20 August 2022
Earth Surface Dynamics Manuscript No.: egusphere-2022-19

Reply to Reviewer Comments

(C and R denotes comment and reply, respectively)

Reviewer 1:

General comments:

C1: I enjoy reading this manuscript. It proposes a new ‘combined’ approach to back-analyze seismic signals of a landslide process. The idea is great!

The methodology is technically sound. The proposed simulation process is deemed logical and the results were properly verified and discussed.

However, the writing (English language) must be carefully examined/fixed to make it easy to read and understand.

From places to places, I feel many descriptions are somehow redundant, they are telling the same idea. Please check the whole text again.

I would like to make sure that readers can apply the simulation techniques to their own landslide cases. Therefore, I suggest the DemMat, inversed and synthetic codes shall be shared to readers and are accessible to readers.

R1: Thank you for spending the time to review and assess our manuscript. As instructed, we have now supplemented the information according to the comments received from the expert reviewer. At the same time, we have also deleted the unnecessary materials pointed out by the reviewer. Please see our detailed point-by-point reply to the comments below.

Specific comments:

C1: Abstract is lengthy. Please re-write for concise and clarity.

R1: Thank you for your constructive comments. Combining the comments from Reviewer 2, the abstract is shortened as below:

Landslides present a significant hazard for humans, but continuous landslide monitoring is not yet possible due to their unpredictability. In recent years, numerical simulation and seismic inversion method have been used to provide valuable data for understanding the entire process of landslide movement. However, each method has shortcomings. Dynamic inversion based on long-period seismic signals gives the force-time history of landslide using empirical Green’s function, but lack of detailed flowing characteristics of the hazards. Numerical simulation can simulate the entire movement process, but results are strongly influenced by choice of modelling parameters. Therefore, developing a method for combining those two techniques has become a focus for research in recent years. In this study, we develop such a protocol based on analysis of the 2018 Baige landslide in China. Seismic signal inversion results are used to constrain and optimize the numerical simulation. We apply the procedure to the Baige event and, combined with field/geological survey, show it provides a comprehensive and accurate method for dynamic process reconstruction. We found that the Baige landslide was triggered by detachment of the weathered layer, with severe top fault segmentation. The landslide process comprised four stages: initiation, main slip, blocking, and deposition. Multi-method mutual verification effectively reduces the inherent drawbacks of each method, and multi-method joint analysis improves the rationality and reliability of the results. The approach outlined in this study could help better understand the landslide dynamic process.

C2: Line 31: Using “low frequency curve" is not clear. What curve? Motion curve or others?

R2: Thank you for the useful comment. What we would like to express here is the low-frequency signal of dynamic parameter changes during the evolution of debris flow. We are sorry that there are some problems with our expression, which has been revised. We have now deleted "curve of".

C3: Line 38: … obtain the best numerical “simulations”?

R3: Thank you for your constructive comments. This sentence is inaccurate and has been revised to “Seismic signal inversion results are used to constrain and optimize the numerical simulation”.

C4: Line 45~46: “The approach outlined in this study could be used to support hazard prevention and control in sensitive areas.” I don't think this method can support hazard prevention and control landslide hazard. It just one kind of back-calculation to understand the landslide process. What's happened has happened, so how can we prevent and control the landslide? Considering write something else that is appropriate.

R4: Thank you for your advice. We totally agree with you. We have modified this sentence to “The approach outlined in this study could help better understand the landslide dynamic process.” in manuscript.

C5: Line 137: Explain how to obtain the “Probabilistic power spectral density”, what is the technique or provide references. How you identify the ‘background noise level of the seismic station” from Fig. 3. And, how to apply it next? And why this is important?

R5: Landslide force history inversion uses long-period seismic waveforms and thus requires that the ambient noise at periods of tens of seconds should be at a low level in the study area.

We provided references (e.g., McNamara and Buland, 2004; Peterson, 1993) for the PSD calculation. Fig. 3 provided the new high noise model (NHNM) and new low noise model (NLNM) derived by Peterson (1993) as references. The PSD of the vertical component for station BTA (Fig. 3) reveals that the main seismic energy is distributed between the reference models, indicating that the study area has a relatively good seismic observation environment.

The modified version is shown in below:

"We selected broadband seismic signals from seven seismic stations that are distributed around the landslide with adequate azimuth coverage (Fig. 1d) to carry out the analysis. Landslide force history inversion uses long-period seismic waveforms and thus requires that the ambient noise at periods of tens of seconds should be at a low level in the study area. We used the probabilistic power spectral density (PSD) technique (McNamara and Buland, 2004) to characterize the background seismic noise. As illustrated by the PSD of the vertical component for seismic station BTA (Fig. 3), the main seismic energy is distributed between the new high noise model (NHNM) and the new low noise model (NLNM) (Peterson, 1993), indicating that the study area has a relatively good seismic observation environment."

Reference:

McNamara, D. E., Buland, R. P. 2004. Ambient Noise Levels in the Continental United States. Bull. Seismol. Soc. Am. 94, 1517–1527. https://doi.org/10.1785/012003001.

Peterson, J. R. 1993. Observations and modeling of seismic background noise, U.S. Geological Survey Open-File Report 93-322. https://doi.org/10.3133/ofr93322.

C6: Line 147: What kind of "joint time-frequency domain transform" was used? Just delete 'joint'?

R6: Thank you for your constructive comments. We did not express it accurately enough. We have revised the sentence to remove the "joint".

