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Numerical simulation and construction technology optimization of collapsible loess subgrade deformation

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Abstract: It is extremely important to simulate and evaluate the deformation degree of road foundation under the condition of collapsible loess to solve the practical engineering problems and optimize the construction technology. In this paper, a municipal road is taken as the research object, which suffers from collapsible loess along the subgrade, and has the characteristics of thick loess foundation depth and large area, which is not suitable for large area replacement. Settlement characteristics of subgrade using finite element method. According to the settlement simulation results, revise the construction process, excavation and drainage measures, replacement and drying, etc. Through the improvement of the construction technology, the settlement of the subgrade is effectively reduced, and after the later observation of the project, the quality standard has reached the design requirements. This result is of great reference significance for the optimization of the construction technology of the same type of engineering.

1. Ask the question

Fsisible loess refers to the soil with significant additional deformation due to the structural damage of the soil under the action of self-weight stress and additional stress. Collapsibility is an important characteristic of loess. Widely distributed in northwest China, North China and other regions. Under the influence of water pressure, the overall structure of the water-bearing soil will be rapidly destroyed, such as a relatively large additional subsidence, accompanied by deformation, resulting in the reduction of the strength of the soil. Therefore, when the project encounters collapsible loess foundation, subsidence deformation is often encountered engineering problem. That is to say, when the project encounter collapsible loess foundation, according to the importance of the building, the size of the foundation possibility and during the use of uneven settlement limit strict, take reasonable foundation treatment means, to effectively prevent the foundation subsidence caused large deformation and serious harm to the building itself.

There have been various theories about the theory of loess collapsible deformation, such as the wool tube hypothesis, salt dissolution hypothesis, colloid insufficiency, water film wedge theory and under-compaction theory. The causes of collapsible deformation are explained from various aspects of physics, physics, chemistry and geology. They can explain one aspect of the problem, but they cannot fully explain all the collapsible phenomena and the nature of deformation[1]. One of the important problems is the determination of loess foundation. The traditional method of calculating the collapsible amount of loess foundation is to calculate the total amount of collapsible amount of stratified soil according to the actual stress value of the soil layer according to the relative collapsible coefficient obtained by the compression test. Based on the effective stress-strain relationship of humidification test and pore pressure characteristic test, three-dimensional nonlinear numerical analysis method is adopted to carry out deformation and stress transformation in the whole process of loess foundation [2].

For example, a city key project, through the new municipal road, comprehensive market and rain and sewage pipe network project, improve the overall quality of urban living ecological environment, laying the foundation for the construction of civilized city demonstration area. One of the projects, Liucaowu Avenue project, is an urban secondary trunk road, the red line is 32m wide, and four lanes in both directions. The construction content includes road engineering, drainage engineering, traffic engineering, lighting engineering, greening engineering, etc. Subsubgrade design is shown in Figure 1 below. According to the geological exploration, the road suffers from collapsible loess along the subgrade, which has the characteristics of thick loess foundation depth and large area, which is not suitable for large area replacement. Therefore, one is to strengthen the effective drainage control of the collapsible subsidence, and the second is to understand the road settlement caused by the collapsible deformation, so as to minimize the impact on the foundation and protect the stability of the roadbed.

Based on the above, this paper analyzes the conditions, the reasons and the subsidence, and the subsidence of the loess, and to verify the reliability and correctness of the model and predict the basic law of subgrade subsidence deformation. The relevant results are of important reference significance for evaluating the collapsible deformation of foundation under different immersion degrees.

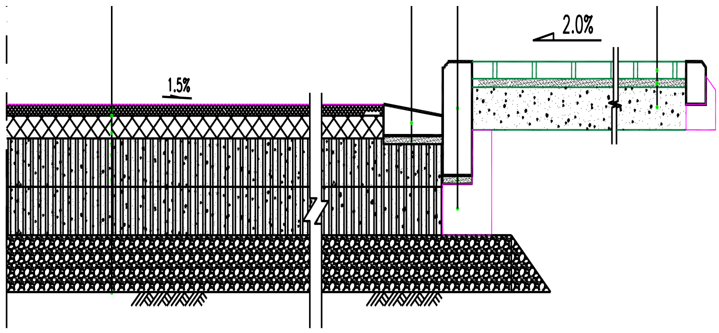

Figure 1: Road engineering design drawing

2. Soil mechanics test

According to the JTG 3430-2020, the field survey of the project subgrade is conducted and the soil samples were monitored. According to the survey report, the upper layer is loess, its main component is silt soil; of which coarse clay particles of 0.05~0.01mm constitute about 48% of the total weight; clay particles less than 0.005mm constitute about 25% of the total weight and slightly less content; more than 0.1mm, fine sand particles constitute about 18% of the total weight; medium sand particles greater than 0.25mm constitute about 9% of the total weight. Natural water content is saturated water content. Then the lower layer is permeable sand. Its natural water content is 22.2%, the plasticity index is 14.1, the liquid limit is 33.7, the mean cohesion force is 15.1kPa, and the liquid property index is 14.9. The soil layer has relatively large pores, high natural water content and plasticity, strong water permeability, easy to touch and change, poor shear strength and engineering performance, and insufficient bearing capacity. Some related soil mechanical parameters are shown in the table 1 below.

