Comments on “Simulation analysis of 3D stability of a landslide with a locking segment: A case study of Tizicao landslide in Maoxian County, Southwest China”

RC2: 'Comment on egusphere-2023-28', Anonymous Referee #2, 16 Apr 2023

Firstly, I would like to thank the Editor for giving me the opportunity to comment on this scientific article.

The paper focuses on the simulation analysis of the 3D stability of a landslide with a locking elements. The Tizicao landslide in Maoxian County, Southwest China represents a case study for the research. The locking elements plays a crucial role in the stability of the Tizicao landslide, acting as a barrier to sliding, thereby increasing the slope's stability. However, the locking elements can create stress concentrations and increase the risk of failure in other parts of the slope, emphasizing the importance of considering the presence and characteristics of locking elements when analyzing landslides. The authors attempt to numerically model a rock mass discontinuity problem through a continuum method.

However, there are several critical issues reported below:

English

1. Firstly, the English language requires revision as it includes numerous errors and repetitions, and the form requires adjustment as it can be unclear and confusing at times.

Response 1: Thank you for your valuable and thoughtful comments. We have asked a professional proofreading company to improve the writing of this manuscript, and a native English speaker has carefully checked and polished the language of this manuscript.

Geomechanical characterization

2. Another issue is the geomechanical characterization. How was it conducted, and what tests were performed to acquire the mechanical parameters? For instance, the sentence "the equivalent shear strength parameters were determined based on penetration rates" on page 6, line 15, needs explanation about the method used to

determine these parameters.

Response 2: Thank you for your suggestions. As for the geomechanical characterization, we collected rock samples from the sliding body, sliding bed, and sliding surface of the landslide to conduct the geotechnical tests. The rock density was obtained using the wax-sealing method; the Young's modulus, Poisson's ratio, internal friction angle, and cohesion of rocks were collected from the triaxial test; and the tensile strength was obtained from the Brazilian test. The obtained rock parameters (Table 1) were used for the numerical simulation. We have added the descriptions of the laboratory tests in section "3.2 3D stability simulations" in the revised manuscript. Please see the text marked in red for details. Thanks.

For the sentence "the equivalent shear strength parameters were determined based on penetration rates" on page 6, line 15, according to the JM model, the slope stability was calculated by assigning the equivalent shear strength corresponding to different penetration rates to the potential sliding surface. The equivalent shear strength parameters can be calculated as follows:

$$c_{eq} = (1-k)c_r + kc_j \quad (1)$$

$$\tan\varphi_{eq} = (1-k)\tan\varphi_r + k\tan\varphi_j \quad (2)$$

where c_{eq} and φ_{eq} are the equivalent cohesion and the equivalent friction angle, respectively; φ_r and φ_j represent the friction angles of an intact rock and joints, respectively, and c_r and c_j are the cohesion of an intact rock and joints, respectively.

Considering that co-planar joints are separated by the intact rock bridge, the relative quantity of intact rocks along the sliding surface can be expressed as the ratio k, which is defined as follows (Jennings, 1970):

$$k = \frac{\sum A_j}{\sum A_j + \sum A_r} = 1 - k_L \quad (3)$$

where $\sum A_j$ denotes the surface area of joints, $\sum A_r$ is the surface area of the rock bridge, and k_L is the locking ratio (the ratio of the surface area of the rock bridge to the total sliding surface area).

So, the equivalent shear strength parameters were obtained from equations (1) and (2) based on the shear strength parameters of the rock bridge and the sliding surface in Table 1, as well as the different locking ratios in Figures 11c-d. The equivalent shear strength parameters are shown in Figures 11c-d.

Numerical Modeling

3. The authors don't explain how the numerical analyses were set up in Flac3D. The

paper should clarify how the IRMM, JM, and CSP-HSP constitutive models were implemented in the Flac3D code. The reviewer is wondering if Perfectly Plastic Mohr-Coulomb model was modified.

Response 3: We are sorry for the lack of clarification on the implementation of these models in the FLAC3D code. The IRMM, JM, and CSP-HSP models are simplified models of landslides with rock bridges. We replaced the rock bridges and the sliding surface with different elements (tetrahedral elements and contact surface elements) in the FLAC3D code. The details are described as follows:

As shown in Fig. 9a, in the simulation of a landslide with a locking segment, the rock bridge (S1), which is an intact rock mass, was simulated using the tetrahedral elements in the FLAC3D program, the sliding surface (S2) was simulated using the contact surface model in FLAC3D program, and the sliding body (Block A) and the sliding bed (Block B) were linked with the continuous rock bridge (S1).

