

Slope Stability Considering the Top Building Load

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Abstract

Slope stability is one of the most important subjects of geotechnics. The slope top-loading plays a key role in the stability of slopes in hill slope areas. When the building load is too large or the point of action from the shoulder is too close, the shear stress of the slope will be significantly greater than its shear strength, resulting in reduced slope stability. Therefore, it is of great importance to study the relationship between the building load and the stability of the slope. This study aims to analyze the influence of different building loads applied at different distances on the top of the slope and deduces their effects on the slope stability. For this purpose, a three-dimensional slope model under different building loads with different distances to the slope shoulder was established using the finite-difference analysis software Flac3D. The results show that the loads applied at different distances on the top of the slope have different effects on the slope stability. The slope factor of safety (FOS) increases with the increase of the distance between the top-loading and the slope shoulder; it varies from 1.37 to 1.53 for the load $P = 120$ KPa, 1.27 to 1.53 for the load $P = 200$ KPa, and from 1.18 to 1.44 for $P = 300$ KPa, resulting in the decrease of the coincidence area between the load-deformation and the potential sliding surface. The slope is no longer affected by the potential risk of sliding at approximately 20 m away from the slope shoulder.

Keywords

Building Load, Finite-Difference Analysis, FLAC3D Software, Slope Factor of Safety, Slope Stability

1. Introduction

Human activities account in various ways for the instabilities of slopes. These activities have been recognized as an important triggering factor that leads to

many landslides [1] [2] [3]. With the rapid increase of the population and the economic development in some countries around the world, the constructions sites needed for the development of the country are rapidly expanding outward, and the demand for land for a series of industries, housing, railways, highways, roads, water dams, and many other infrastructures constructions driven by the economic development is increasing, resulting in the increasing of the terrain complexity which may induce failures, cause many fatalities and strong destruction in hill slope areas. In these areas, the infrastructures are built at the toe, in the middle, or at the top of the slope through excavation, applied loads constructions, etc. The external load on top of the slope is one of the main causes of instability [4] [5]. Under the action of the upper load, the slope will produce a slip surface that does not pass through or under the slope toe, which increases the risk of instability [6].

From the available literature, it has been found that the stability analysis of the slope under building loads has been treated extensively; many scholars have earlier studied the influence of the load applied on the top of the slope; Zhihai Zhao *et al.* [4], established six slopes models with the building load set as variable and analyzed them by soil mechanism, numerical simulation, and multiple regression analysis to find the influence of the load on the stability of the loess slope; they observed that the stability of the loess slope has a significant relationship with the building load, and with the increase of building load, the variation trend of slope stability coefficient is different. In their study on the influence of top load on the slope stability under strong earthquakes in the loess area, Li Xudong *et al.* [6], used the shaking table test and FLAC3D software, and they found that, with the increase in distance of the top buildings to the slope, the coincidence area between the top load-deformation area and the potential sliding surface of the slope decreases. D.K. Paul and Satish Kumar [7], studied the stability of slopes subjected to building and seismic loads, concluding that a slope may fail in two ways: first, local failure may occur near the building foundation; second, global failure of the slope, including the building foundation system, may take place. Huang Xian-Wen *et al.* [8], have introduced a new random rock contour algorithm for obtaining a better estimation of limited loading on the slope under top-loading, considering soil-rock slope models with different rock contents and shapes.

The building effect on slope stability is an important research topic related to the safety of sloped areas. However, in most of the research, it is either the load or the distance that is considered as a variable, a few studies have considered both as variables. Therefore, in this study, based on a real building construction project in a sloped area, and considering the building load and its applied distance as variables, the influence of different building loads with different distances from the slope shoulder was studied. By analyzing the total displacement with and without load, the maximum shear strain, and the FOS of the slope, the potentially dangerous area of the slope was judged.

2. Slope Model, Soil Parameters, and Analysis Method

2.1. Slope Model and Soil Parameters

The slope model size and boundary conditions were designed regarding an actual slope, and the loads on top are the base pressure of three different types of buildings, which are 120 KPa, 200 KPa, and 300 KPa. The slope model is 120 m long, 50 m high, strike direction is 10 m, and the slope angle is 45° . The physical and mechanical parameters of the soil are listed in **Table 1** and the slope geometrical model is shown in **Figure 1**.

