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Finite Element Analysis of Geotechnical Excavation Based on COMSOL Multiphysics

To cite this article: Jue Han and Qianqian Ma 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **592** 012060

IOP Conf. Series: Materials Science and Engineering **592** (2019) 012060 doi:10.1088/1757-899X/592/1/012060

Finite Element Analysis of Geotechnical Excavation Based on COMSOL Multiphysics

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Abstract. As the current geotechnical excavation process is affected by many factors, excavation will easily lead to abnormal conditions in the geotechnical excavation process. Based on this, this study used COMSOL Multiphysics finite element analysis to analyze the various factors affecting the geotechnical excavation process and set the various parameters of the project. This study studied the geotechnical excavation works in the presence of buildings and the absence of buildings. At the same time, the data were statistically analyzed and the changes of various parameters in the process of geotechnical excavation were studied on the basis of finite element simulation analysis. The research shows that COMSOL Multiphysics finite element analysis can effectively imitate the geotechnical excavation conditions and draw effective laws, which will be helpful for the effective development of follow-up projects and provide theoretical reference for subsequent related research.

1. Introduction

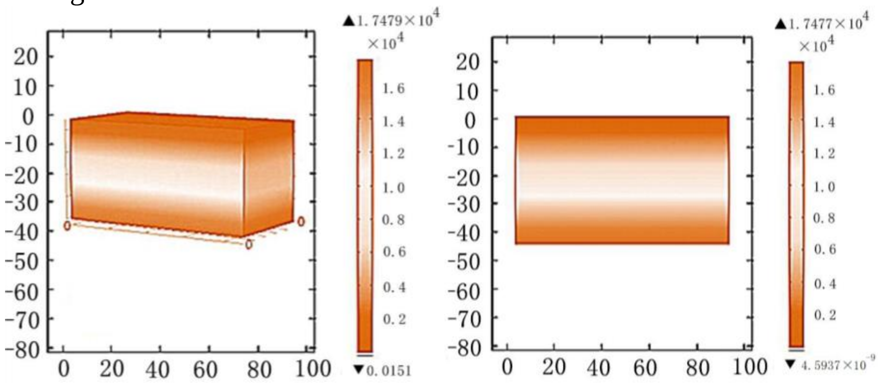
In the process of geotechnical excavation, there will be some load transmission. Under the effect of load, the geotechnical structure will undergo certain changes. This change has favorable and unfavorable effects. The beneficial effect is to promote the effective development of rock excavation and promote the effective development of geotechnical engineering. The unfavorable effect is to cause certain adverse effects in the construction process and even cause potential safety hazards. Therefore, in the actual construction process, it is necessary to effectively analyze the geotechnical excavation process and predict the changes that may be caused by the structure, so as to promote the effective development of the geotechnical excavation process.

Ou C Y et al . found that the road surface would be subject to fatigue failure under the effect of driving loads, and a simulation analysis was carried out on it. The analysis of fatigue life influencing factors of various engineering materials has always been of concern to researchers in various countries (Ou C Y, 2016). Burd et al.'s researchers analyzed the effect of stress amplitude, waveform, and frequency on rock fatigue life through tests (Burd, 2015). Dang H P studied the fatigue experimental study of the notch axis with annular groove under low-cycle, tension-bend cantilever bending and cantilever bending and twisting loads (Dang H P, 2014). Li J P et al. studied the effect of stress concentration, surface processing, and size on the fatigue life distribution by experimental analysis of mechanical materials (Li J P, 2014). Liu X X, through fatigue test studies, analyzed the effect of fatigue load order on the fatigue life of steel materials (Liu X X, 2014). Ibrahim studied the shear fatigue properties of asphalt mixture materials through repeated uniaxial penetration tests. Ibrahim analyzed the shear fatigue process of asphalt mixture specimens under semi-chord dynamic load, and designed and conducted indoor tests based on different influence factors of asphalt mixture shear fatigue life (Ibrahim, 2014).

Through the above analysis, the researchers tend to focus on the test methods, material types, loading methods, stress concentration, stress amplitude and frequency, and specimen size. However, few researchers have considered what might happen during the actual excavation process. This paper analyzes and researches the two aspects of geotechnical engineering's geotechnical excavation and deep excavation process by COMSOL Multiphysics finite element analysis software, which provides a theoretical reference for subsequent research.

