Analyzing the influence factors' sensibility of calculating stability safety coefficient of the slope

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Abstract

In order to study the factors affecting the stability and safety of slope in soft soil foundation, we select slope of a high-speed section in Harbin for field trips. The subgrade model is calculated by the finite element method.Using the control variable method, the sensitivity of the influence factor of stable safety factor is explored by changing parameters of geometric size and material of the computer model.The calculating results show that : and the internal friction angle φ is more sensitive to the safety factor of soft foundation embankment.

Keywords

Soft ground embankment, Stability safety coefficient, FEM numerical calculation, Sensitivity analysis.

1. Introduction

China has a vast territory, the soil of the economically relatively developed coastal areas is mostly saturated compact clay, and in the western areas there are also soft soil with unique properties [1].

Soft soil generally has the following characteristics, such as, water content, high compressibility, poor carrying capacity, lowshear strength, high sensitivity, long settling time and so on. In highway construction, due to the low shear strength of soft soil, soft foundation embankment may have lateral sliding, slipping of the slope, or a greate settlement under the the pressure after filling, which will lead to the destruc- tion of roadbed, the fracture of asphalt pavement, the misplacement and fracture of cement pavement panel and other problems, resulting in that theroad can not be used normally[2]. In view of the adverse effects of soft soil in road construction, in order to ensure the quality of the project and improve economic efficiency, it is very im-portant to explore the influencing factors of the stability factor of the soft foundation embankment and to discuss the sensitivity of the stable safety factor in the practical engineering construction. At present, there are two main methods of calculating thesoft foundation: limit equilibrium method (Swedish method, Bishop method, etc.) and finite element method (ABAQUS, PLAXIS)[3~5]. The limit equilibrium method is relatively simple and widely accepted, and the finite element method has its own advantages in dealing with the complex and comprehensive problems in slope stability. With the popularization of the computer, the calcu-lation of the finite element software has begun to become popular. By studying the factors affecting the stability safety coefficie-nt of slope, the finite element software is used to calculate the stability factor K of soft embankment under various conditions and to analyze the sensitivity of each influencing factor. Finally,the theoretical reference has been put forward for the problems that should be paid attention to in road construction.

2. Project support

A highway project in Harbin was selected as the project support, The highway is a four-lane expressway with a roadbed width of 28m, and the slope of the embankment slope is 1: 1.5. Within the control range of drilling depth, the soil layers in the study area were investigated and the results were summarized as follows Table 1:

Table 1. Soil layer and soil parameters

Layer	Name	Thickness/m	Characteristic
1	Artificial fill	0.5~4.5	
2	Peat mud	1.5	Black, stench
3	Silty clay	0.4~0.7	Gray, stench
4	Silt	0.9	Gray, stench Gray, saturated
5	Fine sand	-	Gray, saturated
6	Medium Sand	-	

According to the specifications of the embankment construction, figure 1-1 shows the design size of the soft embankment, the distribution conditions of different types of soil of foundation and subgrade. (In meters)

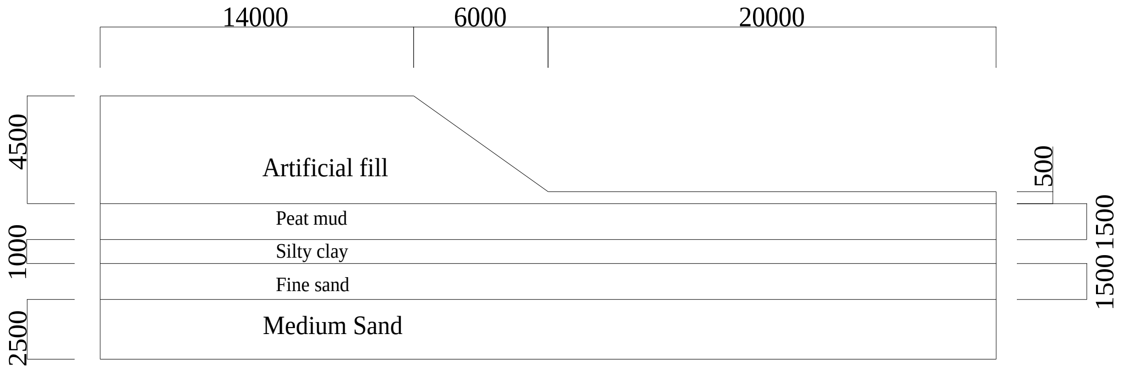

Figure 1. Geometric model of embankment on soft foundation

The engineering test parameters of embankment soil was obtained by above site visits and laboratory tests. And the main physical and mechanical indexes of each soil layer are shown in Table 2:

