Comparative Study on Calculation Methods for Stability Evaluation Based on BIM Models of Soil Landslides

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Abstract. The purpose of landslide prevention and control is to keep the stability within a safe range. This paper proposes a new direction of landslide information prevention and control with BIM technology for soil landslide, which is a typical type of landslide. The BIM model was established by referring to the engineering geological parameters of typical soil landslides, and then several commonly used landslide stability calculations were compared and studied by using the model research method. On the basis of BIM model of typical soil landslide, the results of calculating related engineering geological problems by different stability calculation methods were verified, and the characteristics of different stability calculation methods were revealed. When several common methods were used to calculate the stability of typical soil landslides, how to select the appropriate methods for calculations is an inevitable problem whenever the stability evaluation of landslide prevention and control is carried out, so it is of important engineering value and significance for this research.

1. Introduction
Landslide prevention and control work has the following characteristics: short reaction time, many factors involved, high technical requirements, wide range of influence and so on. The root cause of long-standing havoc with the high efficiency of landslide prevention and control work in China is that there is not a set of suitable, universal-format technologies to integrate the work content of the relevant participants.

This leads to the work contents of different backgrounds and identities of the project participants are hard to be linked up effectively, which wastes a lot of resources in information exchange and communication. As the CAD mapping software, which is widely used in landslide control projects in China nowadays, it is in fact equivalent to the electronic version of manual drawings, which can play a limited role and does not have the function of parameter linkage. Therefore, it is impossible to form a highly effective parametric modeling calculation method.

Once the relevant parameters change, or there is a change in the actual working conditions other than design, then all the original design drawings and calculation values have to be pushed back to the very beginning for new work, which not only wastes a lot of time and human resources, but also misses valuable time and there will always be a certain time difference with the changing situation on the site.
BIM technology can be used to visualize and parameterize modeling, which can play an important role in the whole life cycle of engineering projects, and is suitable for landslide prevention and control. Compared with the static design method of manual drawing, the landslide prevention scheme based on BIM technology is characterized by the parameterized BIM model, which can adjust the design parameters according to the dynamic and real-time situation of the field feedback, so as to solve related engineering geological problems. In order to solve the related problems, a dynamic variable landslide prevention and control scheme can be worked out accordingly. This method is no longer in the same era as those old methods which can only be based on the static data at a certain time, in the form of manual calculation, lagging behind the landslide to formulate prevention and control schemes.

2. Typical soil landslides

2.1. Selection of basic research objects

Although different landslides have their own characteristics, the same types of landslides have similar mechanical genetic mechanism. Therefore, classification of different types of landslides from the point of view of mechanics, essentially by studying and mastering the characterizations of different types of landslides in different stages of evolution, the corresponding countermeasures for landslide prevention and control can be formulated according to the characteristics of different types of landslides.

According to the application of BIM software GEO5, it can be learnt that although the specific parameters of each landslide are different, there are no identical landslides in reality. However, landslides can be divided into two categories according to their constituent materials: soil landslides and rock ones. The change of landslide stability is closely related to the evolution and development process of landslide deformation and failure. The stability calculation method is just the mathematical expression equation to reflect how the engineering geological conditions to influence the landslide stability, in other words, it can reflect the change law of landslide stability under the influence of different engineering geological conditions. Therefore, the comparative study of landslide stability under multi-method and multi-working condition combination can reveal the influencing factors of landslide stability, and formulate the soil landslide prevention and control scheme according to the relevant influencing factors, thereby the stability of landslides can be controlled within a safe extent more effectively, which is also the goal of landslide prevention and control.

The following is a literature review of relevant studies on landslide stability.

[1] Fu Xiaodong et al. proposed a new method for calculating landslide safety factor based on vector and DDA; [2] Yang Tao et al and [3] Xu Qing et al used the ideal elastoplastic constitutive model of Mohr-Coulomb Strength Criterion to simulate sliding zone materials, and put forward the point safety factor method to analyze the spatial sliding mechanism of landslide, with the overall safety factor being used to evaluate the stability of landslide. [4] Yang Tao et al. studied the difference of stability safety factor and thrust distribution curve between strips by rigid body limit equilibrium method, block element method and finite element method for a specific landslide; [5] Liu Mingzhen put forward that the safety factors stipulated in the "Code for Design of Building Foundation" should be applicable only when the dip angle of the sliding surface is greater than 0; when the dip angle of the sliding surface in a certain section of the landslide is less than zero, the setting of safety factors should be minus (less than 0) as well. [6] Yang Tao et al put forward the conditions for the application of [2] [3] point safety factor method; [7] Liu Zhenming put forward that the value of safety factor should improve the accuracy of objective factors and minimize the influence of subjective human factors. [8] Wu Ye put forward the relationship between landslide safety factor and sliding probability, taking Xuetangping landslide in Badong County as an example; [9] Tang Fen put forward double strength safety factor to calculate landslide thrust; [10] Wu Yongfeng et al., taking the large landslide in the three Gorges Reservoir area as an example, put forward that different landslide control projects should not adopt the unified safety factor standard; [11][12] Rao Yunzhang et al established the relationship between slope safety factors and landslide occurrence probability, and the application comparison and analysis were carried out as well.
To sum up, this paper selects the typical soil landslides as the basic research object. How to select the appropriate methods for calculations is an inevitable problem whenever the stability evaluation of landslide prevention and control is carried out, so it is of important engineering value and significance for this research.

