Dear Editors and Reviewers:

Thank you for the comments concerning our manuscript entitled “Analysis of three-dimensional slope stability combined with rainfall and earthquake” (Manuscript nhess-2023-181). Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. According to the comments, we have made extensive modifications to our manuscript. In this revised version, changes to our manuscript were all highlighted within the document by using red-colored text. The main correction in the paper and the responds to the comments are as following:

**Responds to the Referee #1’s comments:**

**1. Response to the comment**: In the introduction, only a few lines are mentioned about landslides, slope, rainfall and earthquake, and the background of the research is quickly mentioned. The introduction part should be explored more deeply.

**Response**: We sincerely appreciate the valuable comments. We have rewritten the beginning of the Introduction, discussed more about the relationship between landslides, slopes and rainfall, and added more about the background of the research.

**2. Response to the comment**: Line 74. Scientific gaps about these models need to be further highlighted.

**Response**: Thanks for your suggestion. We have added scientific gaps about these models.

**3. Response to the comment**: Line 258. Please insert figure reference to ease reading the slope elements.

**Response**: Thanks for your careful checks. We add figure reference at the beginning of the paragraph.

**4. Response to the comment**: The quality of the Fig.12 is low.

**Response**: Thanks for your suggestion. We are very sorry for our poor quality of Fig.12. To make it clear, we have redrawn Fig.12.

**5. Response to the comment**: Line 313. Here, the authors have given no information on the geological context of the area studied. a brief geological background indicating the lithology affected, etc.

**Response**: We sincerely appreciate the valuable comments. We have added some information on the geological context according to the Referee #1’s suggestion.

**6. Response to the comment**: Line 347. The paper discusses a phreatic surface, but no phreatic surfaces are presented in the paper.

**Response**: Thanks for your suggestion. We apologize for the lack of an explanation of the phreatic surface, and we have added an explanation where the phreatic surface first mentioned according to the Referee #1’s suggestion. The phreatic surface is the interface between the saturated and unsaturated zones within the slope. Physical and mechanical parameters of the sliding below the phreatic surface adopt saturated, while above the phreatic surface adopt naturally. Based on the known initial phreatic surface, the rainfall-induced changes in the phreatic surface, and consequently the evolution of slope stability, are investigated.

**7. Response to the comment**: The topic of landslides and the effects of slope, rainfall and earthquake should be discussed more deeply in the conclusion section.

**Response**: Thanks for your suggestion. We have added an in-depth discussion of landslides and the effects of slope, rainfall and earthquake combined with the calculation results of the actual slope in the Three Gorges reservoir area in the conclusion section.

**Responds to the Referee #2's comments:**

a) L. 244-245:

Do you have any reference slope gradient? Probably, I misunderstood, but the reference sliding surface is it 45º?

**Response**: We are sorry for our misleading expression. The sliding surface is not 45º. The slip surface of this wedge consists of two structural planes, ABC and OAB, and the coordinates of the vertices have been listed in Figure 8, so the slope gradient is not specifically given. We have added some explanations for the slope.

b) L. 281:

Was the peak ground acceleration (0.05g) taken from any specific earthquake event or return period? Could you clarify?

d) L. 322-323:

Perhaps this information about PGA could come earlier in L. 281, to better understand from where comes the data.

**Response**: We sincerely appreciate the valuable comments. We now combine our answers to these two comments. According to the reviewer's suggestion, we have explained earlier how the peak ground coefficient is taken. We refer to the peak ground acceleration at the place where the Three Gorges reservoir slope is located, and therefore take consistent with the actual slope in Section 5.

c) L. 318:

Could you state the gradient (º) or the range of gradient values?

**Response**: We sincerely appreciate the valuable comments. We have added the general gradient of Woshaxi slope.

e) L. 369:

Would soil porosity have the same effect on the phreatic surface, under rainfall conditions, with higher slope gradients?