Table 2. Calculation table of subgrade materials

material type	Application area	γ (KN/m^3)	c (KPa)	φ (°)	μ	E (MPa)	k (m/d)
Medium Sand	foundation	16.8	7	24	0.2	7.6	1.08E+00
Fine sand	foundation	16.6	10	29	0.25	3.3	1.00E-03
Silty clay	foundation	13.6	27	12	0.3	3.5	—
Peat	foundation	10	30	11.5	0.35	2	—
Artificial fill	Embankment	20.5	98	25	0.3	34	—

3. The use of finite element software to calculate

PLAXIS is selected as the finite element software, and the strength reduction method is used to study the influencing factors of the stability safety coefficient of soft foundation embankment and to make numerical analysis[6~8].The PLAXIS finite element is used to divide the subgrade and foundation units as shown in Figure 2.

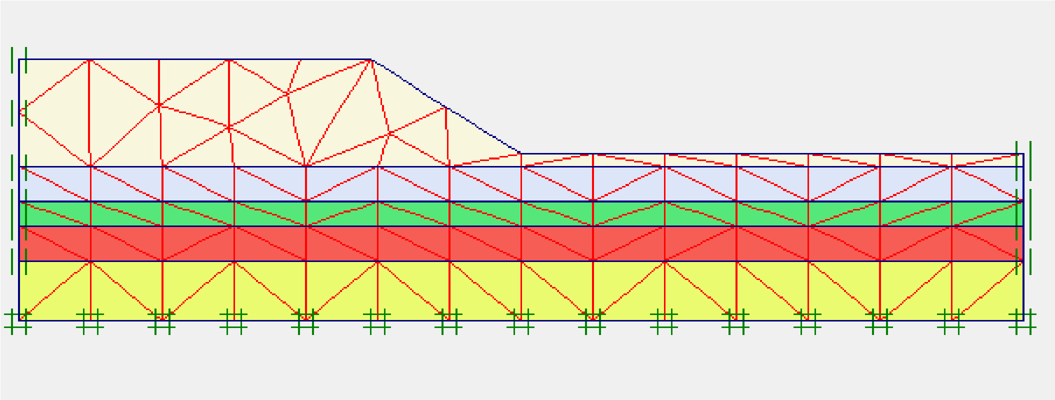

Figure 2. The mesh of geodetic model of soft foundation embankment

According to the above calculating parameters of the model, the material characteristics, the boundary condition, the groundwater level and the consolidation of the two sides, under the action of the self-weight of the soil mass, the total displacement shadow of the soft embankment is calculated by PLAXIS finite element software as follows Figure 3.:

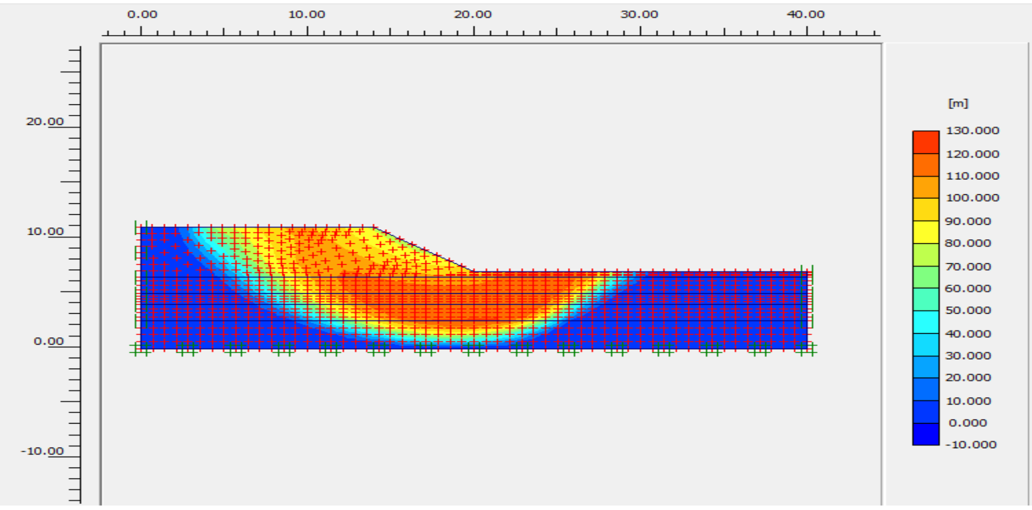

Figure 3. The total displacement shadows after the completion of the layered embankment

The strength reduction factor can be obtained in the output result, or by looking at the calculation results in the output result, $\sum\text{-}Msf=3.641$ is the strength reduction factor, and that is the safety factor of the slope stability of the soft embankment.

