And the Euler step is actually a process to complete the transport of materials between adjacent units. Therefore, CEL method is often used to study large deformation problems such as soil cutting and pile sinking in recent years.

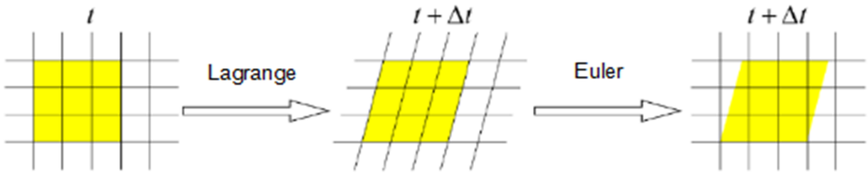


Fig. 1. Schematic diagram of operator splitting method

2.2 Three-dimensional finite element model

Firstly, establish a CEL three-dimensional finite element model for the insertion of pipes into the soil, and the size of the model is based on the pile pipe size used for on-site insertion machine construction. Figure 2 shows CEL three-dimensional finite element model and intubation diagram respectively. In figure 1, the diameter of the tube is 0.133 m, with a length of 16 m, and the bottom is a plug with a length of 0.5 m at the bottom is located in the center of the model. And the plug is inserted into the soil at a certain speed from the soil surface. The diameter of the three-dimensional soil model is 10 m, the height of the soil is 20 m, and the cavity is set within 1 m above the soil surface to accommodate the soil uplifted and backsilted during the process of inserting the tube into the soil.

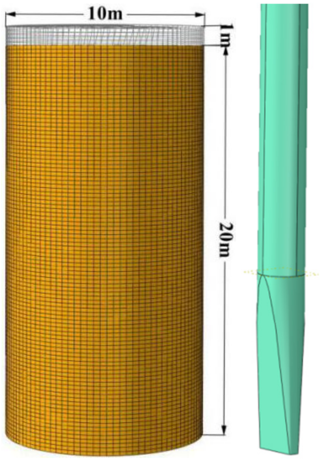


Fig. 2. Schematic diagram of 3D finite element model

The parameters of soil in the model are selected according to the research content in the following table. For soil, the stress-strain relationship is described by an ideal elastic-plastic model obeying the molar Coulomb yield criterion. For pile pipe, generalized Hooke's law is used to describe the stress-strain relationship of cutter teeth, and Poisson's ratio is 0.25. Among them, the working conditions of sandy soil are mainly divided into fine sand and medium coarse sand, and the other type of soil is divided into silt and clay. Based on the actual exploration data, the soil parameters such as heavy weight, friction angle, modulus of elasticity, as well as the penetration speed of pipe pile are given in Table 1.

Table 1. Calculation conditions and soil PARAMETER

conditions	soil	Density /kg/m^3	friction angle/°	modulus of elasticity/MPa	Speed /m/s
1	silt	1600	μ=0	4	0.5
2				4	0.4
3				4	0.35
4				4	0.3
5	clay	1800		10	0.5
6				10	0.4
7				10	0.35
8				10	0.3
9	fine sand	1900	35	25	0.5
10				25	0.4
11				25	0.35

12				25	0.3
13				35	0.5
14	medium-coarse sand	1950	38	35	0.4
15				35	0.35
16				35	0.3

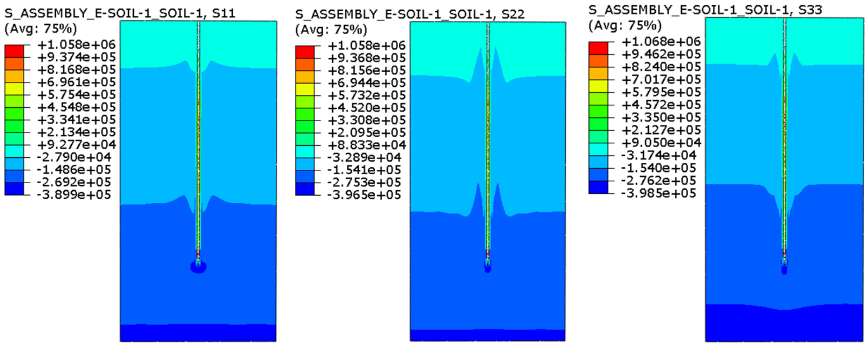
For the horizontal soil grid division, the size of the grid cell is 0.1 m within 5 m of the center, and the size of the grid cell is 0.2 m outside. For vertical mesh size, 0.2 m is uniformly taken. In the calculation model, the contact between soil mass and cutter teeth in Euler region is set as universal contact, and the normal direction is separable and the tangential direction is smooth. For soils in the Euler region, the horizontal velocity of the left boundary and the front and back boundary is set to zero. It is set as the Euler absorption boundary to eliminate the influence of finite boundary on the calculation result. Set the vertical velocity of the bottom boundary to zero.

