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Analysis of Hall Anchor Pulling Force on Soft Soil Condition

PENG Guoyan[a]; LI Jintai[b]; ZHANG Meng[c],*; TANG Wenxian[b]; ZHANG Jian[b]

[a]Chongqing Productivity Council, Chongqing, China.
[b]School of Mechanical Engineering, Jiangsu University of Science and Technology, Zhenjiang, China.
[c]Chongqing Qianwei Science & Technology Group Co., Ltd, Chongqing, China.
*Corresponding author.

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Abstract

Taking 60kg C Hall anchor as an example. We established the pulling anchor model on soft soil condition based on the theoretical formula and hall anchor simulation model in CEL analysis method of ABAQUS software. That got the pulling force in soft soil and the flow of soft soil. These results show that although the method of theoretical calculation can accurately calculate the pulling force, could not reflect the change of the pulling force with the change of the distance of pulling anchor, and could not assess the stability of the pulling force. In the results of numerical calculation, the pulling force in soft soil is a wave force. In the results of the flow of soft soil, the wave of the force in first 20 seconds is related to the concave pit in the initial formation of the anchor, in this stage, to avoid the slide of the anchor, the pulling speed and the pulling force should be controlled to reduce.

Key words: Hall anchor; Pulling anchor model; Numerical calculation

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INTRODUCTION

The Hall anchor is a standard type of plain rodless anchor. It is convenient to cast and it has great grasp force. It is the main anchor for large and medium ships, and has been widely adopted in modern ships. The main sea areas, rivers and lakes in China are mostly soft soil (Yang, H., Xu, & Duan, 2015; Qian et al., 1998). Hall anchor's grip force on soft soil is 3-5 times its own weight (Xia, 1998, pp.58-61). The magnitude and stability of its grip force will greatly affect the safety of the ship, so that it is necessary to analyze the grip force of Hall anchor. The anchor inserting in the soil is mainly divided into three stages, the first stage is buried stage; the second stage is the fluke flip to the maximum angle stage; the third stage is holding steady stage. In the third stage the hall anchor will no longer continue to insert in soil. Meanwhile grip and stability up to maximum, the angle between the bolt and horizontal plane is about 30 degrees (Shin, Seo, & Lee, 2011). The above is the reason why we choose the third stage as the important basis for the analysis of Hall anchor.

At present, many scholars have chosen to carry out the ship test (Shin, Seo, & Lee, 2011; Lee, Seo, & Shin, 2011; Liu & Gen, 1999; Jiang & Yu, 2014). Although the ship test can accurately estimate the magnitude and stability of its grip force of the anchor, it can not observe the flow of soil intuitively, and can not give the numerical calculation method of the anchor grip force. Most scholars believe that the calculation of the grasping force, should choose to anchor the upper or lower surface as the surface induced by anchor movement (Stewart, 1992; Neubecker & Randolph, 1994, pp.767-770; Aubeny, Murff, & Kim, 2008; Aubeny & Chi, 2010). Other scholars believe that the anchor induced plane should be between the upper and lower surfaces (Liu, Zhang, Liu, & Hu, 2012; O'Neill, Randolph, & Neubecker, 1997; O'Neill & Randolph, 2001). Randolph and Neubecker reveal that the anchor induced surface is indeed between the upper and lower surfaces of the fluke, and 5 degrees to a range of 15 DEG, through a series of centrifuge experiments (Neubecker &

Randolph, 1996). Because the fluke anchor's section is wedge shaped, so the calculation of the grasping force, calculation method should choose to use the Randolph and Neubecker's. The finite element analysis method can simulate all kinds of complicated conditions. And the process and results can be visualized. CEL coupling method can simulate the elastic-plastic deformation of soil under tension and anchor. By combining this method with theoretical calculation, the simulation model of Hall anchor can be effectively established.

Therefore, according to the national standard GB/T546-1997, the 60kg C Hall anchor on soft soil is studied based on the theoretical calculation. In addition, the numerical model is established by the CEL coupling method. It provides some guidance for ship anchor on soft soil.

1. THE CALCULATION MODEL OF HALL ANCHOR'S GRIP FORCE

Hall anchor consists of two main parts, fluke and bolt, and the bolt can be regarded as a rigid body in the process of calculation. The force and direction of motion of Hall anchor in the third stage are shown in Figure 1. T_a is the pulling force of anchor shackle, T_m and T_n are the component forces of the T_a in the direction of the anchor movement and in its vertical direction; is the weight of the anchor, W_m and W_n are the component forces of the W in the direction of the anchor movement and in its vertical direction; F_{bs} and F_{bf} are borne forces by the bolt and fluke along the direction of movement; F_{ss} and F_{sf} are the shear force of bolt and anchor along the direction of movement. To reduce the formula, make $F_b=F_{bs}+F_{bf}$, make $F_s=F_{ss}+F_{sf}$.