When analyzing the safety coefficient of slope stability, Taylor proposed 5 parameters, namely, the height of the slope H, basal slope of side slope β, soil gravity γ, and the shear strength of the soil: the cohesion c and internal friction angleφ. In the case of knowing any of the four parameters, the fifth parameter can be obtained. In order to facilitate the calculation,Taylor combines the cohesive force c, the Soil gravity γ and the slope height H into a new parameter Ns, and this new parameter is called the stability factor, namely:

$$N_s = \frac{\gamma H}{c} \tag{1}$$

Based on Taylor's five calculated parameters:the height of the slope H, basal slope of side slope β, soil gravity γ, and the shear strength of the soil: the cohesion c and internal friction angle, the influence of each parameter on the safety factor of slope stability was studied by controlling the variable method, and the sensitivity of the influencing factors was further explored[9~11].

4. Sensitivity analysis of material parameters to influencing factors of stability safety of soft foundation embankment

In the study of the sensitivity values of influencing factors of the stability safety coefficient of the soft foundation embankment, cohesion c, internal friction angleφ and soil gravity γ these three parameters were simultaneously made a same ±20 change reference, as shown in Table 3, which is in line with the actual engineering conditions, and is conducive to analysis of the impacts of different parameters on sensitivity of the stability safety factor. The results are calculated using the finite element software as follows: Table 4

Table 3.The change value of parameters of soft soil foundation

Para-meter	Change rate of Parameter / Result	-20	-15	-10	-5	0	+5	+10	+15	+20
c (KPa)	Peat	24	25.5	27	28.5	30	31.5	33	34.5	36
	Silty clay	21.6	23.0	24.3	25.7	27	28.4	29.7	31.1	32.4
	Fine sand	8	8.5	9	9.5	10	10.5	11	11.5	12
	Medium Sand	5.6	6	6.3	6.7	7	7.4	7.7	8.1	8.4
φ (°)	Peat	9.2	9.8	10.4	10.9	11.5	12.1	12.7	13.3	13.9
	Silty clay	9.6	10.2	10.8	11.4	12	12.6	13.2	13.8	14.4
	Fine sand	23.2	24.7	26.1	27.6	29	30.5	31.9	33.4	34.8
	Medium Sand	19.2	20.4	21.6	22.8	24	25.2	26.4	27.6	28.8
γ(KN/m^3)	Peat	12.8	13.6	14.4	15.2	16	16.8	17.6	18.4	19.2
	Silty clay	14.5	15.4	16.3	17.2	18.1	19	19.9	20.8	21.7
	Fine sand		16.8	17.6	18.6	19.6	20.6	21.6	22.5	23.5
	Medium Sand		16.8	17.6	18.6	19.6	20.6	21.6	22.5	23.5

Table 4. D-value and changing rate of stability safety factor K after variation of soft soil foundation's parameters

Param-eter	Change rate of Parameter / Result	-20	-15	-10	-5	0	+5	+10	+15	+20
c (KPa)	K	3.385	3.496	3.544	3.595	3.641	3.689	3.735	3.783	3.825
	D-value K	-0.256	-0.145	-0.097	-0.046	0	+0.048	+0.094	+0.142	+0.184
	Change rate K(%)	-7.0	-4.0	-2.7	-1.3	0	+1.3	+2.6	+3.9	+5.1
φ (°)	K	3.186	3.304	3.419	3.531	3.641	3.752	3.822	3.986	4.080
	D-value K	-0.455	-0.337	-0.222	-0.11	0	+0.111	+0.181	+0.345	+0.439
	Change rate K(%)	-12.5	-9.3	-6.1	-3.0	0	+3.1	+5.0	+9.6	+12.1
γ(KN/m^3)	K		3.499	3.509	3.576	3.641	3.702	3.761	3.810	3.859
	D-value K		-0.142	-0.132	-0.065	0	+0.061	+0.12	+0.169	+0.218
	Change rate K(%)		-3.9	-3.6	-1.8	0	+1.7	+3.3	+4.6	+6.0

Slope instability is mainly due to the lack of shear strength of the soil on the slip surface, which leads to the destruction of the slope.The improvement of the shear strength of the soil increases the shear strength of the potential slip surface of the soil effectively, thus enhancing the stability of the slope.

$$\tau_f = c + \sigma tan\varphi \tag{2}$$

Similarly, the increase of soil gravity leads to the increase of the shear stress of the potential slip surface of the soil. In the case of constant shear strength of soil, the shear strength of soil is not enough to resist soil destruction due to the increase of shear stress on the sliding surface of slope soil, so instability occurs.