Based on the CEL three-dimensional finite element model established above, the effects of soil elastic modulus and pile and pipe penetration velocity on penetration resistance under different soil conditions are proposed to be studied. The influence of these parameters on the penetration resistance of pile and pipe is quantitatively described.

3 Results and analysis

3.1 Soil stress

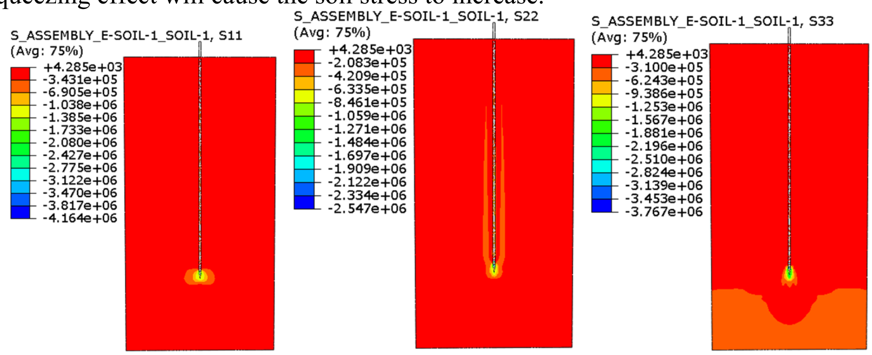
Based on the CEL three-dimensional finite element model established above, the effects of soil elastic modulus and pile and pipe penetration velocity on penetration resistance under different soil conditions are proposed to be studied. The influence of these parameters on the penetration resistance of pile and pipe is quantitatively described. Figure 3 shows the stress nephogram of soil under typical conditions in clay. As can be seen from the picture, the soil around the pile is affected by penetration within 0.5 d (d is the diameter of the pile pipe), and the stress distribution in the soil at the end of the pile is similar to that in the sand, showing a law of larger in the middle and gradually decreasing symmetrically to both sides. The maximum stress in the soil at the action center of the pipe pile is about 1.1 MPa. The influence range of the horizontal direction is about 1.5-4 d, and the influence range of the vertical direction is about 3 d. The stress in X direction and Z direction shows symmetrical sag distribution, while the stress in Y direction shows symmetrical uplift distribution. The reason for this phenomenon is that the wedge-shaped pile head structure will cause the soil stress to rise symmetrically on the side facing the wedge due to the squeezing effect. In addition, the soil stress around the pile is depressed due to the return action of soil on both sides.



(a) X direction (b)Y direction (c)Z direction

Fig. 3. Stress nephogram of soil under typical conditions in clay

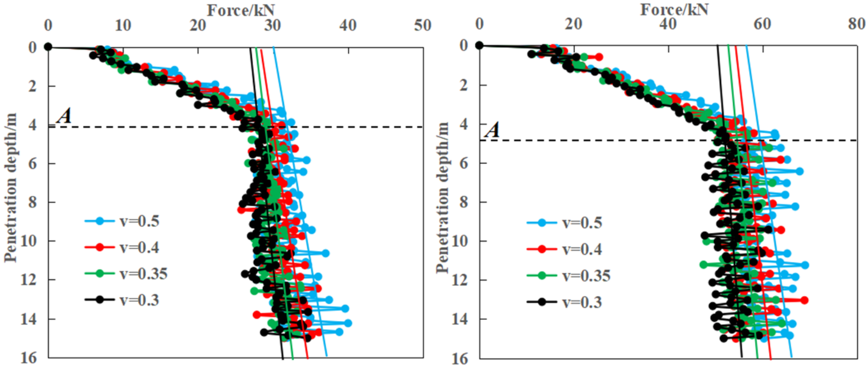
Figure 4 shows the stress nebulogram of soil under typical conditions when the pipe pile is inserted into sand. As can be seen from the figure, in the horizontal direction, the soil stress increases sharply within a certain range at the end of the pipe pile when the pipe pile penetration is completed. The stress distribution in the soil is larger in the middle and decreases symmetrically to both sides gradually. The maximum stress in the soil at the action center of the pile and barrel is about 2.5 MPa. The influence range in the horizontal direction is about 2-6 d, and the influence range in the vertical direction is about 3 d. For the vertical direction, the stress distribution in the soil at the end of the pipe pile is the same as the first two directions, and the stress distribution in the soil presents a law of larger in the middle and gradually decreasing symmetrically to both sides. The maximum stress in the soil at the center is about 3.8 MPa. The influence range of the horizontal direction is about 2-4 d, and the influence range of the vertical direction is about 5 d. In the Y direction, the soil stress is distributed symmetrically from the middle to the end of the pile barrel, and the influence range in the horizontal direction is about 3 d. This phenomenon is mainly caused by the wedge structure at the end of the pile barrel. When the wedge pile head penetrates into the soil, the pipe pile with round section continues to penetrate into the soil, the soil squeezing effect will cause the soil stress to increase.