C7: Line 150: "… that corresponds to a specific moment…" What kind of 'specific moment'?

R7: Thank you for the useful comment. This refers to all seismic, i.e., the source of the source that produces the signal.

C8: Line 168: "… the records were resampled to 0.2 s." What does this mean? You mean 5 Hz sampling rate?

R8: Yes, the records were resampled at a sampling rate of 5 Hz.

C9: Line 182: "… and 9+ Xs" Is the 9+ a typo?

R9: "…9+ X_s is the tangential displacement" This should be a clerical error. We have modified to "K_s is the tangential stiffness; and X_s is the tangential displacement".

C10: Fig. 4: Do you need to predefine the properties of the "slide bed elements"?

R10:

Thank you for your constructive comments. In this study, the properties of "slide bed elements" are not defined separately but adopt the same value as "source area elements". This is because the soil types in the landslide area are the same. The "slide bed elements" are equivalent to a certain thickness of soil layer under the "source area elements". We have added a reference at here, as follows:

Fig. 4. Schematics showing properties of landslide particles and discrete element model. (a) Linear elastic bonded model; (b) Discrete element model of the Baige landslide (Fan et al., 2019a).

Reference:

Fan, X., Yang, F., Subramanian, S. S., Xu, Q., Feng, Z., Mavrouli, O., Peng, M., Ouyang, C., Jansen, D., and Huang, R.: Prediction of a multi-hazard chain by an integrated numerical simulation approach: the Baige landslide, Jinsha River, China, Landslides, 17, 147-164, http://doi.org/10.1007/s10346-019-01313-5, 2019a.

C11: Line 206: How about "We used a simulation block of 2270×1980×1680 m, with …"?

R11: Thank you for the useful comment. We want to express the scale in x, y, z three direction of landslide model is 2270 m, 1980 m, 1680 m. we have changed "simulation area" to "simulation block".

C12: Line 207: Is this "cells" means "elements"? Is there any other better word?

R12: Thank you for the useful comment. We have changed the "cells" to "elements" in line 242.

C13: Line 218: What are the macro and micro conversion formula? Are they important?

R13: Thank you for your constructive comments. “macro and micro conversion formula” was an experience formula proposed by Liu et al. 2013, its build a bridge from macro parameters, such as E, v, C_u, T_u, μ_i to micro parameters K_n, K_s, F_{s0} X_b, μ_p。This formula used to obtain initial parameters of elements, initial parameters still need to adjusted to obtain reasonable simulation result.

We have supplied the reference in manuscript in Line 244-245, and added the macro and micro conversion formula in the Appendix 1, as follows:

$$K_n = \frac{E}{\sqrt{3(1-2v)(1+v)}} \tag{A1}$$

$$K_s = \frac{E(1-4v)}{\sqrt{3(1-2v)(1+v)}} \tag{A2}$$

$$X_b = \frac{2K_n + K_s}{2\sqrt{3}K_n(K_n + K_s)} T_u d \tag{A3}$$

$$F_{s0} = (\frac{1}{4} - \frac{\sqrt{3}}{4}\mu_p)C_u d \tag{A4}$$

$$\mu_p = \frac{-3\sqrt{3} + \sqrt{3}I}{3 + 3I}, I = [(1+\mu_i)^{0.5} + \mu_i]^2 \tag{A5}$$

where Kn and Ks are the normal and shear stiffness of the particle, respectively; E is Young’s modulus; v is Poisson’s ratio; X_b is breaking displacement; T_u is uniaxial tensile strength; d is particle diameter; F_{s0} is initial shear resistance; μ_p is intergranular friction coefficient; C_u is uniaxial compressive strength; μ_i is internal friction coefficient.

C14: Line 219: Why 40% is fine? Any prove?

R14: Thank you for the useful comment. It is generally accepted that there is a significant reduction in strength with increasing specimen size (Darlington et al., 2011). Hoek (2000) suggests this reduction in strength is due to the increased probability that failure of rock grains will occur as the specimen size increases. Therefore, elastic modulus in laboratory tests is usually higher than those in large-scale rock masses in the field.

As for the selected value in this study, it is related to the shape and volume of the selected samples. With the volume of test samples increases, the strength may decrease for 50%. As reported by Pratt et al. (1972), the field tests results are only 30%~70% of the laboratory test. This reduction may relate to the lithology and weathering.

Regarding the numerical simulation results of the landslide, they are mainly related to the size of the spherical unit. Less quantitative research results on the differences between the strength characteristic values and the results of indoor tests and field measurements at the numerical simulation scale have been reported. Liu et al. (2019) used MatDEM to simulate Xinmo landslide, set Young's modulus and strength to about 40% of the test value, and an excellent simulation result is got when using this threshold. In our study, the landslide scales, characters element radius, and even the lithology are similar to this work, therefore, we take reference to Liu et al (2019), which carried out the DEM simulation on the Xinmo landslide, and the threshold 40% of the laboratory test value is used in our simulation. We have supplied the reference in manuscript.

Reference:

Darlington, W.J., Ranjith, P.G., and Choi, S.K.: The Effect of Specimen Size on Strength and Other Properties in Laboratory Testing of Rock and Rock-Like Cementitious Brittle Materials, Rock Mech Rock Eng, 44, 513, https://doi.org/10.1007/s00603-011-0161-6, 2011.

Heuze, F.E.: Scale effects in the determination of rock mass strength and deformability, Rock Mechanics, 12, 167–192, https://doi.org/10.1007/BF01251024,1980.

