Analysis of the Influence of Initial Gravity Field on the Stability Analysis of Soil Slope

Ping Yang

1 Faculty of Architectural Engineering, Kunming Metallurgy College, Kunming, Yunnan, 650033, China

*Corresponding author’s e-mail: 36100587@qq.com

Abstract. In order to study the influence of initial gravity field on slope stability analysis under the conditions of slope height, slope angle and soil bulk density, some slope examples are analyzed by combining finite element method and shear strength reduction method. The calculation results show that the initial gravity field has a great influence on the slope displacement and shear stress. But this effect has nothing to do with the slope height, slope angle or soil bulk density, but has little effect on the slope stability safety factor. The relevant results can be used by engineers and technicians for reference in slope design.

1. Introduction
Slope stability problems are widely found in construction projects such as roads, buildings, water conservancy, and mines. The instability of the slope seriously endangers the people's life and property safety and the construction and operation of the construction project. The slope stability problem has always been an important research direction in the field of geotechnical engineering. Any slope has zero displacement before being disturbed, but there is some kind of stress field (such as self-heavy stress field), that is, the natural slope is in a state of stress without displacement before artificial transformation, which is the equilibrium of ground stress. Based on the shear strength reduction finite element method, this paper studies the influence of slope height, slope angle and soil bulk density on the analysis of slope stability analysis without considering the initial gravity field, and obtains some useful conclusions. This result is for the reference of the majority of engineering and technical personnel.

2. Analytical method
The initial stress field of each slope in the project is different. This paper considers the initial gravity field. The finite element analysis uses ANSYS software and Drucker-Prager failure criterion. According to the plane strain problem, the boundary conditions are applied to the slope finite element model, and gravity is applied to calculate the stress response of the slope under the action of gravity field. The four stress components $S_{11}, S_{22}, S_{33}$, and $S_{12}$ at the centroid of each unit apply these stress to balance the slope stress, and obtain an initial state of the slope with a stress field without displacement. Then solve the stress field and displacement field and stability safety factor of the slope. Taking the slope safety factor and the displacement and shear stress at the foot of the slope as the indicators, the effects of the initial stress field on the above three indicators are considered or not considered when the slope height, slope angle and soil bulk density change.
3. Establishment of slope finite element model

3.1 Related parameters of the example and boundary conditions
All slope examples have cohesion = 120 kPa, internal friction angle = 18°, modulus of elasticity = 600 MPa, Poisson's ratio = 0.3. Under the condition that the above parameters are unchanged, the slope height H, the slope angle and the soil bulk density are changed, and a total of 18 slopes are involved in the analysis (Table 1).

| Slope   | H (m) | α (°) | γ (kN/m³) | Slope   | H (m) | α (°) | γ (kN/m³) |
|---------|-------|-------|-----------|---------|-------|-------|-----------|
| slope 1 | 5     | 45    | 18        | slope 10| 20    | 45    | 18        |
| slope 2 | 10    | 45    | 18        | slope 11| 20    | 50    | 18        |
| slope 3 | 15    | 45    | 18        | slope 12| 20    | 55    | 18        |
| slope 4 | 20    | 45    | 18        | slope 13| 20    | 45    | 15        |
| slope 5 | 25    | 45    | 18        | slope 14| 20    | 45    | 16        |
| slope 6 | 30    | 45    | 18        | slope 15| 20    | 45    | 17        |
| slope 7 | 20    | 30    | 18        | slope 16| 20    | 45    | 18        |
| slope 8 | 20    | 35    | 18        | slope 17| 20    | 45    | 19        |
| slope 9 | 20    | 40    | 18        | slope 18| 20    | 45    | 20        |

Considering the boundary effect, the slope calculation model size is determined according to the optimal size of the literature [1] (Figure 1), and the CPE4 plane strain element is used to establish the slope finite element model, and the slope foot nodes are selected as the displacement and shear stress observation points.

Figure 1. Slope model size.

The slope finite element model uses displacement boundary conditions. The left and right boundaries limit the X-direction degrees of freedom, and the Y-direction is free; the bottom limits the degrees of freedom in the X and Y directions; the slope is a free interface.