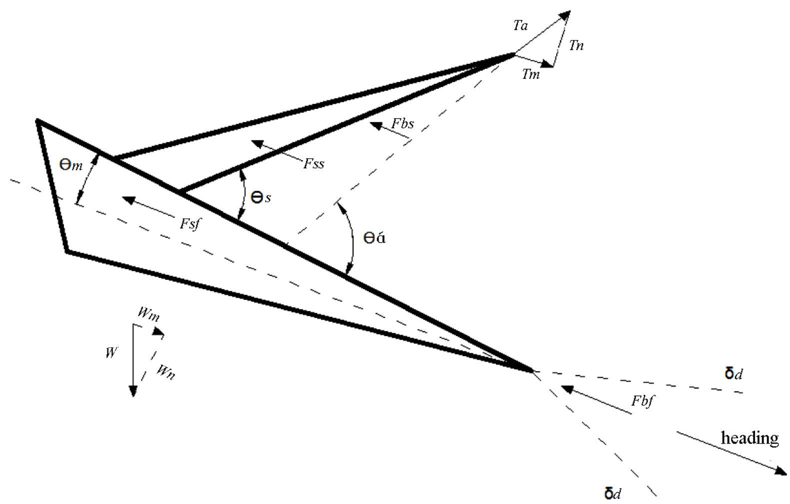


Figure 1
Pull Anchor Mechanics Model

The equation of motion of a ship anchor is (Liu & Gen, 1999):

$$T_m+W_m=F_{bs}+F_{bf}+F_{ss}+F_{sf}. \quad (1)$$

The pulling force of anchor shackle, is (Ibid.):

$$T_a=\frac{1}{\cos(\theta_\alpha-\theta_m)}[F_b+F_s-W\sin(\theta_0-\theta_m)] \quad (2)$$

Where: θ_α=50°, it is the included angle between the upper surface of the fluke and the T_a,θ_m=10°, it is the included angle between the upper surface of the fluke and the anchor's heading, θ_0=30°, it is the included angle between the fluke and the horizontal direction.

The undrained shear strength of soft soil is (Ibid.):

$$S_u=S_{u0}+K_z. \quad (3)$$

Where: S_u is the undrained shear strength of soft soil, S_{u0}=1.5kPa, it is the undrained shear strength of soft soil on the seabed surface, K=1KPa/m is the undrained shear strength gradient of soft soil, z=3m is soft soil depth.

Ignore the changes of the undrained shear strength of soft soil at the tip of the anchor to anchor shackle, bolt and anchor fluke along the direction of motion of the force can be expressed as (Ibid.):

$$F_b=N_cS_uA_b. \quad (4)$$

Where: F_b is the borne force of the fluke and the bolt along the heading direction, N_c=9.7 is bearing capacity factor. N_c=5.14(1+0.2 L/t), L is the length of the fluke, which is 0.15m; t is the average thickness of the fluke, which is 0.034m. A_b is the projected area on a vertical surface at the anchor bolt and anchor and the direction of movement, which is 0.044m^2.

Neglecting the change of adhesion factor of soft soil around the anchor, the shear force of bolt and fluke along the heading direction of motion can be expressed as (Ibid.):

$$F_s=\alpha S_uA_s. \quad (5)$$

Where: F_s is the shear force of the fluke and the bolt along the heading direction; A_s is adhesion factor, which is 0.4, A_s is the projected area on a parallel surface at the anchor bolt and anchor and the direction of movement, which is 0.0338m^2.

2. HALL ANCHOR SIMULATION MODEL OF SOFT SOIL

2.1 Hall Anchor-Soft Soil Model

CEL method is the coupled Euler Lagrange method, which can greatly improve the fluid solid coupling simulation ability of ABAQUS software. Therefore, this paper uses this method as the guidance to establish the correlation model. According to the national standard GB/T 546-1997, the three-dimensional model of 60kg C Hall anchor is established. In order to reduce the amount of calculation, ignoring the features such as chamfer. In calculation, the deformation of the Hall anchor does not need to be considered, so it can be considered as a rigid body and the number of meshes can be reduced as much as possible. In this paper, HyperMesh software is used to mesh the Hall anchor. The mesh type is C3D4, the number of nodes is 4,805, and the number of mesh is 17,810. Soft soil is modeled and meshed by ABAQUS software. The mesh type of soft soil is EC3D8R, the number of nodes is 302,211, and the number of mesh is 288,000. The mesh is shown in Figure 2.