Hoek E (2000) Rock engineering course notes by Evert Hoek. http://www.rocscience.com/education/hoeks_corner.

Liu, C., Fan, X., Zhu, C., and Shi, B.: Discrete element modeling and simulation of 3-Dimensional large-scale landslide-Taking Xinmocun landslide as an example, J. Eng. Geol, 27, 1362-1370, https://doi.org/10.13544/j.cnki.jeg.2018-234, 2019. (In Chinese)

Pratt, H. R., et al. (1972): The Effect of Specimen Size on the Mechanical Properties of Unjointed Diorite, Int. J. Rock Mechanics and Mining Science, V. 9, pp. 513--529.

C15: Fig. 5: Why 35 and 10 % of delta is reasonable?

R15: Thank you for the useful comment. Traditional back-analysis of landslide usually use the final deposition accuracy to validate the results of numerical simulation due to the lack of continuous on-site monitoring during the whole process (Sassa et al., 2010; Ouyang et al.,2016; Li et al., 2022). The critical success index proposed in recent year (Mergili et al. 2017), considering both accuracy and error, has been introduced into landslide back analysis with application (An et al. 2021). However, due to lack of continuous monitoring, the same deposition pattern may be caused by different dynamical processes, which blind the dynamic inversion of landslide using numerical simulation. Fortunately, the seismic signal generated by landslide can record the dynamic process of landslide such as force-time history.

The calculation efficiency and accuracy are considered as two main issues in numerical simulation. Landslide simulation using DEM may produce a saltation of particles and cause errors. In this study, we selected 2 key indicators, peak displacement Dmax and time when peak velocity achieved Tvmax, as two key indicators to constrain the simulation. It should be noted that in previous landslide simulations, the maximum distance of runout and the actual error usually between 20% and 30 % (Ouyang et al.,2016； Scaringi et al., 2018). Therefore, two parameters that controlling the landslide movement process, are chosen a threshold of 10%. The other two parameters, peak velocity Vmax and landslide duration T, less important compared with first two, have certain reference value for describing the process of landslide movement. Here two reasons are considered for choosing a relatively large threshold of 35%. First, the method of inverting the landslide velocity can be affected by topography change and entrainment process especially in complex mountain areas. Second, the starting point of the actual landslide movement may not be so clear, and even after the deposition is completed, there will still be local small scale of landslides which produce a continuous seismic signal. Therefore, compared with actual observation (e.g., CSI), they could be given a higher degree of tolerance.

It should be noted that whether it is 10% or 35%, it is not yet a generally accepted threshold. In this study, the simulation results obtained beyond the above thresholds will have large difference compared with the actual deposition. Therefore, the above thresholds should be adjusted for the purpose of the study, especially depending on the case of the study or the accuracy of the input terrain data. However, less threshold means more times of try and error, which will dramatically increase the time of calibration. Therefore, in considering the calculation efficiency, we use threshold of 10% or 35% for those four parameters.

Reference:

Li, Y., Chen, J., Li, Z., et al. (2022). Comprehensive analysis of a paleo-landslide damming event on the upper reach of the Jinsha River, SE Tibetan Plateau. Bulletin of Engineering Geology and the Environment, 81(8). doi:10.1007/s10064-022-02791-z

Ouyang, C., Zhou, K., Xu, Q., Yin, J., Peng, D., Wang, D., & Li, W. (2016). Dynamic analysis and numerical modeling of the 2015 catastrophic landslide of the construction waste landfill at Guangming, Shenzhen, China. Landslides, 14(2), 705-718. doi:10.1007/s10346-016-0764-9

Sassa, K., Nagai, O., Solidum, R., Yamazaki, Y., & Ohta, H. (2010). An integrated model simulating the initiation and motion of earthquake and rain induced rapid landslides and its application to the 2006 Leyte landslide. Landslides, 7(3), 219-236. doi:10.1007/s10346-010-0230-z

An, H. C, Ouyang, C. J, Zhou, S.: Dynamic process analysis of the Baige landslide by the combination of DEM and long-period seismic waves., Landslides, 18, 1625-1639, https://doi.org/10.1007/s10346-020-01595-0, 2021.

Mergili, M., Emmer, A., Juřicová A., Cochachin, A., Fischer, J. T., Huggel, C., and Pudasaini, S. P.: How well can we simulate complex hydro-geomorphic process chains? The 2012 multi-lake outburst flood in the Santa Cruz Valley (Cordillera Blanca, Perú)., Earth Surf Process Landf, 43, 1373-1389., https://doi.org/10.1002/esp.4318, 2017.

Scaringi, G., Fan, X. M., Xu, Q., Liu, C., Ouyang, C. J., Domenech, G., . . . Dai, L. X. (2018). Some considerations on the use of numerical methods to simulate past landslides and possible new failures: the case of the recent Xinmo landslide (Sichuan, China). Landslides, 15(7), 1359-1375. doi:10.1007/s10346-018-0953-9.

C16: Fig. 5: Is CSI 0.6 is a commonly acceptable value? Any references?

R16: Thank you for your constructive comments. An et al. (2021) conducted 25 simulations by changing the parameters such as static friction coefficient, thermal weakening friction coefficient and normal bond strength. The results showed that only 8 cases acceptable had CSI > 0.6 with the highest CSI of 0.83. Among the 15 groups of results simulated by Mergili et al. (2017), the maximum CSI is chosen as 0.59. In addition to the CSI value, this study also needs to further adjust the simulation parameters according to the dynamic characteristics. Therefore, the CSI value should not be set too high to avoid low simulation efficiency. Therefore, CSI > 0.6 is chosen in this study. We have supplied the reason and reference in manuscript.