Table 1: Soil mechanical parameters

natural rate of water content (%)	water ratio limit			Natural density (g/cm^{-3})	internal friction angle (^{o})	cohesive strength	compress coefficient	kick-back modulus
	liquid limit	plastic limit	ductility index number					
22.2	33.7	19.6	14.1	1.92	14.9	15.1	0.4	22.3

3. Finite-element numerical simulation of subgrade deformation

3.1 Simulation principle

The finite element method is to use multiple units at finite scales to discretize the continuous units through the finite nodes to describe the deformation characteristics with the displacement function. By solving the system of equations, the physical quantities such as displacement, stress and strain on the nodes of each unit are expressed in numerical values. In short, finite element analysis is a mathematical approximation method, which is a relatively mature means to solve complex problems numerical. It is one of the most effective engineering analysis methods with high calculation accuracy and strong adaptability.

The settlement characteristics of subgrade are related to the saturation of soil, and for unsaturated soil, its settlement characteristics depend on the modulus of soil skeleton. For the saturated soil, there is a certain correlation between the foundation settlement characteristics and the action time. This feature is the foundation of subgrade settlement prediction and settlement pretreatment. This section intends to calculate and analyze the settlement deformation characteristics of the unsaturated foundation based on the relevant parameters of the engineering area, and compare the simulation results with the field observation, so as to verify the reliability and correctness of the model and predict the basic law of subgrade settlement deformation in the engineering area.

3.2 Simulation software

Simulation calculation uses the widely used finite element ABAQUS, computational software, its excellent analytical ability and simulation complexity Reliability of the system. It can be simulated as arbitrary geometry Of the cell library, as well as the simulated typical engineering materialOf its properties, such as the metal, the steel reinforced concreteAnd soil and other materials. The Standard / Explicit two solver modules are used to simulate the stress and displacement of the structure.

3.3 The basic equation

Zhang Aijun et al[2-4]It is pointed out that the constitutive relationship of loess is not only related to stress but also related to temperature, time, strain rate, deformation history and physical microstructure, especially to the water content in the soil. It can be said that the collapsible deformation is the result of the joint action of external forces and water. If the duration of subsidence is only the final subsidence condition of various layers of soil under different water content (including saturated and unsaturated), the constitutive relationship of loess subsidence can be expressed by the following general formula:

$$\epsilon_{ij} = f(\sigma_{ij}, \omega) \tag{1}$$

$\epsilon_{ij}\sigma_{ij}\omega$Where, it is the collapsible deformation tensor, the stress tensor, and the water content of the soil after immersion.

Liu Dun li[3-7]The finite element equation is used to calculate the settlement of the subgrade, and it is pointed out that the calculation of geotechnical engineering should adopt the famous Mohr-Coulomb strength criterion. The intensity criteria are:

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

For the strain tensor, the increment takes the form of:

$$d_\varepsilon = d_\varepsilon{}^{el} + d_\varepsilon{}^{pl} \tag{3}$$

$d_\varepsilon d_\varepsilon{}^{el}$Where is the total stress variable, the elastic strain increment and the plastic stress increment.$d_\varepsilon{}^{pl}$

For the yield characteristics, the basic equation is:

$$F = R_{mcq} - p\tan\varphi = 0 \tag{4}$$

φWhere R mc is the partial stress coefficient, the inclination of the yield surface in a certain plane (q), p is the equivalent compressive stress, and q is the effect force such as Mises[7-8].

For flow rule, it is defined as:

$$d\varepsilon^{pl} = \frac{d_{\bar{\varepsilon}}{}^{pl}}{g}\frac{\partial G}{\partial \sigma} \tag{5}$$

Where, G is a function of the flow potential.

3.4 Calculation model and calculation parameters

The relevant calculation steps are described as follows: first, the project is simplified and the geometric model is established, the engineering boundary conditions are added to the established geometric model, and the model is grid divided. After completing the above setting, start the stiffness calculation, stress and strain solution, etc. Among them, according to the subgrade engineering design drawing and related parameters, the subgrade is simplified, and the simplified geometric model is shown in the following figure 2. After simplification, according to the plane strain problem, the horizontal boundary is set to the rolling support, and the single directional displacement is fixed. The bottom of the model also adopts the rolling support to fix the displacement in the single direction.