2. Research Methods

In the process of excavation of rock and soil, in order to reduce the difficulty of the problem processing, and let the research process accord with the actual situation, it is necessary to carry out hypothetical processing of the actual excavation process of rock and soil. First, in order to improve the analysis accuracy, some restrictions need to be set during the finite element analysis. And in the analysis, we need to separately analyze the soil stress, and combine the two-dimensional analysis and three-dimensional analysis to compare the differences in data. The comparison is shown in Figure 1. Figure 1(a) is a three-dimensional finite element analysis, and Figure 1(b) is a two-dimensional finite element analysis. Because the data obtained through the comparison of two-dimensional and three-dimensional comparisons are consistent, the two-dimensional finite element analysis method is used to analyze the geotechnical excavation.



(a) Three-dimensional finite element analysis (b) Two-dimensional finite element analysis

Figure1. Comparison between three-dimensional finite element analysis and two-dimensional finite element analysis

Table 1 Statistics of Soil Material Parameters for Construction Projects

research material	Excavation engineering part of soil
	1900
Poisson's ratio	0.495
Young's Modulus E（Pa）	12e6
Cohesion CoH（Pa）	130e3
Internal friction angle PHIMAX（radians）	30

The construction surface part is set to have no buildings at present, and the geotechnical structure will not be affected by the weight of the building. The soil material is relatively uniform, so there is no direction difference. At the same time, it is assumed that the soil is elastic soil, eliminating the effects of various factors such as drainage and exhaust during the excavation process. There are many factors that affect the settlement of rock land surface settlement. The mainly factors are the size of the rock and soil diameter; the distance between the rock and soil excavated from the surface; the physical characteristics of the ground; the parameters of the rock and soil construction. It is generally believed that when the distance between the excavated part of the rock and the ground increases, the maximum value of surface settlement will decrease. The material parameters of the soil during excavation are shown in Table 1.

Although the process of excavation of rock and soil is three-dimensional, some restrictions have prompted us to use two-dimensional finite element method for simulation. At the same time, in order to improve the calculation accuracy and speed, we use the two-dimensional environment provided by COMSOL software to model in this study. Therefore, the main method used in this experiment is the method of solving the plane problem. The model established according to the scale size is shown in Figure 2. The soil size parameter is: the length of the soil model is 100m and the width is 50m. After setting this size, a semicircle with a radius of 5m must also be made in the y-axis and -20m direction.

In this study, COMSOL automatically generated grid can meet the requirements of the solution. In the entire geometric model, meshing is performed in a finer manner. The number of elements in the x direction is 27, the number of elements in the y direction is 15, and the number of elements in the semicircle is 24 in total. The conditions for setting the boundary are shown in equation (1) (Tan R, 2015):

$$[K_G]\{\Delta d\}_{nG} = \{\Delta R_G\} \qquad (1)$$

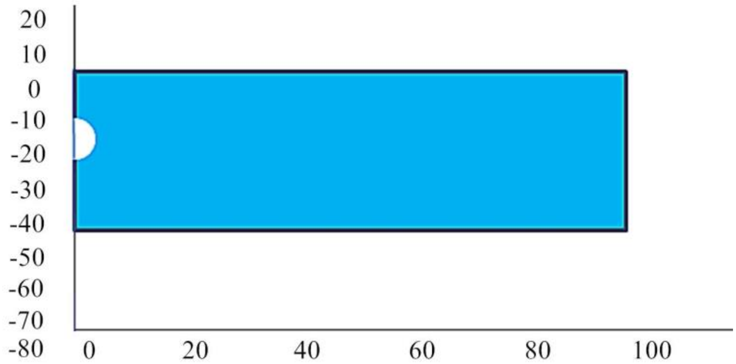


Figure 2. Size setting of the soil model in the study

The first type of boundary conditions only affects the right side of the equation (ΔR_G). Such boundary conditions are load boundary conditions, including point load, surface load, volume force, and filling and excavation. The second type of boundary condition only affects the left side of the equation ($\{\Delta d\}_{nG}$). Such boundary conditions are known as known displacement boundary conditions. The third type of boundary conditions is also a more complex one that affects the structure of the general equation. It includes local coordinates, which needs to perform coordinate transformation on the stiffness matrix and the load vector on the right side of the equation.; constrained degrees of freedom, influences the number of degrees of freedom and the set of stiffness matrices; spring boundary conditions, also affect the set of stiffness matrices.