Reference:

An, H. C, Ouyang, C. J, Zhou, S.: Dynamic process analysis of the Baige landslide by the combination of DEM and long-period seismic waves, Landslides, 18, 1625-1639, https://doi.org/10.1007/s10346-020-01595-0, 2021.

Mergili, M., Fischer, J. T., Krenn, J., and Pudasaini, S. P.: r. avaflow v1, an advanced open-source computational framework for the propagation and interaction of two-phase mass flows, Geosci. Model Dev, 10, 553-569, https://doi.org/10.5194/gmd-10-553-2017, 2017.

C17: Fig. 5: After the adjustment of Intergranular friction coefficient μp and damping coefficient C, don't you need to check if CSI>0.6 again? The CSI is possible smaller than 0.6, isn’t it?

R17: Thank you for your advice, After the adjustment of intergranular friction coefficient and damping coefficient C, we check if CSI>0.6 at first, then check the other indices. We have now adjusted the Fig.5.

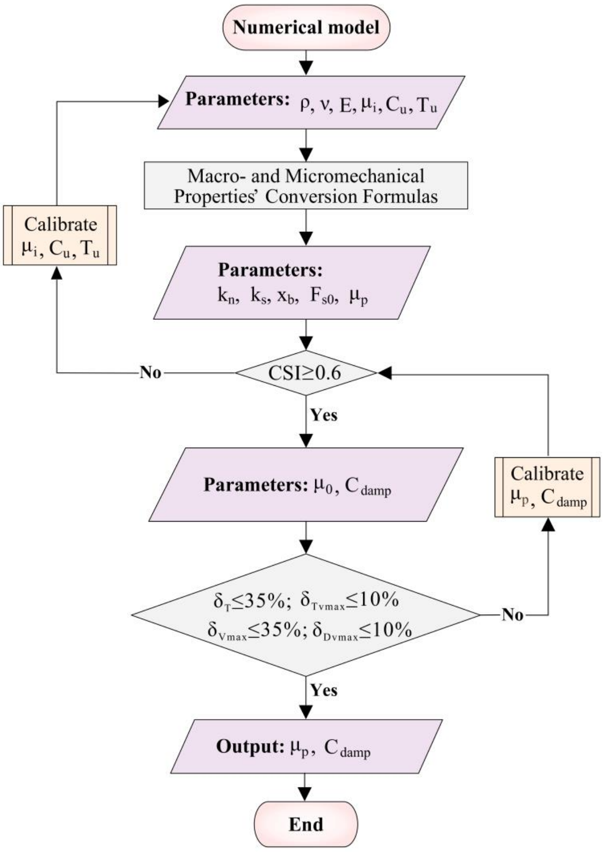


Fig. 5. Flowchart of the method of discrete element parameter adjustment based on seismic signal inversion.

C18: Line 252: “post-event geological survey showed sliding was mainly in a south-east-to-south direction” By observing Fig. 3, it seems that the sliding was almost in an eastward direction. Isn't it?

R18: That is what we would like to say, and we made it clear accordingly, as follows:

“The SNR of the vertical (V) and east (E) components is relative higher, compared with north (N) component, roughly reflecting the main slide direction of landslide is E and N. Post-event geological survey showed sliding was mainly in south-east-to-south, approximately eastwards.”

C19: Fig. 6 shows "showing signal-to-noise ratio of the low-frequency components"? Explain how to identify high and low SNR. From Fig. 6 I feel they are approximately the same SNR in the E\N\V direction, even in the low frequency range. Therefore, I treat Line 249~259 is a kind of qualitatively discussion.

R19: Thanks a lot. The legend in Figure 6 “showing signal-to-noise ratio of the low-frequency components (E\N\V direction).” This expression is somewhat inaccurate. To be precise, it reflects the signal-to-noise ratio of the entire data band, especially the distinction between high-frequency and high-frequency signal-to-noise ratios. From the three graphs, the high-frequency signal-to-noise ratios of E and V are relatively high, and N is relatively high. lower. We have now corrected Lines 298~301 as:

“The SNR of the vertical (V) and east (E) components are relative higher, compared with north (N) component, roughly reflecting the main slide direction of landslide is E and N. Post-event geological survey showed sliding was mainly in south-east-to-south, approximately eastwards.”

C20: Line 272: how about “The time domain velocity recorded at …”?

R20: This represents the curve formed by the acceleration of the GZI station at each moment. The signal analysis in this manuscript involves the frequency domain and the time domain, where the time domain is used to distinguish it from the frequency.