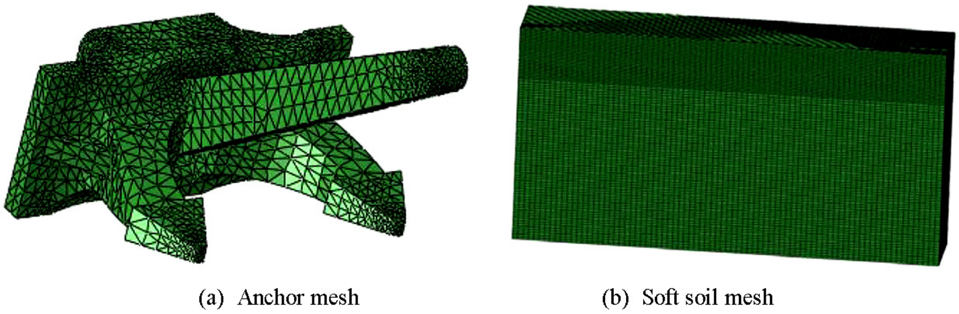


Figure 2
Hall Anchor in Soft Soil Model Mesh

The soft soil is divided into two layers. The first layer is a hole and the second layer is soft soil. In order to simulate the flow of soft soil accurately, the mesh of the hole layer is denser than the soft soil layer. According to the position of the anchor in third stages, anchor bolt and anchor fluke showed a maximum angle of 45 degrees, and set the anchor in the soft soil, see Figure 3 below.

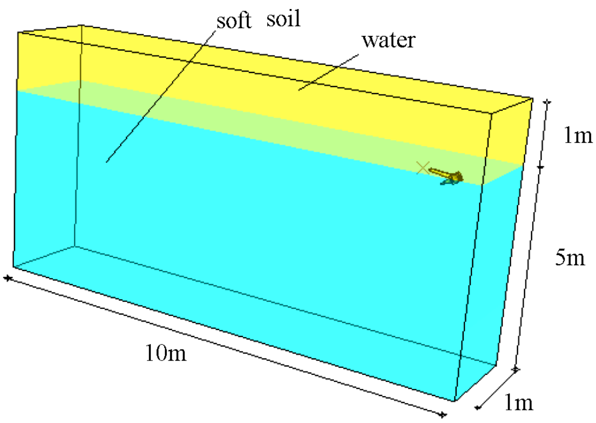


Figure 3
Size Map of Hall Anchor in Soft Soil

2.2 Material Parameter of Hall Anchor-Soft Soil Model

Hall anchor's material is ZG200-400, which is elastoplastic material, its density is 7,900kg/m^3, the elastic modulus is E=210GPa, and the Poisson's ratio is 0.3. The mud is soft soil, which is elastoplastic material, its density is 1,800kg/m^3, the elastic modulus is E=5.5MPa, the elastic modulus is 0.49. The undrained shear strength of the soft soil on the seabed is 1.5kPa, the undrained shear strength gradient of soft soil is 1KPa/m. The depth of Hall anchor soil embedded in the third stage is 3m. In the calculation, if the Hall anchor is set under the seabed surface 3m, it will be difficult to observe the flow of the soft soil. In order to avoid this situation, the Hall anchor is set in the seabed surface below 0.5m, and the undrained shear strength of the soft soil on the seabed is set to 3kPa. Thus, according to the Formula (3), the undrained shear strength of the soft soil conforms to the actual situation, and the flow of the soil is also clearly observed. The anchor pulling speed is set at 0.1m/s, the direction is parallel to the long side of soft soil, and the anchor pulling time is 45s.

3. RESULT ANALYSIS AND DISCUSSION

3.1 Theoretical Results Analysis

By Formula (3), S_u=4.5kPa; substituting them into Formulas (4) and (5) can be obtained, F_b=1920.6N, F_s=60.84N, substituting F_b and F_s into Formula (2) can be obtained, T_a=2501.7N. Therefore, the weight ratio of Hall anchor (λ) in soft soil can be obtained. $\lambda = \frac{T_a}{W} = 4.17$. According to Hall anchor's the anchor grip in soft soil is 3-5 times the size of its own weight. The theoretical results are in line with reality. But the theoretical results can only be used to calculate the size of Hall anchor in soft soil, and can only calculate the grasping force in a certain state, and it does not reflect the change of the magnitude of Hall anchor grip with the change of pull anchor distance, the stability of grasping force can not be evaluated.