2.2. Analysis Method

Numerical simulation was performed using the finite-difference method through FLAC3D (Fast Lagrangian Analysis of Continua), large commercial software. **Figure 2** shows the slope numerical model. Considering the effect of the building loads on the top of the slope, the simulation was focused on calculating the slope factor of safety (FOS) under different loads applied at $d = 5$ m, $d = 10$ m, $d = 15$ m, and $d = 20$ m respectively the distances between the slope shoulder and the applied load. The boundary condition is set fixed at the bottom, and while the soil model is assumed to be an isotropic material, the Mohr-Coulomb constitutive model is selected without considering the influence of rain, groundwater, soil cracks, and other factors. In short, the procedure followed the including: building the slope model, defining the model soil parameters and boundary conditions, applying the top-load at a different distance, viewing the slope total

Table 1. Physical and mechanical parameters of the model soil.

Density ρ (kg/m ³)	Elastic Modulus E (MPa)	Poisson Coefficient μ	Cohesion c (KPa)	Friction angle ϕ (°)
1750	120	0.23	62	25

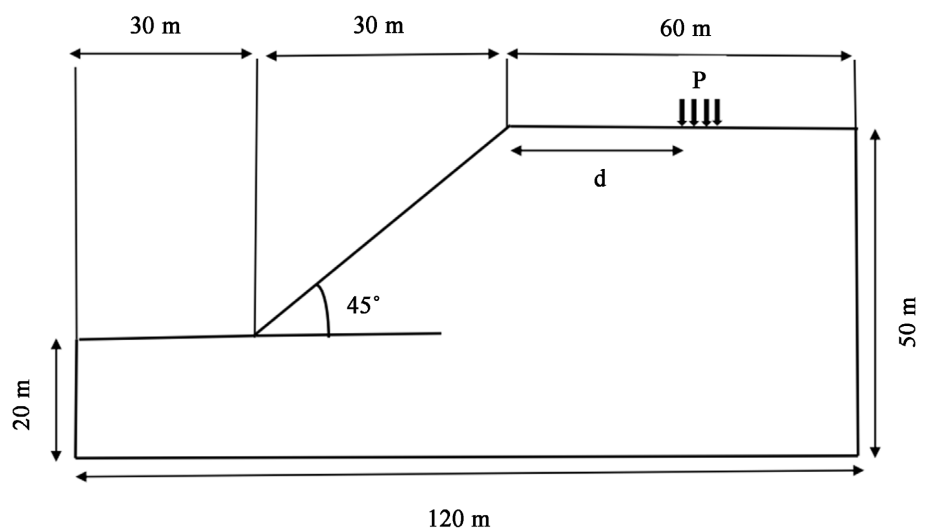


Figure 1. Slope model.

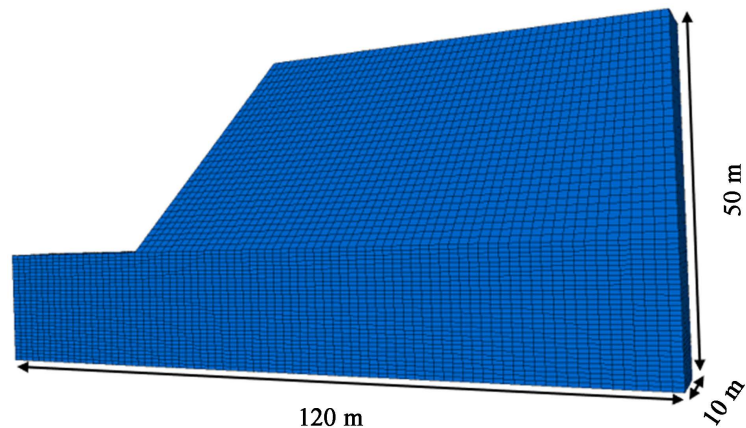


Figure 2. Slope numerical model.

displacement, maximum strain increment, calculating the factor of safety (FOS) for each condition, and viewing the results. The factor of safety is defined as the ratio between the actual shear strength and the reduced strength of the soil.

3. Result Analysis

3.1. Slope Total Displacement under Top Loading

A three-dimensional model was used to simulate the slope stability under the action of the building load. The simulation was carried out through four working conditions of the distances of 5 m, 10 m, 15 m, and 20 m, respectively, the distances between the slope shoulder and the applied load. The case of the building load $P = 120$ KPa is taken as an example for the whole paper.