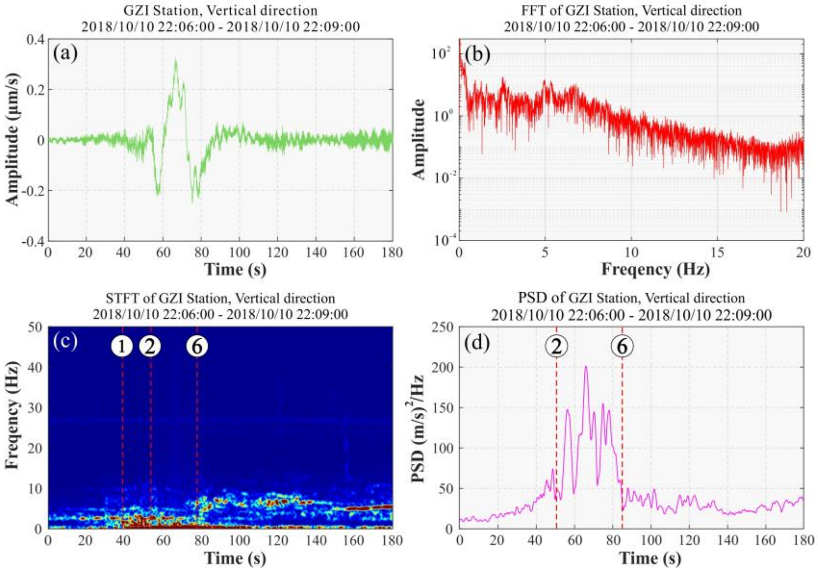
C21: Line 279: Although I get what you want to say, please re-write the sentences: “… and the signal may also be affected by superimposition of vertical and horizontal waves, which makes the end time lag. So, the critical moments of the landslide derived from the original seismic signal would be lagged, and the duration too long.”

R21: We have made changes based on the reviewer's comments as follows:

"…what's more, the signal is mixed by longitudinal wave that stack with transverse wave, which makes the ending time picked by seismic signal much latter than the actual time. All these make the time of the landslide derived from the original seismic signal would be lagged and longer, compared to the real time."

C22: Fig. 7: The time axis appears redundant times? e.g., 22:06 22:06 ...

R22: We have modified Fig. 7 as follows :



C23: Fig. 7: You can show the Fig. 7 b in log-scale for better low frequency resolution.

R23: Thank you for the useful comment. We have modified Fig. 7b as responded in C22.

C24: Fig. 7: Why choose vertical component (V) for analysis? Isn't that the GZI east (E) component has a lower SNR, with less noise?

R24: This is because the V component has the highest signal-to-noise ratio, and the inversion of V component can reflect the force on main sliding direction and normal direction, and its analysis accuracy is relatively reliable.

C25: Line 300: Change to "… with the time domain stages (as in Table 2), …"

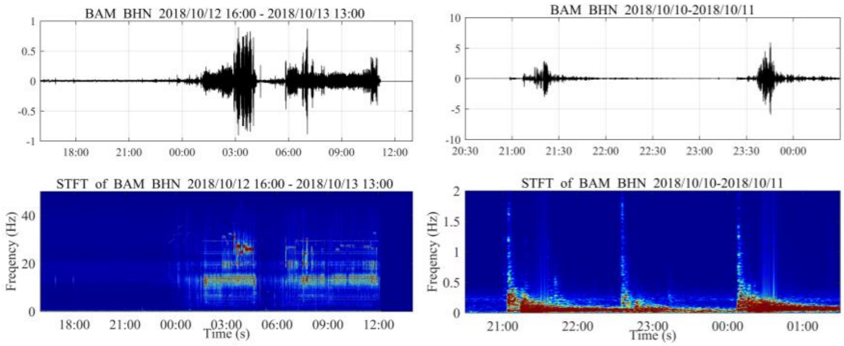
R25: We thank the reviewer for this comment. We have modified this sentence as follows:

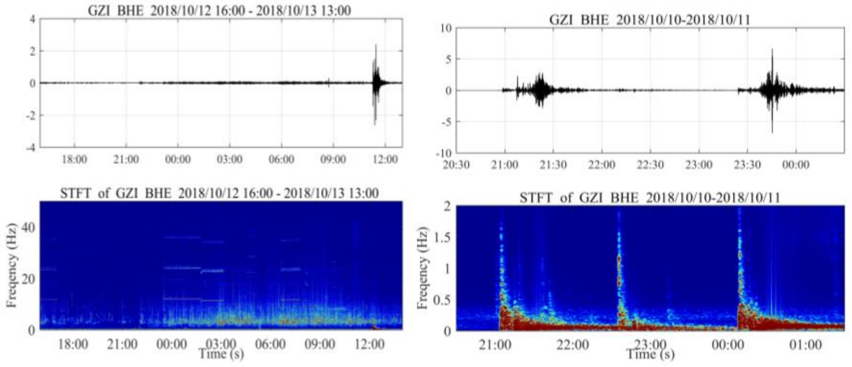
“Comparing with the time domain stages (as in Table 2), the first PSD stage corresponds to the first acceleration…..”

C26: Line 309: “also, there is a clear difference from the outburst flood signal on October 12, 2018.” Can you present a figure for showing the differences between outburst flood on Oct. 12?

R26: According to the statistics in our previous research, when water is involved, that is, debris flow or high-density flow, the frequency of the seismic signal is relatively high, and its main frequency range can reach 3~50Hz, and more than 5Hz (Yan, et al, 2021; Yan, et al, 2017). "Clear difference" refers to the frequency of the seismic signal of the flood discharge event after the second landslide in Baige, and the difference between the curve mentality and the current landslide; because there are relatively many studies on the seismic signal of floods and debris flows, so this time the seismic signal for the second flood event was not added. In the revised manuscript, we have added a description of the second landslide seismic signal frequency information. We changed the paragraph of the original Line306-310 as follows:

According to Yan et al (2021), the frequency of landslide hazard seismic signals is usually low (0~5Hz), and the morphology in the time-frequency domain and time domain presents single-peak or double-peak characteristics, while the frequency of flood or high-density flow seismic signals is usually high (5~50Hz), and the morphology in the time-frequency domain and time domain mostly presents the characteristics of flat. Combined with this landslide seismic signal has relatively low frequency (0–1 Hz) and the single-peak feature in time and time-frequency characteristics, apparently different from the spectrum (main frequency :15~30Hz) of the outburst flood signal triggered by the second landslide on October 12, 2018 (An et al, 2021). So, we think there was no flood discharge during the landslide process.