**Response**: Thanks for your suggestion. As noted by the Referee #2, it is clear from Eq. 1 that the change in the phreatic surface under rainfall is indeed closely related to both soil porosity and slope gradient. In this actual slope, the gradient of the surface element corresponding to each slip surface element is different, so our analysis does not specifically address changes in different gradients.

f) L. 369-371:

Since permeability coefficient and saturation vary directly with porosity, wouldn't be expected that all these factors could have correlative impact on slope stability?

**Response**: Thank you for your insightful comments and question regarding the interrelationship between permeability coefficient, saturation, and porosity, and their collective impact on slope stability. In our study, we employed a controlled variable method to individually analyze the impact of permeability coefficient, saturation, and porosity on slope stability. This approach allowed us to clearly understand the influence of each individual parameter without the confounding effects of their interactions. We recognize that permeability coefficient, saturation, and porosity are interrelated in real-world scenarios and that their combined effect could present a more complex influence on slope stability. However, to simplify our analysis and to better understand the independent role of each parameter, we chose to study them separately. We acknowledge that this might limit the comprehensive understanding of the combined effects of these factors and could potentially lead to an overestimation or underestimation of their impact on slope stability in certain situations. Future research will consider the interrelation of these parameters and explore their combined effect.

g) L.388-389:

Besides 0.05, the horizontal earthquake coefficients you refer to, are they assigned to any specific earthquake magnitude or return period? Could you state which?

**Response**: Thanks for your suggestion. We have added a statement in the revised manuscript. In this research, we employed three different horizontal earthquake coefficients: 0.05, 0.1, and 0.15. The coefficient of 0.05 is based on the seismic zoning map of China, corresponding to the seismic characteristics and expected level of seismic activity in the study area. As for the other two coefficients, 0.1 and 0.15, they are not directly associated with any specific earthquake magnitude or return period. These values were set based on engineering requirements and safety considerations, aiming to assess the variation in slope stability under stronger seismic actions. This approach allows us to understand the response of the slope under different seismic intensities and provides a safety margin for seismic activities that may exceed expectations.

h) Probably you could better highlight the role of slope gradient combined with both rainfall and earthquakes, since slope is an important conditioning factor that amplifies their effects.

**Response**: We think this is an excellent suggestion. You have aptly noted that the role of slope gradient is indeed crucial in amplifying the effects of rainfall and earthquakes on slope stability and should be more prominently highlighted. In the current study, our focus was predominantly on the impacts of soil permeability coefficient, porosity, and saturation on slope stability, without explicitly considering slope gradient as a variable factor. This was primarily due to our study was based on predetermined slope conditions rather than treating the gradient as a changing parameter. The slope gradient is determined for a real slope, so the change in gradient is not considered. However, we acknowledge that slope gradient is a key conditioning factor that can significantly magnify the effects of rainfall and earthquakes when combined. As such, we plan to incorporate the impact of slope gradient in our future research endeavors to explore how it interacts with rainfall and seismic activities to influence slope stability.

**FIGURES:**

i) Figure 11:

A geographical map with the general setting of the area, i.e., a map with the geographic location of the site should be included in Fig. 11. This would help readers from abroad to better locate the area.

**Response**: We sincerely appreciate the valuable comments. We have added the geographic location of the site in Fig. 11.

j) Figure 12:

Please, improve the resolution of the figure and increase the font, which is too small.

k) Figures 13, 14, 15, 16, and 17:

Please, increase the font.
**Response**: We have modified Figs. 12-17 according to the Referee #2's suggestion.