For $P = 120$ KPa, at 10 m away from the slope shoulder, the comparison of the slope total displacement and maximum shear strain with and without the building load is shown in **Figure 3** and **Figure 4**.

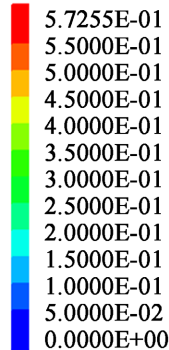
It can be seen from **Figure 3** that when there is no building load at the top of the slope, the slope is mainly affected by its gravity, the maximum displacement occurs at the shoulder of the slope, and gradually decreases inward along the slope surface; there are many near-parallel potentials inside the slope. In **Figure 4** when the building load is applied to the top of the slope, the shear strain is concentrated in the stressed area, and the potential failure surface extends from the angle of the slope to the top load application.

3.2. Slope Displacement under the Four Working Conditions

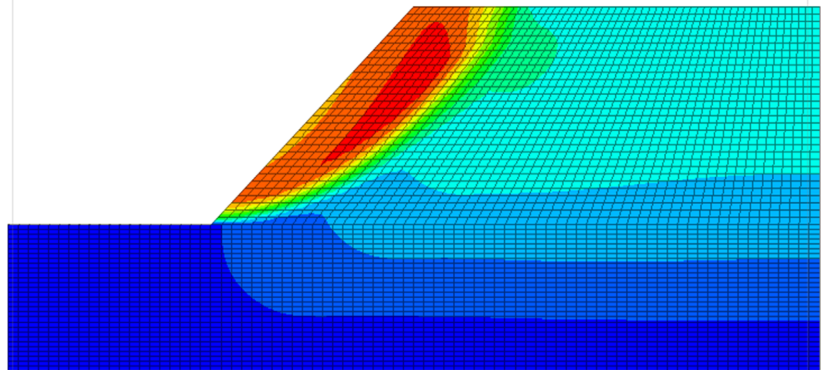
Taking the calculation results of load $P = 120$ KPa as an example, the cloud map when the distances are $d = 10$ m and $d = 20$ m is shown as follows: It can be seen that as the distance between the slope shoulder and the applied load increases, the slope is no longer affected by the load, thus the displacement decreases. When the load is applied at 20 m away from the slope shoulder, the distance from the load to the slope has exceeded the radius of its influence on the slope

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Contour Of Displacement

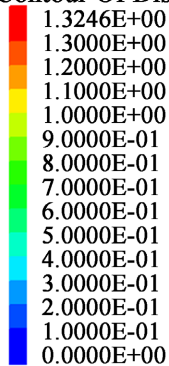


(a)



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Contour Of Displacement



(b)

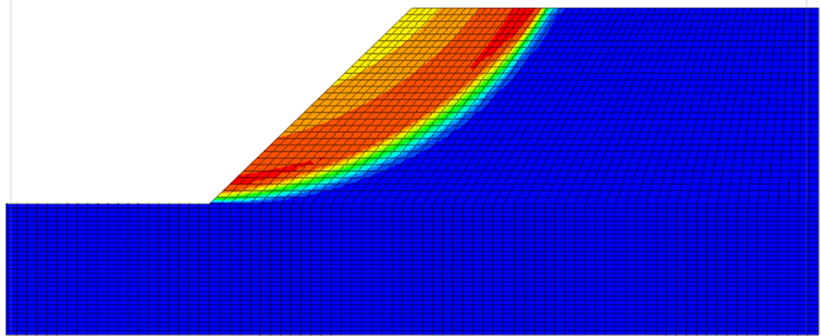
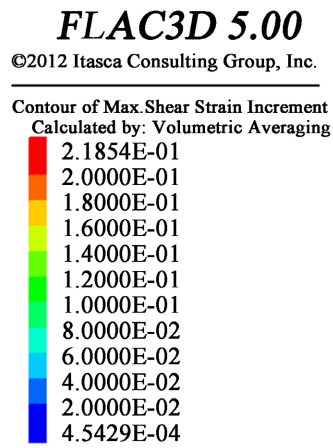


Figure 3. Comparison of the slope total displacement with and without load. (a) Slope total displacement without load; (b) Slope total displacement with load.