By summarizing the three graphs of the cohesive force c, internal friction angle and saturated density of gravity of soft soil together and comparing the influence of the parameters of soft soil on the safety factor of slope stability, the results can be obtained as Figure 3-1:

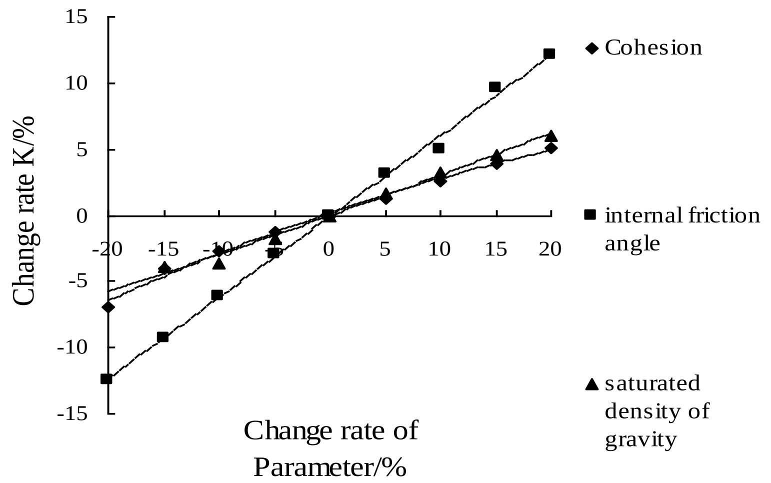

Figure 4. The line chart of effect of parameters on sensitivity of stability safety factors of soft soil embankment

Through observing the above-mentioned line graph, studying the change rate of the safety factor of the slope stability by comparing the cohesion c, the internal friction angle φ and the saturated density of gravity γ of the soil at the same parameter rate of change, we can obtain the conclusions as follows: The cohesive force c is positively related to the stability factor of soft foundation embankment. The change of cohesion c has little effect on the stability coefficient of soft foundation embankment. When the cohesion c changs by 5%, the stability safety coefficient of the soft foundation embankment changes about 1.3% ; The internal friction angle φ is positively related to the safety factor of soft foundation embankment. The change of internal friction angle has a great influence on the stability factor of soft foundation embankment. When the internal friction angle changs by 5%, the stability safety coefficient of the soft foundation embankment changes about 3% ; The saturated density of gravity γ of the soil is positively related to the stability factor of soft foundation embankment. The effect of saturated density of gravity γ on the stability factor of soft foundation embankment is not so big, which is close to the cohesion c. When the saturated density of gravity γ changes by 5%,The K value of the stability factor of soft foundation embankment changes about 1.5% ~ 1.7%.

5. Sensitivity analysis of geometric parameters to stability safety influencing factors of soft foundation embankment

5.1 Sensitivity analysis of basal slope of soft foundation embankment to stability and safety coefficient

In the study of sensitivity analysis of basal slope to stability and safety coefficient of soft foundation embankment, using the control parameter variable method, the slope angle is changed in the case of ensuring keep the parameters of the soft foundation: cohesion c, the internal friction angle φ, the gravity γ and the slope height H constant.

In the process of slope modeling, the finite element software is used to ensure the parameter cohesion c, the internal friction angle φ and the gravity γ and the slope height H of the soft soil embankment remain unchanged. Under this condition, only the slope ratio is adjusted to calculate the new stability factor K of soft foundation embankment, as shown in Table 5.

Table 5. The coefficient of slope variation and stable safety factor of embankment on soft soil

Slope angle	Change of side slope(m)	-4	-2	0	+2	+4	+6
	Slope ratio	1:0.5	1:1	1:1.5	1:2	1:2.5	1:3
	K	3.442	3.555	3.641	3.721	3.808	3.908
	D-value K	-0.199	-0.086	0	+0.08	+0.167	+0.267
	Rate of change K	-5.5	-2.4	0	+2.2	+4.6	+7.3