**Responds to the Referee #3's comments:**
**1. Response to the comment**: The introduction needs reworking to give a clearer view of the background of the paper considering the more relevant slope stability methods and their inherent limitations.
**Response**: We sincerely appreciate the valuable comments. I have revised the introduction to provide a more comprehensive and clear background on the various slope stability methods and their inherent limitations according to the Referee #3's suggestion.
**2. Response to the comment**: In the two comparison cases studied the base assumptions considered in each case should be organized in a clear way, for example as tables with the relevant input variables e the safety factor obtained.
**Response**: Thank you for your valuable suggestions. In order to enhance the clarity and readability of the document, we have added Tables 1 and 2 as suggested by the reviewer, which list the input variables and calculation results as tables.
**3. Response to the comment**: For the Three Gorges Landslide studied, are missing important pieces of information: The limits of the landslide in Fig. 11 seem too schematic and is only presented one cross section of the landslide. With these simple elements how a 3D method was applied to this case. This aspect needs clarification.
**Response**: We sincerely appreciate the valuable comments. In response, we have added a graph with contour lines for a more detailed representation of the landslide area. Additionally, geological information has been included in the landslide cross-section to enhance its descriptive accuracy. Regarding the slip surface, it has been modeled based on monitoring data.
**4. Response to the comment**: The groundwater flow direction is assumed to be constant in all the sliding soil mass or it is derived from a predefined phreatic surface?
**Response**: Thanks for your suggestion. In our study, the direction of groundwater flow within the sliding soil mass is not assumed to be constant. Instead, it is determined by the inclination of the phreatic surface in each differential soil slice. As shown in Fig. 4, the flow direction of groundwater is oriented at an angle $\beta$ relative to the horizontal plane, which varies across different sections of the sliding mass. This approach ensures a more accurate representation of groundwater dynamics within the slope, contributing to the reliability of our slope stability analysis under seepage conditions. In the revised manuscript, we have added an explanation of the direction of groundwater flow within the sliding soil mass.
**5. Response to the comment**: The Three Gorges landslide results are not discussed in relation with its behavior – The computations attain safety factors below 1, which would indicate failure or start of the movement but the true predictive capacity of the method is not assessed – this is a fundamental aspect that must be properly treated.
**Response**: Thank you for your valuable feedback regarding the discussion of the Three Gorges landslide results in our manuscript. I appreciate your point about the necessity of a more comprehensive treatment of the landslide's behavior in relation to the computed safety factors. In response to your comment, we have revised the conclusion section of our

manuscript to include an in-depth discussion of the relationship between the calculated results and the actual behavior of the Three Gorges landslide, and explained the corresponding slope stability state under different working conditions. This revision aims to better contextualize the safety factors obtained through our analysis, particularly those falling below 1, which may indicate potential failure or initiation of movement.

**6. Response to the comment**: This case results should be compared with those obtained with other methods, as in examples 1 and 2.

**Response**: Thanks for your suggestion. The model in example 1 has an analytic solution, and the calculations have been compared to the analytic solution in the manuscript. For example 2, we perform a 2D stability analysis of the intermediate cross-section of the model using Rocscience's Slide and compared them with our 3D results. We have added a discussion of comparative results in the revised manuscript.

**7. Response to the comment**: There is no discussion on the differences of the results of the application of the method in comparison with other methods in the two cases and the landslide analysis presented.

**Response**: Thanks for your suggestion. In response to your observation, I would like to clarify that in Example 1, we analyzed an asymmetric wedge model for which an analytical solution exists. We compared the safety factors calculated using our proposed method with the existing analytical solution and found a close agreement between them. This consistency demonstrates the effectiveness of our method in calculating slope stability for such configurations. For example 2, we studied an ellipsoidal slip surface model, a scenario extensively researched under natural conditions by various scholars. We extended the analysis to include complex conditions such as groundwater presence and seismic activity. We performed a 2D stability analysis of the model's mid-cross-section using Rocscience's Slide software and compared the results with our 3D findings. The comparison revealed minimal differences in the calculated results across all four conditions (natural, with groundwater, with seismic loading, and combined), indicating that our method is also effective in assessing slope stability under complex scenarios. I hope this explanation addresses your concern and demonstrates the comparability and effectiveness of our method in slope stability analysis across different scenarios and in comparison, with other established methods.

**8. Response to the comment**: The size of figures and the font used are too small to be easily readable. Examples: Fig. 1, 2, 3, 4, 6, 8, 13, 14, 15.