Reference:

Yan Yan, Yifei Cui, Dingzhu Liu, et al. Seismic Signal Characteristics and Interpretation of the 2020 “6.17” Danba Landslide Dam Failure Hazard Chain Process [J]. Landslides, 2021, 18(6): 2175-2192. https://doi.org/10.1007/s10346-021-01657-x.

Yan Yan, Peng Cui, Su-chin Chen, et al. Characteristics and interpretation of the seismic signal of a field-scale landslide dam failure experiment [J]. Journal of Mountain Science, 2017, 14(2): 219–236. https://doi.org/10.1007/s11629-016-4103-3.

C27: Fig. 8 caption: “Corresponding absolute values are shown as dashed black lines.” How you calculate the absolute values? For what reason we need it?

R27: Thank you for the useful comment. The absolute values are the square roots of the sum of squares of three component values. We need the absolute values because, for example, an absolute sliding speed is more intuitive than a three-component velocity.

We are sorry that there is an error here. Absolute values are represented using black lines. Vertical dashed black lines marked the landslide start and end times (the first and third ones) and the time that the sliding mass reached the maximum speed (the middle one). Therefore, we made change of title of Figure 8: “Corresponding absolute values are shown as black lines.”

C28: Fig. 9 caption “Red dotted lines indicate that the seismic trace was not used in the inversion.” Why not used? What are your considerations?

R28: Thank you for pointing this out. We calculated the signal-to-noise ratio (SNR) of each processed seismic record and selected seismic traces with an SNR larger than 10 dB to carry out the inversion. This part was modified in the revised manuscript.

“Seismic data were processed using the following procedure before carrying out the landslide force history inversion. Firstly, they were deconvolved with the instrument response to obtain displacement; then a 4th-order Butterworth bandpass filter in the frequency band of 0.006–0.2 Hz was then applied; and finally, the records were resampled at a sampling rate of 5 Hz. The processed seismic records have a high signal-to-noise ratio (SNR) as shown in Table 3. Sixteen seismic traces with an SNR larger than 10 dB were selected to carry out the inversion.

Table 3. SNR of seismic signals used in the inversion and CC and VR of the inversion results

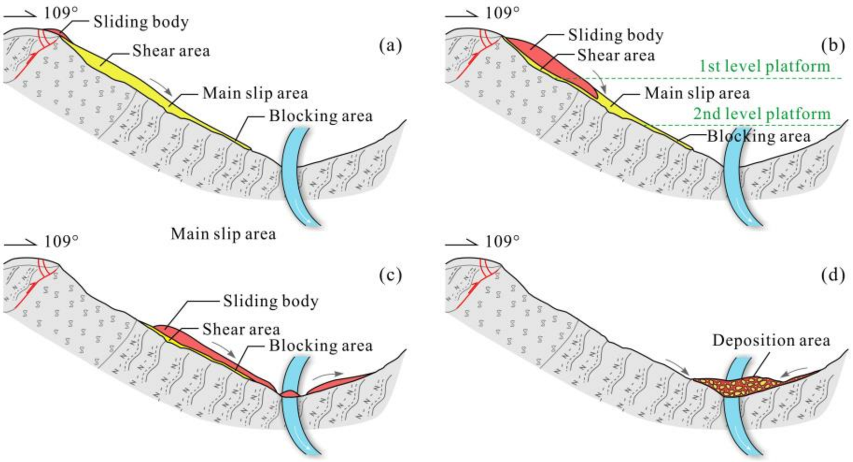
Seismic Station		Signal-to-noise ratio SNR	Cross-correlation (CC)	Variance reduction (VR)
BTA	Z	19.19	0.96	0.90
	E	4.28	0.56	0.28
	N	8.45	0.60	0.34
GZI	Z	29.63	0.99	0.99
	E	20.39	0.99	0.98
	N	15.29	0.97	0.94
LTA	Z	24.67	0.99	0.98
	E	7.92	0.86	0.71
	N	15.12	0.97	0.94
DFU	Z	23.60	0.99	0.99
	E	17.58	0.99	0.98
	N	5.92	0.54	0.28
YJI	Z	22.58	0.98	0.97
	E	11.64	0.93	0.85
	N	16.75	0.95	0.90
YUS	Z	18.05	0.94	0.89

	E	19.39	0.98	0.97
	N	18.01	0.98	0.96
BAM	Z	21.48	0.99	0.98
	E	5.86	0.74	0.53
	N	10.91	0.94	0.88

The inverted force histories are shown in Fig. 8. The good fit of the synthetic and recorded seismic waveforms in Fig. 9 and the high cross-correlation (CC) and variance reduction (VR) between synthetic and recorded seismograms provided in **错误!未找到引用源。** indicate the high quality of the inversion results. The inverted forces show landslide initiation at 14:05:37.6, with ~61 s duration of the main motion.”