2.2. Main engineering geological parameters of soil landslides

According to the macro-control theory of soil mass founded by Fan Shikai\cite{13}, the following engineering geological parameters table can be obtained by referring to the relevant literature.

Table 1. Table of Relevant Parameters of Soil Landslide

| Related parameter | Sliding body (clay with debris) | Sliding zone (silty) | Sliding bed (mudstone) |
|-------------------|-------------------------------|---------------------|-----------------------|
| Natural density   | 20.40kN/m³                   | 18.90kN/m³          | 26.70kN/m³            |
| Saturated unit weight | 20.60kN/m³                  | 19.15kN/m³          | 26.90kN/m³            |
| Natural cohesion C | 13.80kPa                      | 12.70kPa            | 41.90kPa              |
| Natural internal friction angle φ | 24.6°                      | 16.5°               | 36.5°                 |
| Saturated cohesion C | 11.40kPa                     | 12.65kPa            | 40.50kPa              |
| Saturated internal friction angle φ | 22.7°                      | 13.5°               | 30.5°                 |

3. Analysis of stability calculation method for BIM model

3.1 Brief introduction of common stability calculation methods

Among the calculations of landslide stability in China, the most commonly used method is the limit equilibrium method, which has the advantages of convenient for calculation and simple for operation. It obtains the sliding force and anti-sliding force of the slider by analyzing the mechanical states and various failure modes of each stage through the theory of static equilibrium mechanics.

Therefore, this method has also been effectively verified and improved in the process of domestic application. At present, the imbalance thrust force method (implicit method) \cite{14} is used in China’s GB 50330-2013 Technical Code for Building Slope Engineering\cite{14}. In previous Chinese specifications, the imbalance thrust force method (explicit method) \cite{15} was commonly used.

Other commonly used methods are Sarma method\cite{16}, Spencer method\cite{17}, Janbu method\cite{18} \cite{19}, Morgenstern-Price method\cite{20} \cite{21}, Shahunyants method\cite{22} \cite{23} and so on.

3.2 Stability comparison of landslide BIM model based on multiple calculation methods

When the landslide prevention and control work is carried out with the soil landslide being taken as the object, the parameters related to the landslide stability calculation can be input into the BIM model, and then the stability calculation can be carried out in the analysis module. Table 2 is the result calculated by different calculation methods in natural state (working condition 1) after the engineering geological parameters of soil landslide in Table 1 are input into BIM model.

Table 2 shows the calculating result of soil landslide in the safety factor calculation in a state of rainstorm (working condition 1):

Table 2. Comparison of safety factor calculated by multiple methods for soil landslide (working condition 1)

| Calculation method | FS       |
|--------------------|----------|
| Sarma method       | 1.16 < 1.35 |
| Spencer method     | 1.24 < 1.35 |
| Janbu method       | 1.02 < 1.35 |
| Morgenstern-Price method | 1.02 < 1.35 |
| Shahunyants method | 0.96 < 1.35 |
The imbalance thrust force method (Implicit method): $FS = 1.05 < 1.35$

The imbalance thrust force method (Explicit method): $FS = 1.05 < 1.35$

The calculated results in Table 2 are less than the reference safety factor of 1.35 in China’s GB 50330-2013 Technical Code for Building Slope Engineering”. Therefore, the landslide is in an unstable state under heavy rain (working condition 1).

For the same reason, Table 3 shows the calculating result of soil landslide in the safety factor calculation in a state of rainstorm (working condition 2):

Table 3. Comparison of safety factor calculated by multiple methods for soil landslide (working condition 2)

| Method                      | FS     |
|-----------------------------|--------|
| (Sarma method)              | $1.10 < 1.35$ |
| (Spencer method)            | $1.04 < 1.35$ |
| (Janbu method)              | $0.98 < 1.35$ |
| (Morgenstern-Price method)  | $0.98 < 1.35$ |
| (Shahunyants method)        | $0.93 < 1.35$ |
| The imbalance thrust force  | $1.02 < 1.35$ |
| method (Implicit method)    |        |
| The imbalance thrust force  | $1.02 < 1.35$ |
| method (Explicit method)    |        |

The calculated results in Table 3 are less than the reference safety factor of 1.35 in China’s GB 50330-2013 Technical Code for Building Slope Engineering”. Therefore, the landslide is in an unstable state under heavy rain (working condition 2).