3.2 Analysis the Finite Element Results

The calculation of the ABAQUS of the anchor shackle is a fluctuating curve, it can be seen that the tension of Holzer anchor in soft soil is not very stable, and need to be optimized, for the convenience of description, the QRIGIN software is used to synthesize the results of ABAQUS to a smooth curve. The similarity between the fitted curve and the original curve is 87.7%, as shown in Figure 4. We can see from Figure 4, when we pull the hall anchor at a constant rate, the first 20 seconds is a big phase of grasping force fluctuations. In 0 to 5 seconds, the grip force drops by about 300N, and in 5 to 20 seconds, the grasping force rises by about 500N. After 20 seconds, the grasping force is basically stable in the range of 3,000N to 3,200N, and the average value is about 3,050N. Therefore, the weight ratio of Hall anchor (λ) in soft soil can be obtaine $\lambda = \frac{T_a}{W} = 5.1\,d$. According to Hall anchor's the anchor grip in soft soil is 3-5 times the size of its own weight. The finite element results are slightly higher than the actual, because the finite element calculation is the optimal condition of the Hall anchor's grasping force. The comparison of the finite element results with the theoretical results shows that the finite element results are higher than the theoretical results by 18.3%. This is because the parameters of the theoretical calculation are empirical and have defects, For example, S_u is linearly related to the depth of soft soil. In practice, undrained shear strength of soft soil does not vary linearly, so it is necessary to carry out in-situ tests to obtain its true value. Therefore, compared with the theoretical results, the results of finite element analysis are closer to the actual situation, which is more instructive for ship anchor.

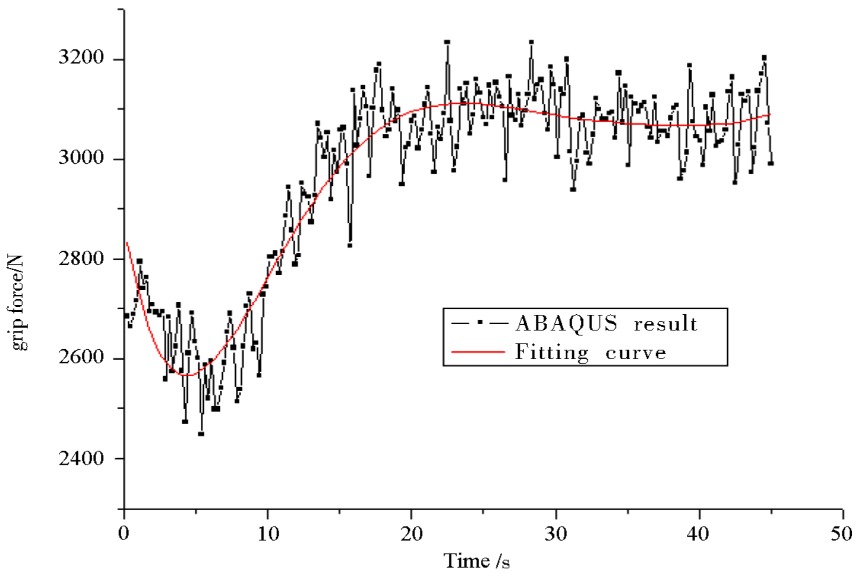
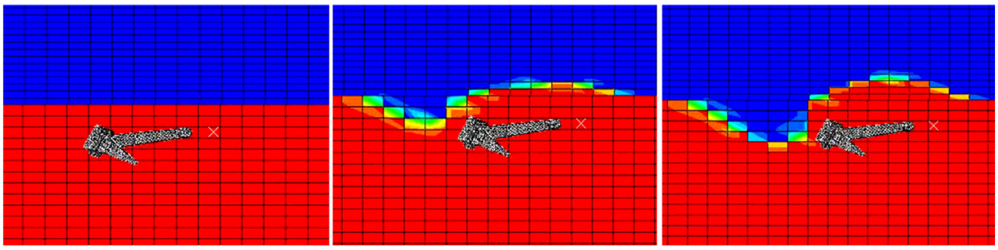