C29: I wonder whether the Fig. 14 a and b shall be switched? What is the red area in Fig. 14 b? Also, please show where are the 1st and 2nd "level platforms" in Fig. 14. I don’t quite get it from your description.

R29: Figure 14.a represents the initial stage, that is, a small amount of top traction area starts to slide; Figure 14.b~d red area represents the sliding body, Figure 14.b represents the landslide body in the traction area covering the shear area, resulting in The shear zone begins to slide down, and drives the main sliding zone to begin to move. 1st and 2nd level platforms are marked accordingly as shown in the figure below.



C30: Line 539~540: I think it is: “Part of the front edge of the landslide was detached on the right bank of the Jinsha River, slid up against the opposite slope on the left bank, and then …” You may reverse the right and left?

R30: Thank you for your comments. Combining other comments, we have deleted this sentence and modified the conclusions. Please refer to the reply to C32.

C31: Line 542: “that combing on-site” Wrong word.

R31: Thank you for your comments. We have deleted this word and modified the conclusions. Please refer to the reply to C32.

C32: The conclusion is not concise and complete. Many parts are redundant. I suggest you rewrite. You may want to write: a brief restatement of your research problem; summarize overall findings, and the implications of your research, etc.

R32: Thank you for the useful comment. We have now modified the conclusions as in below:

In this study, we use on-site geological survey, landslide seismic signal analysis, dynamic inversion, and numerical simulation to provides a comprehensive analysis of “10.10” Baige landslide. We used short-time Fourier transform (STFT) and PSD to analyze the seismic signals for Baige landslide. We then reconstructed the landslide force history by direct deconvolution of the observed seismograms with Green’s functions. We then developed a method that use seismic inversion to constrain and calibrate the numerical input parameters using DEM. With the assessment of numerical simulation, the dynamic process of “10.10” Baige landslide was then analysed. Nevertheless, several key issues, such as friction weaking, base entrainment, particle breakage, are not considered in the DEM, which leads the difference between simulation and inversion, should be considered in future research.

Reviewer 2:

General comments:

C1: The contribution of this work, in comparison to other studies, is not clear. Using seismic data to calibrate numerical models has already been done before. If the analysis of high frequencies in seismic signals (besides, define what you mean by high frequencies) is innovative, it think it is not clear enough in the manuscript how it helps better constrain the landslide dynamics. If the main contribution of the article is using seismic data and numerical modelling to better constrain the dynamics of the Baige landslide specifically (which is perfectly okay), it should be stated more clearly.

R1: We are thankful to our reviewer’s comments on the scientific contents of the present study. As instructed, we have highlighted our contribution in comparison with previous works. Please find in below for the detailed responses.

C2: The methodology is not described precisely enough, and some methodological explanations are given in the Results section instead of the Methodology section. In particular, the method for estimating the landslide dynamics from seismic signal, and the method for calibrating model parameters, should be more detailed.

R2: We have now added detailed descriptions on the landslide force history inversion in the methodology section. At the same time, we adjust the structure of the text and moved methodological explanations that are originally in the Results section to the methodology section.

C3: The authors state that using deposits and seismic data to calibrate the model improves the quality of the simulation results, but do not illustrate it. As this is, if I’m correct, a key point of their work, this aspect could be further developed.

R3: Thank you for the comment. Previous research is mainly focused on optimization of the numerical simulation through the force-time curve inversion of the seismic signal (Moretti et al., 2015; Yamada et al. 2018; An et al., 2021). In the current study, we use a combination of three methods: Seismic signal analysis, Dynamic inversion and numerical simulation to help us better reconstruct the landslide process.

Specially, for numerical simulation, the traditional DEM parameter calibration is a key issue, mostly based on trial-and-error method, which requires a lot of attempts, and the simulation of an ordinary landslide case may consume days or even ten days. Based on this, we propose a new method to calibrate and optimize the input parameters based on information such as velocities from seismic signal inversions, which can greatly reduce the time of calibrations required before obtaining reasonable simulation results. Compared with An et al. 2021, here we developed a method that combine velocity and displacement characteristics inverted by seismic signal, and deposition accuracy to further improve the accuracy of numerical method. This is also one of the main contributions of our study.

Reference:

An, Huicong, Chaojun Ouyang, et Shu Zhou. 2021. « Dynamic Process Analysis of the Baige Landslide by the Combination of DEM and Long-Period Seismic Waves ». Landslides 18 (5): 1625-39. https://doi.org/10.1007/s10346-020-01595-0.

Moretti, L., K. Allstadt, A. Mangeney, Y. Capdeville, E. Stutzmann, et F. Bouchut. 2015. « Numerical Modeling of the Mount Meager Landslide Constrained by Its Force History Derived from Seismic Data ». Journal of Geophysical Research: Solid Earth 120 (4): 2579-99. https://doi.org/10.1002/2014JB011426.

Moretti, L., A. Mangeney, Y. Capdeville, E. Stutzmann, C. Huggel, D. Schneider, et F. Bouchut. 2012. « Numerical Modeling of the Mount Steller Landslide Flow History and of the Generated Long Period Seismic Waves ». Geophysical Research Letters 39 (16): n/a-n/a. https://doi.org/10.1029/2012GL052511.

Moretti, L, A Mangeney, F Walter, Y Capdeville, T Bodin, E Stutzmann, et A Le Friant. 2020. « Constraining Landslide Characteristics with Bayesian Inversion of Field and Seismic Data ». Geophysical Journal International 221 (2): 1341-48. https://doi.org/10.1093/gji/ggaa056.