(a)X direction (b)Y direction ©Z direction

Fig. 4. Stress nephogram of soil under typical conditions in sand

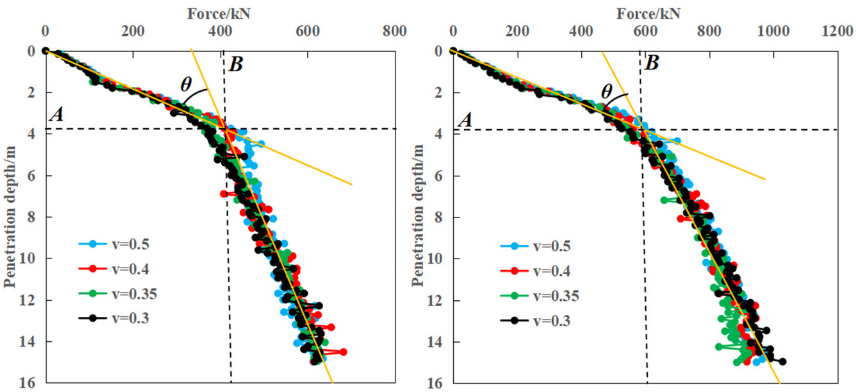
Figure 5 shows the curve of penetration resistance with penetration depth when inserting piles in silt and clay layers and the intubation speed changes. It can be seen from the figure that when piling is inserted in silt and clay, the penetration resistance curve shows an obvious turning point. The penetration resistance in the depth range below the turning point basically reaches the limit value, and the limit value of the penetration resistance in the clay layer is about twice that of the silt layer. In addition, the limit value of penetration resistance increases with the increase of penetration speed, and the vibration is also increasing, which is mainly caused by the inertia of pile and pipe, so it is recommended to set the penetration speed at 0.3 m/s. It can also be concluded that properly reducing the penetration velocity of pile pipe can effectively reduce the penetration resistance during the actual construction of clay layer.



(a) silt (b) clay

Fig. 5. Variation of penetration resistance in clays

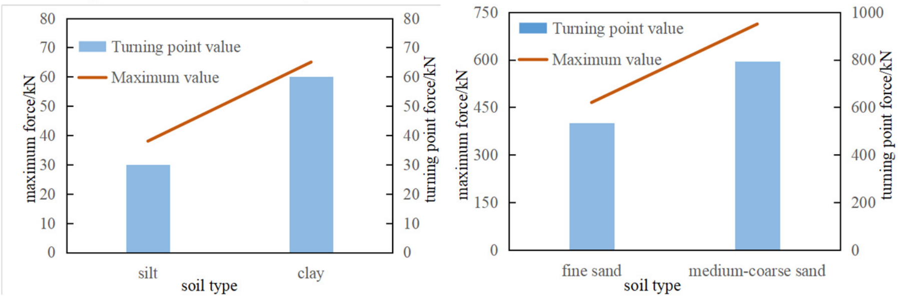
Figure 6 shows the curve of penetration resistance with penetration depth when the intubation speed changes. It can be seen that, compared with the clay layer, the penetration resistance curve does not show an obvious turning point when the pile is inserted in the sand soil. And the penetration resistance curve keeps increasing with the increase of the penetration depth. Meanwhile, there is no limit value of the penetration resistance. In addition, in sandy soil, the penetration speed of the pile bucket has no effect on the penetration resistance, so it is suggested that the construction efficiency of the drainage plate can be improved by increasing the penetration speed in sandy soil.



(a) fine sand (b) medium-coarse sand

Fig. 6. Variation of penetration resistance in sand

In order to more clearly describe the difference of penetration resistance in different soil layers, Figure 7 summarizes the forces corresponding to the turning point and maximum value in the penetration resistance curves of different soil layers when the penetration velocity is 0.5m /s. As can be seen from the figure, the inflection point value and maximum value of the penetration resistance in the clay layer are twice that of the silt layer, and the relationship with the elastic modulus is close to that of the clay layer. The inflection point value and maximum value of the penetration resistance of the medium coarse sand layer are 1.5 times that of the fine sand layer, and the difference of the elastic modulus between the two is about 2.3 times, which is not equal to this relationship. In addition, it is found that the penetration resistance of sand is higher than that of clay under the same conditions.



(a) clay (b) sand

Fig. 7. Turning points and maximum values in the penetration resistance curve

4 Conclusion

In this paper, the relationship between penetration resistance and penetration depth of pile and barrel with different soil layers is studied by numerical method, and the influence of the change of penetration velocity on penetration resistance is explored. The main conclusions are as follows.

(1) The stress distribution of the pile pipe into the soil is symmetrical, and the stress distribution of the clay is uplifted and depressed due to the squeezing effect.

(2) The curve of penetration resistance of clay layer with penetration depth has obvious turning point and limit value. The penetration resistance of sand layer increases with the increase of penetration depth, and there is no limit value.

(3) During the construction of clay layer, the penetration velocity of pile and pipe can be reduced appropriately to reduce the penetration resistance. In the process of sand layer construction, the penetration speed can be appropriately increased to improve the efficiency of construction insertion.

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