From Tables 2 and 3, it can be seen that when several common methods are used to calculate the stability of typical soil landslides, the Shahunyants method has abnormal results which are very different from those of other calculation methods, which can be caused by the following reasons:

A: When the formula of the Shahunyants method is used, special attention shall be paid to the applicable scope of its calculation principle, and the example of the soil landslide is not suitable for using Shahunyants method.

B: At present, there is no suitable conclusion of unfavorable combination study on calculation of sensitive factors for the stability of soil landslide, and this unfavorable combination causes this huge error.

C: When in a state of heavy rain (working condition 2), the stability results calculated by Shahunyants method are lower than that calculated in the state of working condition 1, and the decrease degree is similar to that calculated by unbalanced thrust method, which is widely used in Chinese codes. We notice that both the two calculation methods are based on mathematical inference and are only applicable to the relevant norms of the region to which they belong. It is possible that the systematic error between the mathematical formula and the real phenomenon has led to this result. It is also possible to reveal that the regional calculation method has a certain correlation with the local special engineering geological parameters.

In the process of trouble-shooting the causes of the errors, we noticed that Janbu method and Morgenstern-Price method were both a general slice method developed according to the limit equilibrium, both methods should satisfy the equilibrium conditions of the force and the moment of action on each block, and both methods were assumed that the force between the strips and blocks were non-zero; the difference between the two was that Janbu method makes assumptions on the force position between the strips and blocks. The safety factor was obtained by iterative calculation of the forces between strips and blocks, and then the angle of action of these forces was calculated. However, the stability results calculated by the two methods were very similar in the numerical example of the soil landslide.
To sum up: inappropriate assumptions have been made in the calculation process, which should be the reason why the calculation results of the Shahunyants method are quite different from those of other algorithms.

4. Conclusion
Landslide itself has the property of nonlinear and complex evolution with time, so even if the simulation conditions are similar and the parameters are the same in different regions, the evolution process of landslide will still show differences in reality. In view of this, the landslide BIM model grasps the main factors that affect the landslide in the engineering geological conditions, and then carries on the thorough research to the specific correlated parameters. With the change of the type and depth of the specific research problems, the landslide BIM model is modified according to the field survey data or the corresponding monitoring data, and the idea of parametric modeling based on the changeable data is proposed. It can better analyze and interpret the related processes of landslide development and evolution.

The correct classification of landslide before landslide prevention and control is not only helpful to the field investigation, but also to the establishment of a suitable BIM model, so as to select the correct stability calculation method and obtain the calculation results which more reflect the real situation of the site, so as to make a more targeted landslide prevention and control program. This kind of information prevention and control technology will effectively improve the work efficiency.

(1) The existing BIM technology in China is mainly used in constructions, foundation pits, simulation progress, material tracking and so on. There is no engineering example of a comparative study using calculation method for the stability of BIM model of soil landslide in the field of landslide control found in core and above publications in China. The correct selection of landslide stability calculation method is the key to ensure the effective development of landslide treatment. The conclusion of this paper has the potential to be popularized in the application of BIM technology. However, more engineering examples in different regions and working conditions are needed for further verification and improvement.

(2) Summary: according to the calculation results of working condition 1 and working condition 2, it can be seen that:

The results are very close in the safety coefficient calculating under the same type method with the same working condition. The Janbu method and Morgenstern-Price method are designated as the same type. The results under the influence of water (working condition 2), relative to the natural state (working condition 1) results change 4%.

The imbalance thrust force method (implicit method and explicit method) designated as the same type. The results under the influence of water (working condition 2), relative to the natural state (working condition 1) results change 3%.

And Spencer method is a strict solution. It is the biggest solution to the influence of water (working condition 2), and the result of relative natural state (working condition 1) has changed 16%.

As for the Sarma method, The results under the influence of water (working condition 2), relative to the natural state (working condition 1) results change 5%.

(3) When several common methods were used to calculate the stability of typical soil landslides, the results of the Shahunyants method were quite different from those of other calculation methods.

The most possible reason is that strict attention shall be paid to the applicable scope of its calculation principle when the formula is used, and the Shahunyants method is not applicable to the examples of soil landslide.

In short, at present, the support of BIM software at home and abroad for the scope of application of BIM model calculation method in the field of landslide control and risk is not enough to completely restore the complicated field situation. The results of the calculation need to be further checked and explained by those experts in the field of geology.
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