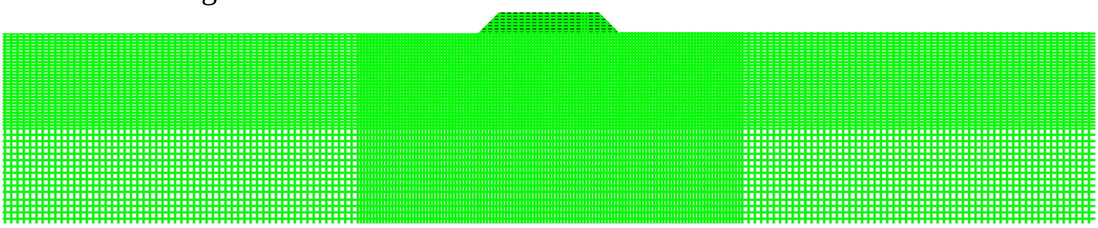

Figure 2: Geometric model and model grid

In the figure, the calculation section adopts the standard double line form, the calculation height of the subgrade is 0.6m, the model calculation width is about 32m, the foundation and soil are calculated, and the depth is about 10m. The simplified unreinforced foundation is divided into two layers from top to bottom, with a thickness of 8m and 2m respectively. The topographic water line is below the calculated depth. The soil parameters are shown in the above soil mechanics room test table.

4. Subgrade deformation analysis

Based on the simulation results, see Figure 3 below. Under the gravity of the subgrade itself, the lower soil is deformed, and its deformation is similar to the parabolic type. The maximum settlement of the subgrade is 6.6mm. Look at the value of settlement from the perspective of engineering quality standards. It can be seen that it is necessary to settle the subgrade to reduce the pavement settlement and improve the stability of the subgrade. Therefore, the construction process needs to be optimized according to the simulation calculation results to reduce the settlement control within a reasonable range.

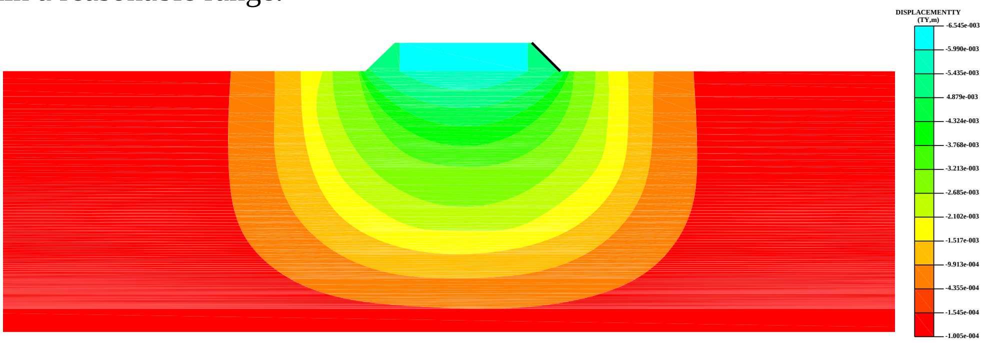

Figure 3: Cloud map of subgrade settlement

5. Optimization of the construction technology

In order to reduce the settlement, the overall construction process of Liucaowu Avenue should be modified, and the optimized flow process is as follows:

5.1 Clear the table. First, the left width along the road for a clear table, within the range of the road

Surface filling, humus, sod and crop roots should be cleaned. The filling section of the site should be leveled at the initial stage to meet the requirements of construction approach, equipment parking and operation.

5.2 Drainage and air drying

According to the actual subgrade exposed by the construction site, the water level along the road is high, and the geological conditions are collapsible loess, which needs to be dried. Part of the collapsible loess with greater water content should be replaced with shallow layer and filled with materials that meet the requirements of the bearing capacity of the foundation.

5.3 Shallow layer replacement

The subgrade treatment within the scope of the project is mainly shallow layer replacement. The general section of the subgrade adopts the treatment method of excavating and filling the soil, and the local section is determined according to the qualitative conditions of the soil base.

Earthwork backfilling. After the completion of special subgrade replacement and drainage pipe network construction, earthwork backfill shall be backfilled to the top elevation of the road bed, and the transverse slope and longitudinal slope shall be controlled. See Figure 4 below for the above drainage and drying work.

Figure 4: Drainage and air drying of the subgrade

5.4 Construction of the pavement structure layer.

After the road bed is formed, the pavement structure layer is constructed, first laying a layer of 20cm thick graded gravel, followed by two layers of 17cm thick cement stabilized gravel. After the second layer of water was formed, curb construction and pavement bed plastic construction began. After the completion of the subgrade project, the sidewalk construction, greening planting and street lamp and traffic safety facilities construction shall be carried out in turn.

6. Conclusion

On the background of the subgrade, the finite element simulation and optimizes the construction technology to improve the subgrade stability.

Water content influence of collapsible loess subgrade, and the numerical calculation results show that the settlement reaches 6.6mm, significantly greater than the engineering design standard.

According to the characteristics of large settlement, the construction technology is optimized, open channel drainage, local filling and drying, etc. Through the application of the above measures, the settlement characteristics of the subgrade are limited controlled. This result provides support for the optimization of construction technology of similar projects.

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