The solid mechanics model in COMSOL was used in this test, and the first boundary condition was selected as the setting of the boundary conditions according to the actual situation in the field. The following boundary conditions and load loading settings were made in the actual analysis process: The soil solid model was set to be almost incompressible and isotropic; The solid model studied was set to an isotropic linear elastic model. At the same time, the isotropic material has symmetrical points; The bottom boundary of the soil is selected as the fixed constraint of the model; The rightmost boundary line of the soil is used as the boundary condition for rolling support of the soil; During the initial stress analysis of the soil, the self-gravity of the soil is set as the body load; In geotechnical excavation, it is necessary to input the initial stress of the soil. After the excavation, the gravity of the excavated soil is used as the body load, and the pressure caused by gravity pressure is used as a negative sign.

3. Results

The test results are mainly divided into two steps. The first step is the stress analysis before the rock and soil excavation. The second part is the effective analysis of the elastic and plastic behavior of the rock and soil. From the actual situation, currently there is no young soil structure model that can reflect the actual mechanical properties of rock and soil, so it is necessary to choose effective mechanical characteristics to respond to the geotechnical structure. The test strives to accurately simulate the excavation site of rock and soil, so it is necessary to simulate the initial stress, stress change, drainage, etc. Before the excavation of geotechnical engineering, the stress calculation is required. The results are shown in Fig. 3. The stress of the soil produces the maximum stress at the lowest end of the rock and soil, and the maximum stress value is 5.712×105 N/m. After the excavation of the rock and soil, a uniform strain is generated around this pipe.

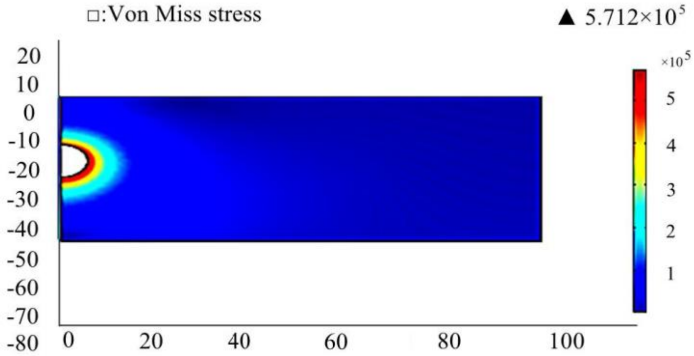
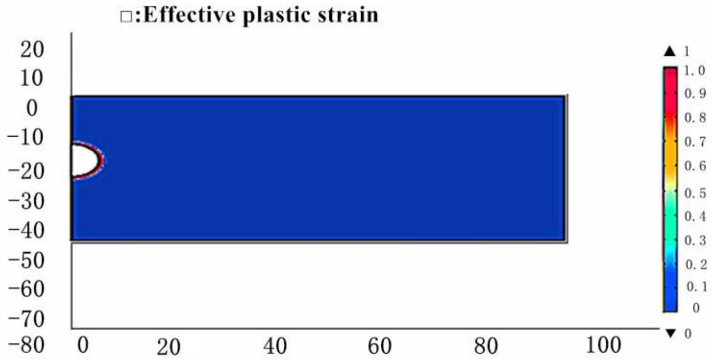


Figure. 3 Stress calculation before excavation of geotechnical engineering

Figure 4 shows the horizontal displacement of the top of the rock and soil layer. It is not difficult to see from the figure that the displacement at the horizontal distance of 0-22m shows a rapid upward trend. The displacement reaches a peak at a horizontal displacement of 22m and the peak value is 50mm.Since then, there has been a downward trend between the geotechnical engineering axis at the end of 90m, where the horizontal displacement is 0m. Changes in the vertical displacement of rock and soil layers: The maximum vertical displacement at the forefront of the geotechnical axis is 100mm, which means that the maximum value is generated in the center of the geotechnical excavation. With the gradual removal from the center of the geotechnical excavation, the vertical displacement of the soil layer gradually decreases, and its minimum value is 20 mm at the end of the geotechnical axis, that is, 90 m. At the same time, the graph as a whole shows a gradual reduction process.



Fingure.4 Plastic strain of rock and soil after excavation

The empirical method for determining settlement caused by rock and soil excavation is based on site observations in undeveloped areas in the suburbs. It is inappropriate for the city center to pass through under existing buildings. The finite element method is used to analyze the interaction between the soil and the building. This can more accurately analyze the changes in soil stress after excavation and the range of settlement. Through the simulation analysis system of two-dimensional geotechnical excavation, the effects of changes in geotechnical diameter (D), distance from the ground to the center of the rock (z), building length (B), and eccentricity (e) on soil settlement and horizontal displacement were systematically studied. The parameters of this simulation test are shown in Table 2.