Figure 4
Change of Hall's Pulling Forcel With Drag Distance

3.3 Soil Flow Analysis of Pulling Hall Chanor

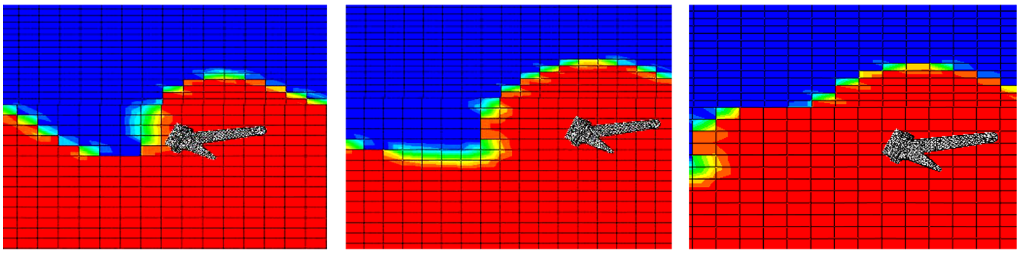
When we pull the hall anchor at a constant rate, the first 20 seconds is a big phase of grasping force fluctuations. In 0 to 5 seconds, the grip force drops by about 300N, and in 5 to 20 seconds, the grasping force rises by about 500N. After 20 seconds, the grasping force is basically stable in the range of 3,000N to 3,200N, and the average value is about 3,050N. Figure 5 is the flow of soft soil in 0-5 second time period, in this period of time to grasp the power decline, mainly because the anchor dragging away part of the soft soil, resulting in the emergence of the pits, the adhesion of soft soil anchor Hall tail anchor itself is smaller. In the actual situation, this time period is also the anchor long hair time period, in order to avoid taking the anchor, the anchor speed should not be too fast, the intensity should not be too large.



(a)0 second (b)2.25 second (c)4.5 second

Figure 5
Flow of Soft Soil in 0-5 Second Time

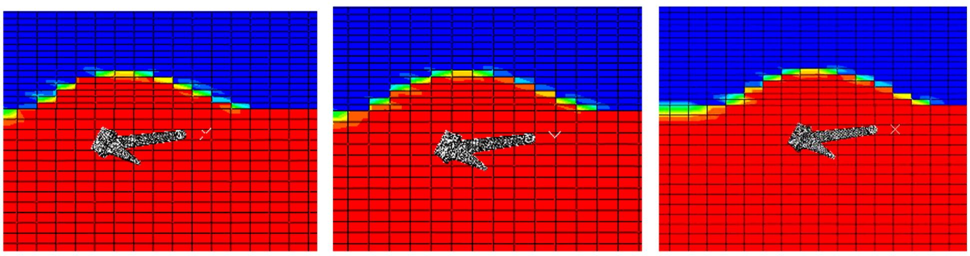
Figure 6 is the flow of soft soil in 5-20 second time period, during the period the grasping force rises, mainly because the formation of pits and anchor drag the right end of the distance at the end of the anchor distance more and more far, impact on the anchor is also getting smaller and smaller, so the anchor's grip force is up.



(a)6.75 second (b)15.25 second (c)20.25 second

Figure 6
Flow of Soft Soil ion 5-20 Second Time

Figure 7 shows the flow of soft soil in the 20-45 second period of time. During this period, the grasping force is basically stable. At the same time, the flow and heave of the soft soil are also basically the same.



(a)24.75 second (b)36 second (c)45 second

Figure 7
Flow of Soft Soil in 20-45 Second Time

Thus, the finite element simulation analysis can fully reflect the flow and uplift of soft soil. It can also clearly describe the changes of the soft soil flow to the gripping force, and supplement the theoretical calculation. It provides a basis for further optimizing the Holzer anchor and making it more stable.

CONCLUSION

(a) Although the theoretical calculation results can accurately calculate the magnitude of Hall anchor grip, it can only calculate the grasping force in a certain state, unable to reflect the magnitude of the magnitude of the Hall anchor grip that changes with the pull anchor distance, and the stability of grasping force can not be evaluated. Moreover, the parameters of the theoretical calculation are mostly empirical values and close values, which tend to produce larger errors, which are unfavorable to predict the change of grasping force.

(b) In the finite element calculation results, at a constant speed to pull the Hall anchor, in 0 to 5 seconds, the grip force dropped first, in 5 to 20 seconds, the grasping force rose, and after 25 seconds, the grasping force was basically stable. However, the grasping force of Hall anchor in soft soil is a fluctuating force, and it is not very stable. It shows that the structure of Hall anchor has defects and needs to be optimized. The calculation in this paper provides a partial basis for Hall anchor optimization.

(c) We can see from the soil flow analysis, in the first 20 seconds, the cause of big fluctuation is related to the pit formed at the beginning of pulling anchor. At this stage, in order to avoid the dragging anchor, the anchor pulling speed should be controlled and the anchor pulling force should be reduced.

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