3.2 Determination of slope failure criterion and stability coefficient
When considering or not considering the initial stress, the displacement and stress of each point of the slope can be directly extracted after the calculation is completed, and the determination of the safety factor of the slope stability is relatively complicated. There are two types of slope instability criteria currently in the mainstream:

1. In the process of finite element calculation, the non-convergence of force and displacement is used as a sign of slope instability [2,3].
2. The generalized shear strain (elastic strain and plastic strain) or equivalent plastic strain is transmitted from the foot to the top of the slope as a sign of slope destroy [4-6].

This paper chooses the instability criterion (1).

4. Calculation results and analysis

4.1 Considering or not considering the displacement of the initial gravitational field when the slope
height changes
Regardless of the initial gravity field mode, the X-direction displacement at the foot of the example 1-6 increases with the increase of the slope height (negative values only indicate the opposite direction), although the absolute value of the displacement is small, the initial is not considered. In the gravity field, the displacement of the slope is 2 orders of magnitude higher than that of the initial gravity field (Figure 2, Figure 3), indicating that the initial gravity field has a greater influence on the displacement, regardless of the slope height.

Figure 2. Displacement with slope height changes (regardless of the initial gravitational field).

Figure 3. Displacement with slope height changes (considering the initial gravitational field).

4.2 Considering and not considering the displacement of the initial gravitational field when the slope angle changes
Without considering or considering the initial gravity field mode, the X-direction displacement at the foot of the example 7-12 increases with the increase of the slope angle. Although the absolute value of the displacement is small, the displacement ratio of the slope is not considered when the initial gravity field is not considered. Considering the initial stress is 1-2 orders of magnitude higher (Figure 4, Figure 5), indicating that the initial stress has a greater influence on the displacement regardless of the slope angle, but the extent of this effect is lower than the slope height.
4.3 Considering or not considering the displacement of the initial gravitational field when the bulk density changes

Without considering or considering the initial gravity field mode, the X-direction displacement at the foot of the example 13-18 increases with the increase of the soil bulk density, although the absolute value of the displacement is small, but the displacement of the slope is not considered when the initial gravity field is considered. It is two orders of magnitude higher than the initial gravity field (Figure 6, Figure 7), which indicates that the initial gravity field has a greater influence on the displacement regardless of the bulk density of the soil, and the degree of influence is similar to the change of the slope height (but the magnitude of the displacement smaller than it).

Figure 4. Variation of displacement with slope angle (regardless of initial gravity field).

Figure 5. Variation of displacement with slope angle (considering initial gravity field).

Figure 6. Displacement changes with bulk density (regardless of initial gravity field).
4.4 Shear stress considering and not considering initial gravity field when slope height changes

Regardless of the initial gravity field model, the shear stress at the foot of the example 1-6 increases with the increase of the slope height (negative value only indicates the direction). When the initial gravity field is not considered, the shear stress ratio of the slope foot is considered. The gravity field is slightly higher (Figure 8). The initial gravity field has little effect on the shear stress of the slope, but this effect increases with the increase of the slope height. When the slope height is 30m (the example slope 6), the initial gravity field is considered to be 10% smaller than not considered, and the other examples are smaller.

4.5 Shear stress considering or not considering the initial gravitational field when the slope angle changes

Without considering or considering the initial gravity field mode, the shear stress at the foot of the example 7-12 increases with the increase of the slope angle. When the initial gravity field is not considered, the shear stress of the slope is slightly higher than when considering the initial gravity field. 9). Initial gravity field has little effect on the shear stress of the slope, but this effect increases with the increase of the slope angle. In the example, when the slope angle is 55° (slope 12), considering the initial gravity field is 14% smaller than the unconsidered, the other examples are smaller.
4.6 Shear stress considering or not considering the initial gravitational field when the bulk density changes

Without considering and considering the initial gravity field mode, the shear stress at the foot of the example 13-18 increases with the increase of the bulk density of the soil. When the initial gravity field is not considered, the shear stress of the slope is slightly higher than when considering the initial gravity field (Figure 10) shows that the initial gravity field has little effect on the shear stress of the slope foot when the bulk density changes, and this effect varies little with the increase of the bulk density. In the example, the initial gravity field is considered to be 7% smaller than the unconsidered when the bulk density is 20kN/m³ (slope 18), and the other examples are smaller.