**Response**: Thanks for your suggestion. We have modified Fig. 1, 2, 3, 4, 6, 8, 13, 14, 15 according to the Referee #3's suggestion.

**9. Response to the comment**: Fig. 11 is too simplistic – It is not possible to include better landslide limits and other features mapping, topography contour lines?

**Response**: Thank you for your feedback regarding Fig. 11. In response to your suggestion for a more comprehensive representation, we have added a new topographic map with contour lines.

**10. Response to the comment**: Fig. 12 – The presented figure is a landslide cross section, and it is not a map, and it does not contain information on the Geology of the area. The font used is also too small.

**Response**: We sincerely appreciate the valuable comments. We have revised the figure to include detailed geological information of the area. Additionally, we have adjusted the font size for better readability and clarity.

**11. Response to the comment**: Lines 90-91 – Detail the assessment of the infiltration capacity in relation to rainfall, which is not a trivial problem, as it varies with slope, soil cover and use, and vegetation.

**Response**: Thank you for your insightful comment regarding the assessment of infiltration capacity in relation to rainfall. You rightly point out that the infiltration capacity is strongly affected by many factors, such as evapo-transpiration, vegetation, superficial cracks and preferential drainage pathways, the effects of which are indeed very difficult to predict. For practical purposes, we adopted assumptions based on Conte and Troncone (2017) to control the amount of rainwater that can infiltrate into the slope.

**12. Response to the comment**: Line 94 - zr is the volume of water (per unit area) that infiltrates the slope – it is also by unit time? Please clarify.

**Response**: Thanks for your careful checks. We are sorry for our misleading expression. $z_r$ is the volume of water (per unit area) that infiltrates the slope due to a rainfall event with a specified duration, not by unit time. We have corrected the explanation in the revised manuscript.

**13. Response to the comment**: Line 95 – Please clarify the following questions: (1) Sr is the initial saturation? (2) How hydraulic coefficient is computed – it is assumed as the slope of the phreatic surface? (3) The water flow is assumed with a single, constant direction in all sliding mass, or the model can cope with variable flow direction?

**Response**: Thank you for your insightful queries. Our response is as follows:

(1) As a further simplification, it is assumed that Sr is constant in our study.

(2) The reviewer's understanding is correct, and the hydraulic gradient is based on the slope of the phreatic surface. In our model, $i = \sin\beta$.

(3) In our study, the direction of groundwater flow within the sliding soil mass is not assumed to be constant. Instead, it is determined by the inclination of the phreatic surface in each differential soil slice. As shown in Fig. 4, the flow direction of groundwater is oriented at an angle $\beta$ relative to the horizontal plane, which varies across different sections of the sliding mass.

We have clarified these issues in the revised manuscript.

**14. Response to the comment**: Lines 151, 152 – Clarify the text.

**Response**: Thanks for your careful checks. We are sorry for our misleading expression. $\boldsymbol{n}$ is the unit normal vector at position vector $\boldsymbol{r}$ on $S$ and pointing to the inside of the sliding body $\Omega$; $\boldsymbol{s}$ is the unit tangent vector at position vector $\boldsymbol{r}$ on $S$ and opposed to the sliding direction of the sliding body $\Omega$.We have modified the interpretation of $\boldsymbol{n}$ and $\boldsymbol{s}$ in the revised manuscript.

**15. Response to the comment**: Line 159 – comas missing.

**Response**: Thanks for your careful checks. I have added comma in the appropriate place.

**16. Response to the comment**: Line 165 – f' corresponds to the tangent of the friction angle?

- Clarify

**Response**: The reviewer's understanding is correct. We have added the explanation in the revised manuscript.

**17. Response to the comment**: Lines 250 – 251 – The problem analyzed is very simple and straightforward, without water or seismic actions, and the two methods should give equal results. Although the obtained difference is small, this should be discussed in detail.