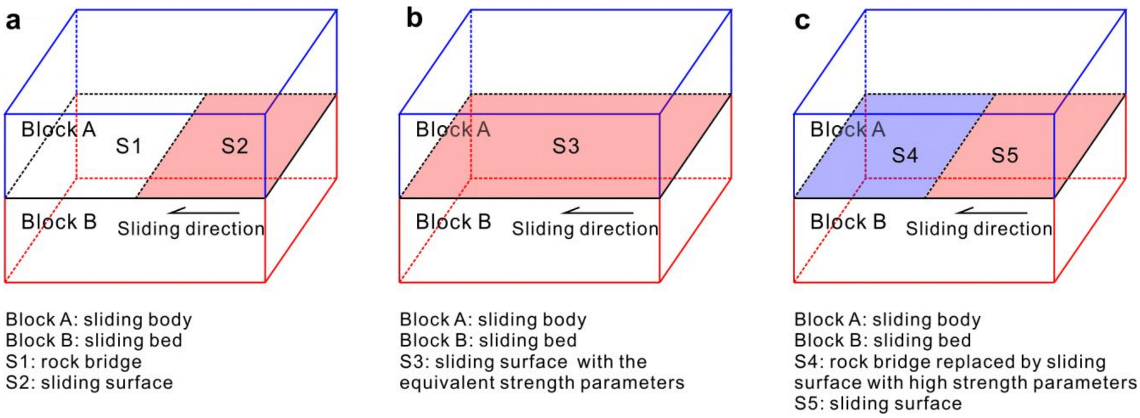

Figure 9: Three rock bridge models used in the FLAC3D program. a Intact rock mass model (IRMM). b Jennings model (JM). c contact surface model with high strength parameters (CSM-HSP).

For the JM model, the limit equilibrium method is initially employed to calculate the 2D stability of rock slopes with discontinuous joints. Specifically, the slope stability is calculated by assigning the equivalent shear strength corresponding to different penetration rates to the potential sliding surface. In this study, we introduced the Jennings model into the FLAC3D program. Then, we simulated the 3D stability of the whole landslide (including the rock bridge and the sliding surface) by assigning equivalent shear strength parameters to the contact surface model (S3), as shown in Fig. 9b.

As shown in Fig. 9c, two contact surface models, one with high strength parameters and the other with low strength parameters, were used to simulate the rock bridge (S4) and sliding surface (S5), respectively. The strength parameters of an intact rock mass were adopted for the rock bridge. In addition, the shear stiffness and normal stiffness higher than those of the sliding surface are required in the CSM-HSP model to simulate the real resistance characteristics of the rock bridge.

According to the above descriptions, we did not establish new constitutive models implemented in the Flac3D code. We just simplified the landslide models and provided different methods to simulate the landslide with rock bridges in the FLAC3D program using different mesh elements. In the simulation of the landslide using the IRMM, JM, and CSP-HSP models, all the mesh elements yielded a Plastic Mohr-Coulomb model, so the Perfectly Plastic Mohr-Coulomb model was not modified in this manuscript.

4. The authors mention Geostudio as a software utilized for 2D calculations, however this sentence doesn't explain the 2D analysis method because Geostudio is a software suite which includes different products so the review is wondering if the numerical simulations were carried out with Limit Equilibrium Method (LEM) of the Slope/W software. The paper should explain how the JM model was introduced into the Bishop algorithm in LEM modelling.

Response 4: Thank you for your comments. We conducted the 2D stability analysis of the Tizicao landslide using the SLOPE/W module of the program GeoStudio 2012. In the SLOPE/W module, there are many limit equilibrium methods for calculating the 2D Fos, among which we selected Bishop's algorithm for 2D calculations. Meanwhile, the JM model was introduced into Bishop's algorithm in the GeoStudio program. In the JM model, we only input the equivalent shear strength determined using equations (1) and (2) based on penetration rates for the sliding surface. In this way, the slope stability can be calculated. For sections A-A', B-B', C-C', and D-D', their locking ratios k_L are 0, 0, 0.23, and 0.26, respectively according to the site survey. The equivalent shear strength was calculated, and the calculated 2D stability factors are shown in Table 2 and Fig. 11.