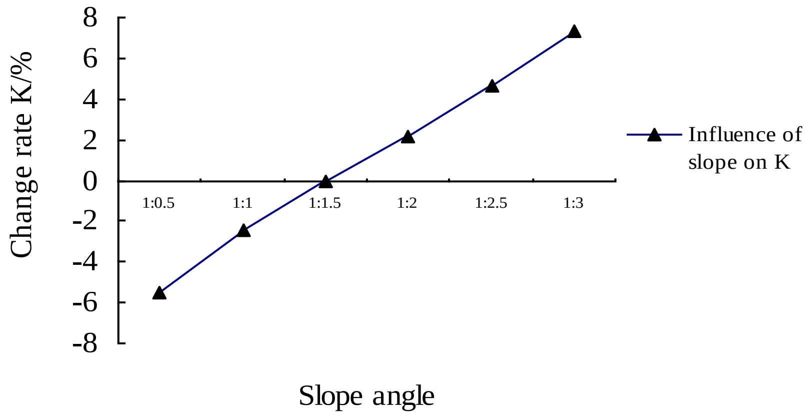

Fig.5 The polygonal line chart about Influence of slope on the stability safety factor of embankment on soft soil

It can be seen from the figure that the slope angle of the soft embankment is the slope angle of the embankment, the slope angle of the soft embankment is negatively correlated with the stability safety factor, that is, the smaller slope angle of the soft embankment is , the more stable the slope is, the bigger stability safety factor is and the more stable the soft foundation embankment is. On the contrary, the larger the slope angle of the soft embankment is, the steeper the slope is, the smaller the safety factor is, and the more unstable the soft embankment is.

5.2 Sensitivity analysis of slope height of soft foundation embankment to stability and safety coefficient

In the study of sensitivity analysis of slope height H to stability and safety coefficient of soft foundation embankment, also using the control parameter variable method, the slope height is changed in the case of ensuring keep the parameters of the soft foundation: cohesion c, the internal friction angle φ, the gravity γ and the slope angle β constant.

According to the study of soft foundation embankment, the original slope height was 4m, the slope height H was changes as Table 6.

Table 6. Height variation and stability safety factor of embankment on soft soil foundation

Height	Change of height(m)	-2	-1	0	1	2
	Height of slope (m)	2	3	4	5	6
	K	5.947	4.425	3.641	3.166	2.845
	D-value K	+2.306	+0.784	0	-0.475	-0.796
	Rate of change K	+63.3	+21.5	0	-13.1	-21.9

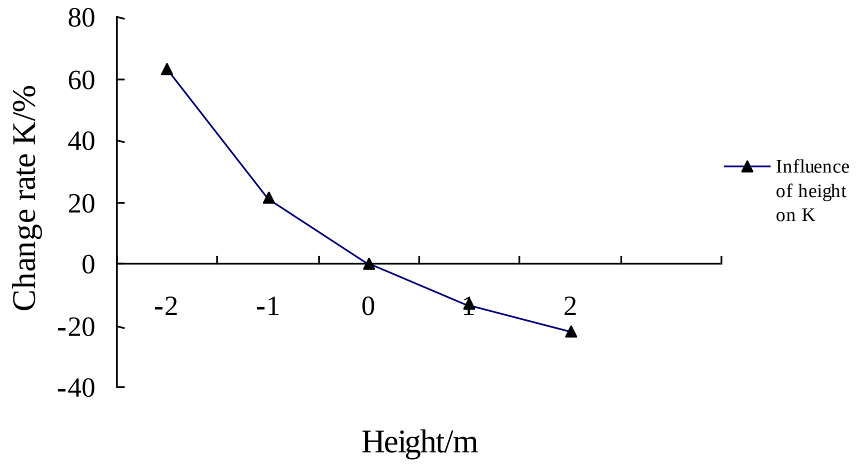

Fig.6 The influencing chart of slope height on stability and safety factor of embankment on soft soil foundation

It can be seen from the figure that the slope height H of the soft embankment is negatively correlated with the stable safety factor, that is, the higher the slope height of the soft embankment is, the smaller the safety factor is, the more unstable the embankment is; The lower the slope height of the soft foundation embankment is, the greater the stability safety factor is, the more stable the embankment of the soft foundation is. Moreover, it can be seen from the figure that the slope height H has a great influence on the safety factor of embankment on soft foundation.

6. Conclusion

(1) In the study of soft embankment, the effect of internal friction angle on the stability of the safety factor is relatively larger.

(2)Therefore, in practical engineering, the stability and safety factor of the soft foundation embankment can be increased by reducing the height of soil slope H, reducing the slope angle, changing the geometric size of the embankment, or the methods changing the soft soil with low-weight-soil and improving the internal friction angle, etc.

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