Table 2 Study test parameters

Experimental parameters	**Experimental values**
Building weight（104N/M）	2、4、6、8、10

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Relative building position（m）	0
Geotechnical Excavation Diameter（m）	10
Vertical distance from the center of the Excavation center（m）	10、15、20、25

4. Discussion and Analysis
Through the above analysis, it can be seen that the vertical displacement of rock soil changes. The largest vertical displacement generated at the forefront of the geotechnical axis is located in the center of the geotechnical excavation. With the gradual decentralization of the central location of the rock and soil, the vertical displacement of the soil layer gradually decreased, and the overall trend showed a gradual decrease.

From the test results, under the influence of the building, with the increase of gravity in the vertical direction, the change of stress after excavation of geotechnical soil is gradually increased. When the vertical gravity is not loaded, the maximum stress value is 5.712×105 N/m. (See Figure 3). After the vertical gravity is loaded respectively, the maximum stress value appears at the bottom of the rock. When the vertical loading of gravity is compared with the non-loaded vertical gravity, the stress increase value shows a gradually increasing trend, and the increased stress variation is also very uniform. After studying the effect of different gravity in the vertical direction on the strain of the rock after excavation of the rock and soil, it can be seen that with the gradual increase of gravity in the vertical direction, the strain around the rock and soil after excavation exhibits a uniform strain to the surroundings; With the gradual increase of gravity conditions in the vertical direction, the strain range around the excavated rock is also showing an expansion phenomenon, and the diffusion range of this strain is relatively uniform.

The influence of different gravity in the vertical direction on the horizontal displacement of the pipe after excavation of rock and soil is: With the increase of gravity in the vertical direction, the maximum horizontal displacement generated by the soil layer is also increasing; Under the condition of different gravity in the vertical direction, the horizontal displacement shows a process of first sharp increase and then gradually decrease, and all of them reach the maximum at a horizontal displacement of 20m away from the position of the rock and soil axis.

The influence of different gravity in the vertical direction on the vertical displacement of the pipe after geotechnical excavation is: With the increase of gravity in the vertical direction, the maximum vertical displacement generated by the soil layer is also increasing. In the case of different gravity in the vertical direction, the vertical displacement is a process of increasing first and then gradually decreasing. At the same time, they all reached their maximum value at a horizontal displacement of 0m away from the location of the geotechnical axis, that is to say, at the middle of the excavation of the rock and soil.

The horizontal displacement, vertical displacement and soil stress variation under different distances from the surface layer of the geotechnical center were studied. The study shows that under different distance conditions, the horizontal displacement, vertical displacement and soil stress all increase with distance. The reason is that as the increasing distance increases, the gravity of the soil itself increases. Therefore, the horizontal displacement, vertical displacement, and the maximum stress occurring at the bottom of the rock and soil are gradually increased after excavation of the rock and soil. The maximum stress of the geotechnical center from the ground surface is at the bottom of the rock and soil excavation.

As the distance between the center of the tunnel and the surface of the soil layer increases, both the horizontal displacement and the vertical displacement show a very uniform decrease. In the 25m position of the project, the horizontal displacement and vertical displacement reach the minimum value, but this minimum value is also larger than the simple soil settlement value. In other words, when we increase the depth of the tunnel from the ground, we can significantly reduce the horizontal displacement and vertical displacement. This will play an important role in selecting the appropriate depth of excavation for actual excavation.

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5. Conclusion

This paper uses COMSOL Multiphysics finite element analysis software to analyze and study the two aspects of geotechnical engineering in geotechnical excavation and deep excavation. The test results are mainly divided into two steps. The first step is the stress analysis before the rock and soil excavation, and the second is the effective analysis of the elastic and plastic behavior of the rock and soil. As this experiment strives to accurately simulate the site of geotechnical excavation, it is necessary to simulate the initial stress, stress change, drainage, etc. After calculating the stress of the soil through the excavation of geotechnical engineering, it was found that the stress of the soil obtained the maximum value at the lowest end of the rock and soil, and the maximum stress value was 5.712×105 N/m. After the rock and soil excavation, a uniform strain was generated around the pipe. Secondly, the results of the excavation process were studied respectively under the influence of the buildings and without the influence of the buildings. Through research, it has been found that the maximum vertical displacement at the forefront of the geotechnical axis is located at the center of the geotechnical excavation without being affected by the building. Under the influence of buildings, the effects of different gravity in the vertical direction and different distances in the geotechnical center on the horizontal and vertical displacements of the pipeline after excavation were studied. At the same time, the best excavation methods and parameters are obtained, which will help the effective development of subsequent geotechnical excavation work.

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