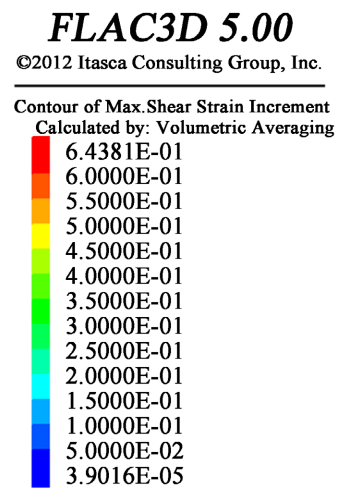
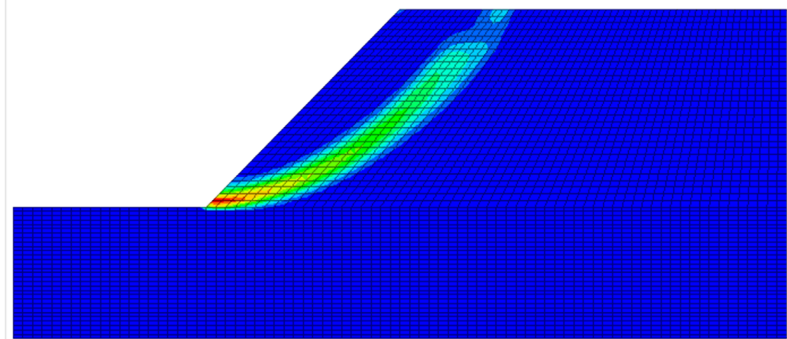
stability. At this time, the stability of the slope surface is mainly affected by the slope structure and its nature. The slope stability goes from an unsafe state to a safe one, which is traduced by the increase of the slope factor of safety, see **Figure 5** and **Figure 6**.

3.3. Analysis of the Slope Strain under Top Loading

Still, for $P = 120$ KPa under the conditions of $d = 10$ m and $d = 20$ m, the distribution of maximum shear strain increment is shown in **Figure 7** and **Figure 8**. It shows the position of the most dangerous sliding surface, which is roughly an arc-shaped sliding surface connecting the slope crest and the slope foot. Under the condition that the load is applied at 20 m away from the slope shoulder, the displacement of the slope has almost no effect; at this time, the stability of the slope is mainly affected by its gravity.



(a)



(b)

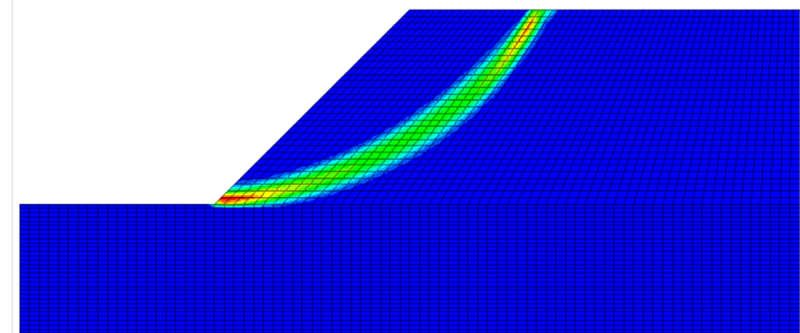


Figure 4. Comparison of slope total strain with and without load. (a) Slope total strain without load; (b) Slope total strain with load.

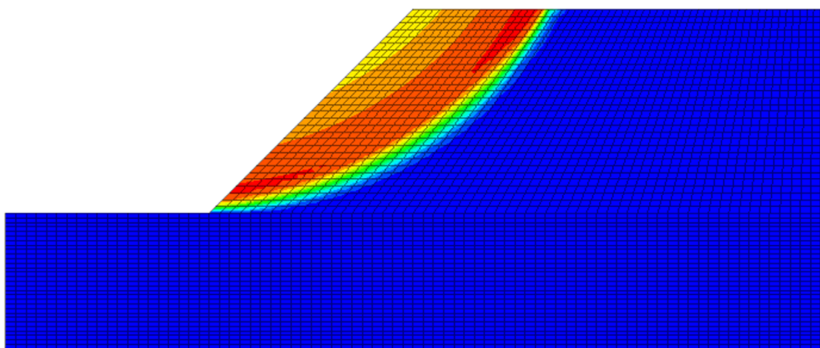
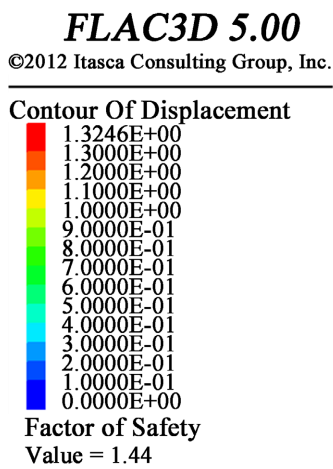


Figure 5. Slope displacement at d = 10 m.