**Response**: We sincerely appreciate the valuable comments. We indeed observed a slight difference between exact value and the result obtained by the method proposed in our study. This discrepancy may stem from the triangulation of the sliding surface. In our method, the sliding surface is approximated using a series of small triangular elements, which might introduce a slight inaccuracy, leading to a minor deviation in the calculated safety factor compared to the exact value of 1.640 by Hoek and Bray (1.652 in our study). We have discussed this point in detail in our revised manuscript.

**18. Response to the comment**: Line 266 – References for the statement.

**Response**: Thanks for your careful checks. We have added relevant references.

**19. Response to the comment**: Lines 292, 293 – "but also softens the geotechnical materials, leading to a significant decrease in the strength of the soil". The saturation cause soil strength reduction but the "softening" seems not appropriate in this context. Consider the revision of the text. Also, which were the relevant input variables considered in the study case.

**Response**: Thank you very much for your valuable comments and suggestions. Regarding your observation on the phrase "softens the geotechnical materials," we agree that the term may not be precisely appropriate in this context. Our intention was to convey that groundwater seepage leads to increased saturation of the geotechnical materials, which in turn impacts their mechanical properties, particularly reducing the shear strength of the soil. To more accurately describe this phenomenon, we will adjust the wording in the manuscript to "increases the saturation of geotechnical materials, leading to a reduction in soil shear strength."

In this study case, we considered the unit weight of the soil and water, and the effective shear strength parameter. Mechanical parameters of the slope below the water surface adopt saturated, while above the water surface adopt unsaturated. We have supplemented Table 1 for detailed parameters of the slope.

**20. Response to the comment**: Line - 321 – "primary sliding direction is oriented at 40°". Is this the general slope of the failure surface? Clarify.

**Response**: Thanks for your suggestion. This phrase refers to the angle between the main sliding direction of the landslide and the due north direction. Specifically, this means that the main sliding direction of the landslide body is toward 40° east of north. We have further elaborated on this in the revised manuscript to ensure that the descriptions are accurate and easy to understand.

**21. Response to the comment**: Table 1 – Why does friction angle vary so much from natural to saturated states? This seems a bit odd – please justify.

**Response**: We were really sorry for our mistake. I would like to clarify that the significant variation noted was actually due to an error in our manuscript. The correct value of the friction angle should be 15°. In our calculations, we primarily focused on the shear strength parameters of the sliding surface, specifically the cohesion and the friction angle. The choice of these parameters was based on the recommended physical and mechanical properties provided in the geological model report of the Woshaxi landslide.

**22. Response to the comment**: Lines 346 to 351 – The text does not make sense and should be corrected.

**Response**: Thanks for your careful checks. We are sorry for our misleading expression. We have revised the section for improved clarity and coherence. The revised text is as follows:

"The analysis indicates that an increase in rainfall does not invariably lead to a decrease in the safety factor of the slope. This phenomenon can be attributed to the fact that increased rainfall raises the phreatic surface within the slope, affecting two key aspects: firstly, it enhances the hydrodynamic forces, and secondly, it increases the pressure at the base of the slope. When the increase in pressure at the slope's base has a more pronounced impact on stability than the hydrodynamic forces, the safety factor of the slope will subsequently increase. Conversely, if the hydrodynamic forces dominate, the stability of the slope will diminish."

**23. Response to the comment**: Lines 390, 391 – This conclusion only applies to this example, because there were no systematic assessments in a variety of landslide morphologies and soil properties to enable the generalization.

**Response**: Thank you for your valuable comments. You rightly pointed out a limitation in our study: our conclusions are primarily based on a specific case analysis and do not cover a systematic assessment of various landslide morphologies and soil properties. We have revised the conclusion. The revised text is as follows:

"Our study has revealed that within the specific context of the examined landslide, as the horizontal earthquake coefficient increases, there is a notable decrease in the safety factor. It is also observed that in this particular case, the impact of seismic activity on slope stability appears to be considerably more pronounced than that of rainfall. However, these findings are derived from a singular case study, focusing on a specific landslide morphology and set of soil properties. Consequently, they may not necessarily be universally applicable across different landslide types and varying geological conditions."