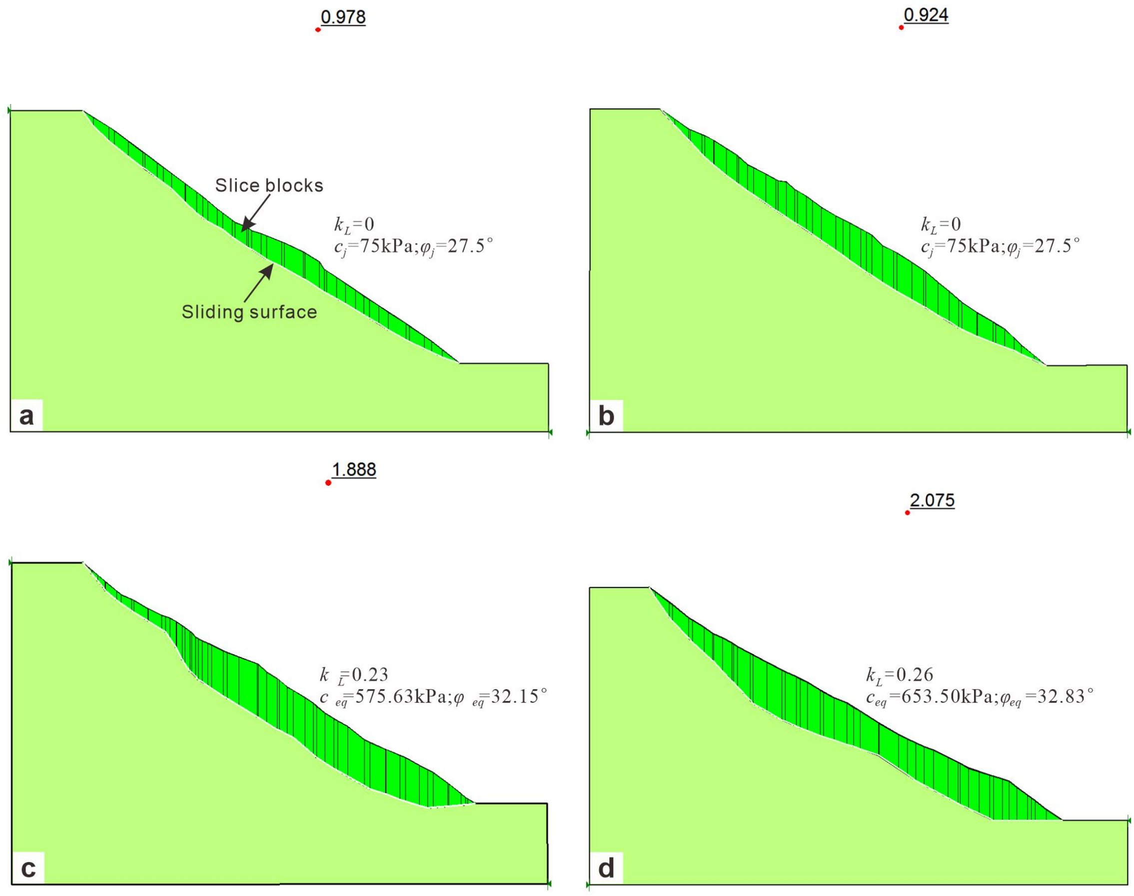

Figure 2: 2D Fos for different sections. a Section A-A'. b Section B-B'. c Section C-C'. d Section D-D' (from the present study).

5. The paper should provide better specification of the comparisons between the four 2D surfaces and the hypothesized 3D surface.

Response 5: Thank you for your suggestions. For the 2D sliding surfaces, they were deduced according to the depth of the sliding zone soil obtained by drilling, as shown in Fig. 4. Meanwhile, the geometric size and shape of the 3D sliding surface were deduced based on the four 2D sliding surfaces and the outline of the landslide. So, the 3D sliding surface was deduced from the four 2D sliding surfaces.

As for the comparisons between the 2D and 3D stability of the landslide, we added detailed comparisons between the four 2D stability and the 3D stability, as described as follows:

For the landslide sections with severe deformation (sections A-A' and B-B'), their 2D Fos values were lower than their 3D Fos values. However, for the landslide sections with slight deformation (sections C-C' and D-D'), their 2D Fos values were significantly greater than their 3D Fos values, especially for the landslide sections with the locking segment. The relatively conservative 2D stability analysis (Li et al., 2010; Park et al., 2017) made the 2D Fos values usually lower than the 3D Fos values. Nonetheless, for the landslide sections with rock bridges, their 2D Fos values may exceed their 3D Fos values (Table 2). The overall stability of a landslide with rock bridges should be assessed using 3D Fos since the 2D Fos represents only the local stability of the landslide.

Monitoring

6. Lastly, while the paper often discusses monitoring of deformations, it fails to explain how the monitoring was conducted and the tools used to obtain the data.

Response 6: Thank you for your so careful reading. In fact, we monitored the Tizicao landslide for several years. In the landslide body, twenty-four fixed non-prism monitoring points (T1−T24) were deployed to primarily monitor the surface displacement from June 1, 2017, to October 2, 2017, as shown in Fig. 8 in reference Zhou et al., 2022. They covered almost the entire landslide body. These raw data on the surface displacement were processed using the measurement adjustment software DDM to obtain their deformation amplitude and rates. The detailed descriptions of the monitoring data and instruments were presented in reference Zhou et al., 2022.