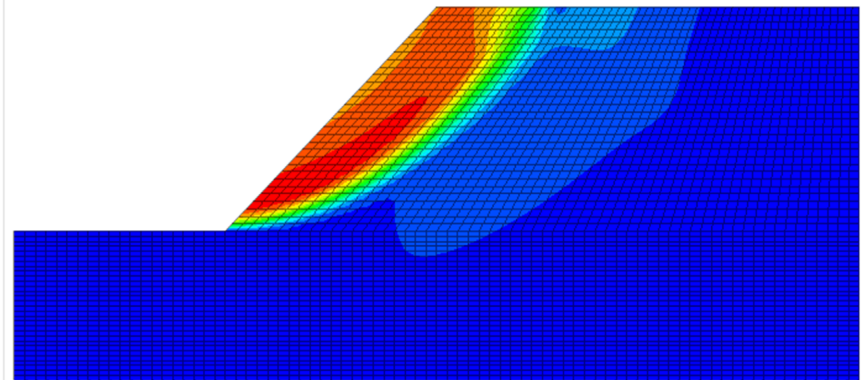
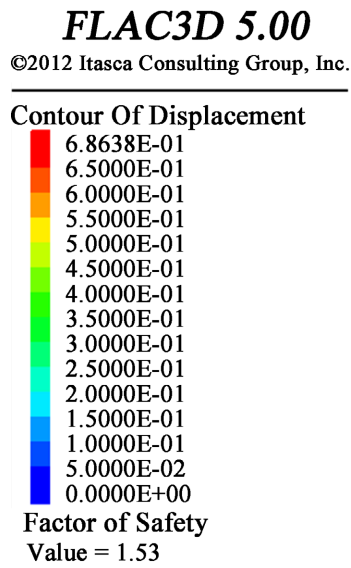


Figure 6. Slope displacement at d = 20 m.

3.4. Results of the Safety Factor

Figure 9 and Table 2 show the change of the slope safety factor considering the variation of the distance between the slope shoulder and the applied loads for different cases. It can be observed that with the increase of the distance between the applied load and the slope shoulder, the slope factor of safety increases. It shows that the load and the distance from where it is applied on the top of the slope, are important factors that can influence the stability of the slope.

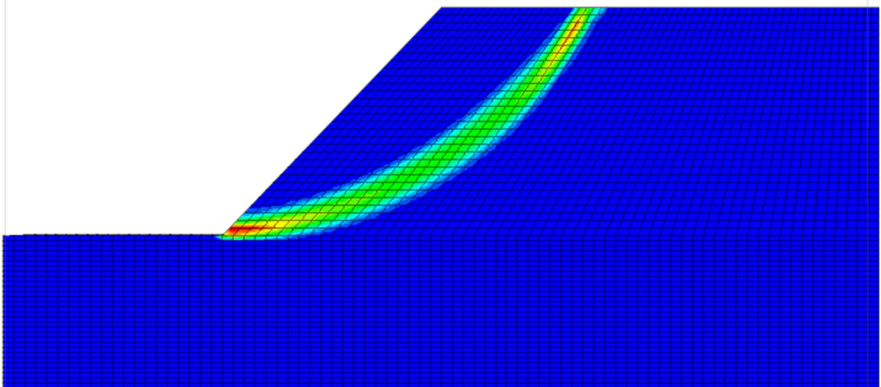
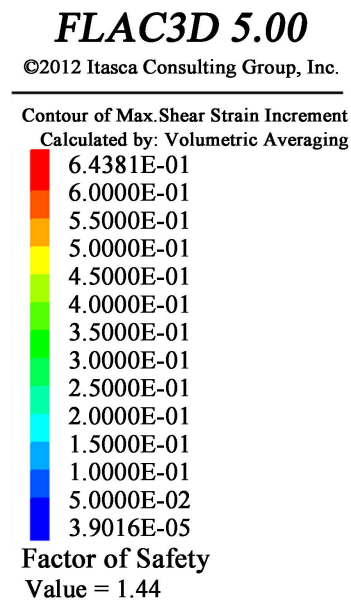


Figure 7. Slope strain increment at d = 10 m.