4.7 Influence of Initial Gravity Field on Stability Safety Factor of Slope

When the examples consider or not consider the initial gravity field, the stability safety factor differs tiny or even same to each other, and it is inconvenient to draw the representation, so the list is shown here (Table 2). In the calculations 1-6 (change slope height) and 7-12 (change slope angle), when considering the initial gravity field, the stability safety factor of some slopes is slightly reduced (the maximum reduction is slope 5, which is 1.4% lower). But this effect does not show a specific pattern. In the case of Example 13-18 (variable bulk density), it is the same stable safety factor as considering the initial stress or not.
Table 2. Stability safety factor of each slope.

|       | F (N)  | F (Y)  | F (N)  | F (Y)  | F (N)  | F (Y)  |
|-------|--------|--------|--------|--------|--------|--------|
| slope 1 | 7.986  | 7.986  | slope 7 | 3.250  | 3.250  | slope 13 | 2.997  | 2.997  |
| slope 2 | 4.458  | 4.443  | slope 8 | 3.017  | 3.017  | slope 14 | 2.873  | 2.873  |
| slope 3 | 3.261  | 3.258  | slope 9 | 2.816  | 2.815  | slope 15 | 2.752  | 2.752  |
| slope 4 | 2.653  | 2.653  | slope 10 | 2.653  | 2.653  | slope 16 | 2.653  | 2.653  |
| slope 5 | 2.287  | 2.254  | slope 11 | 2.503  | 2.503  | slope 17 | 2.559  | 2.559  |
| slope 6 | 1.993  | 1.993  | slope 12 | 2.377  | 2.373  | slope 18 | 2.474  | 2.474  |

Note: F in the table is the slope stability safety factor, “N” means no initial gravity field, and “Y” means there is initial gravity field.

5. Conclusion and Suggestion

(1) After the shear strength is gradually reduced, regardless of the slope height, slope angle and soil bulk density, the initial gravity field has a greater influence on the displacement of the slope, regardless of the initial gravity field. The displacement is greater than considered.

(2) The initial gravity field has a greater influence on the shear stress value at the foot of the slope, but this effect is weaker than the displacement of the slope foot. When the slope height, slope angle and soil bulk density increase, the difference between the slope stress increases when considering the initial gravity field or not. And the shear stress when the initial gravity field is not considered is greater than considered.

(3) In the example, the slopes with different slope heights and slope angles show that the initial gravity field has little effect on the slope safety factor. When the initial gravity field is not considered, the stability safety factor of some slopes is slightly lower than the consideration. When the soil bulk density is changed, the influence of the initial gravity field on the stability safety factor is not shown.

According to the above conclusions, it is suggested that the influence of the initial gravity field should be considered when performing the slope displacement and shear stress analysis of the slope. If only the slope safety factor is calculated, the initial gravity field may not be considered. Separate slopes with complex initial stress fields (such as slopes with strong structural stresses) require separate studies.

References

[1] Zhang L.Y., Zheng Y.R., Zhao S.Y., et al. (2003) Accuracy of finite element strength reduction factor method for calculating safety factor of soil slope stability. Journal of Hydraulic Engineering, 1: 21–27.
[2] Zhao S.Y., Zheng Y.R., Zhang Y.F. (2005) Discussion on the criterion of slope instability in finite element strength reduction method. Rock and Soil Mechanics, 26:332–336.
[3] Griffiths D. V., Lane P. A. (1999) Slope stability analysis by finite elements. Geotechnique, 49: 387–403.
[4] Zheng H., Li C.G., Li Y.F., et al. (2002) Finite element method for solving safety factor. Chinese Journal of Geotechnical Engineering, 24: 626–628.
[5] Zhou C.Y., Liu Y.Q., Dong L.G., et al. (2003) Finite element analysis of large deformation of slope failure process. Rock and Soil Mechanics, 24: 644–647, 652.
[6] Li Y.S., Zhou C.Y., Zhang H.M.. (2012) Slope stability analysis based on strength reduction criterion. Yellow River, 34: 146–148.