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 Contour of Max. Shear Strain Increment
 Calculated by: Volumetric Averaging

2.9542E-01
2.7500E-01
2.5000E-01
2.2500E-01
2.0000E-01
1.7500E-01
1.5000E-01
1.2500E-01
1.0000E-01
7.5000E-02
5.0000E-02
2.5000E-02
2.4318E-05

Factor of Safety
 Value = 1.53

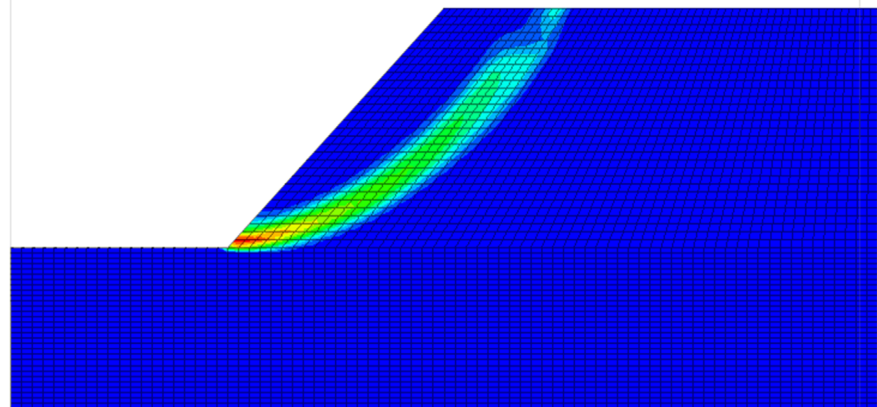


Figure 8. Slope strain increment at d = 20 m.

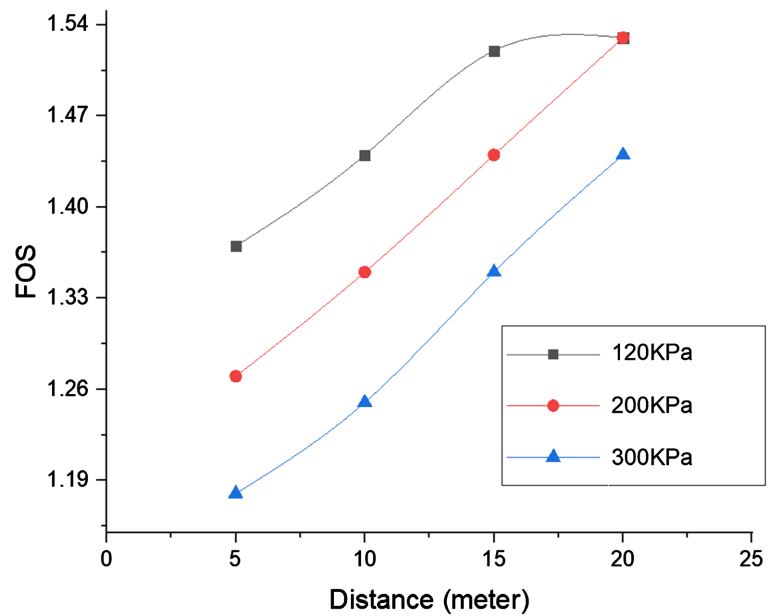


Figure 9. Slope safety factor variation.

Table 2. slope factor of safety under different loads.

Distance (m)	Load P(KPa)		
	120	200	300
5	1.37	1.27	1.18
10	1.44	1.35	1.25
15	1.52	1.44	1.35
20	1.53	1.53	1.44

4. Conclusions

Based on Flac3D finite difference software, a numerical simulation was carried out to analyze the influence of the building load on the stability of the slope. The obtained results lead to the following main conclusions:

- 1) The stability of the slope has a significant relationship with the building load.
- 2) With the gradual increase of the distance between the top-load and the slope shoulder, when the distance of the top-load exceeds its influence radius on the stability, the slope gradually recovers its stability.
- 3) In the numerical model, there is an extreme value of the influence of the slope distance of the top-load on the stability of the slope, and the analysis of the results shows that the extreme value is distributed in the range of 10 - 20 m at the top of the slope.
- 4) Farther studies can be done with consideration of the soil model as an anisotropic material. The influences of groundwater, soil cracks, and other factors can also be taken into consideration.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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