Yamada, Masumi, Anne Mangeney, Yuki Matsushi, et Takanori Matsuzawa. 2018. « Estimation of Dynamic Friction and Movement History of Large Landslides ». Landslides 15 (10): 1963-74. https://doi.org/10.1007/s10346-018-1002-4.

Yamada, Masumi, Anne Mangeney, Yuki Matsushi, et Laurent Moretti. 2016. « Estimation of dynamic friction of the Akatani landslide from seismic waveform inversion and numerical simulation ». Geophysical Journal International 206 (3): 1479-86. https://doi.org/10.1093/gji/ggw216.

C4: The figures, and their caption, can be improved.

R4: We thank the reviewer for the comments. As instructed, we have now modified the figures carefully according to the detailed comments, please see the modified version of each figure in the manuscript.

Specific comments:

C1: The abstract could be shortened. In particular, l.22 to 33 is a too detailed state-of-the-art for an abstract. It is not until l.34 that the aim of the paper is given, I think it should be stated earlier.

R1: We agree with the reviewer’s comments. The abstract is now shortened as below:

Landslides present a significant hazard for humans, but continuous landslide monitoring is not yet possible due to their unpredictability. In recent years, numerical simulation and seismic inversion method have been used to provide valuable data for understanding the entire process of landslide movement. However, each method has shortcomings. Dynamic inversion based on long-period seismic signals gives the force-time history of landslide using empirical Green's function, but lack of detailed flowing characteristics of the hazards. Numerical simulation can simulate the entire movement process, but results are strongly influenced by choice of modelling parameters. Therefore, developing a method for combining those two techniques has become a focus for research in recent years. In this study, we develop such a protocol based on analysis of the 2018 Baige landslide in China. Seismic signal inversion results are used to constrain and optimize the numerical simulation. We apply the procedure to the Baige event and, combined with field/geological survey, show it provides a comprehensive and accurate method for dynamic process reconstruction. We found that the Baige landslide was triggered by detachment of the weathered layer, with severe top fault segmentation. The landslide process comprised four stages: initiation, main slip, blocking, and deposition. Multi-method mutual verification effectively reduces the inherent drawbacks of each method, and multi-method joint analysis improves the rationality and reliability of the results. The approach outlined in this study could help better understand the landslide dynamic process.

C2: You could also try to be more specific about the novelty of your approach, in comparison to previous study. When you write « Seismic signal dynamic inversion results are used to verify the numerical simulation, and then the numerical simulation is dynamically constrained and optimized to obtain the best numerical value », this has already been done in other studies, e.g. (Moretti et al. 2012; 2015; 2020; Yamada et al. 2016; 2018).

R2: Thanks a lot. Inversion of landslide dynamic processes based on numerical simulations has been a good achievement in the past decades, and there are two main mainstream and relatively mature simulation methods. The first is a continuum-based simulation method, which treats landslides as a continuous media and uses a depth integration method to obtain the spatial distribution of the thickness and velocity of the landslide body at different moments (Muceku et al., 2016; Pitman et al., 2003; Shen et al., 2020). It has the advantage of fast calculating, but neglecting the bahviour of granular material such as individual collision between particles and bed, which are precisely the key physical processes that generate the ground seismic signal. The second kind of simulation method is based on Discrete Element Method (DEM), and this type of method treats the landslide as discrete spherical or block units. They are displaced by mutual contact deformation, and the motion occurring in the final particles can be regarded as the motion process of the landslide (Lo et al., 2011; Zhang et al., 2020a; Wang et al., 2020). The advantage of this type of simulation is that it can reflect the physical nature of the granular materials during landslide motion.

However, as a cost, the DEM requires huge computations, sacrificing computational time for more details of the landslide motion.

As stated by the reviewers, we note that previous studies have used a similar approach to simulate disaster dynamics processes and based on this, seismic signal analysis has been performed (e.g., Moretti et al. 2012; 2015; 2020; Yamada et al. 2016; 2018). These studies used the SHALTOP Model for numerical simulation and estimated basal friction distributions by comparing inverted and simulated forces. As analysed before, this method belongs to the first class of simulation methods based on continuous media.

Instead, we use DEM, but we have made improvements accordingly. The traditional DEM parameter calibration is a key issue, mostly based on trial-and-error method, which requires a lot of attempts, and the simulation of an ordinary landslide case may consume days or even ten days. Based on this, we propose a new method to calibrate and optimize the input parameters based on information such as velocities from seismic signal inversions, which can greatly reduce the time of calibrations required before obtaining reasonable simulation results. Our method, therefore, can both accurately describe the physical mechanisms such as particle collisions that generate seismic signals and facilitate the efficiency of discrete element modelling. This is also one of the main innovations of our study.

Reference:

Lo, C. M., Lin, M. L., Tang, C. L., and Hu, J. C.: A kinematic model of the Hsiaolin landslide calibrated to the morphology of the landslide deposit, Eng. Geol., 123, 22-39, https://doi.org/10.1016/j.enggeo.2011.07.002, 2011.

Muceku, Y., Korini, O., and Kuriqi, A.: Geotechnical analysis of hill’s slopes areas in heritage town of Berati, Albania. Period. Polytech., Civ. Eng. 60, 61-73, https://doi.org/10.3311/PPci.7752, 2016.

Pitman, E. B., Nichita, C. C., Patra, A., Bauer, A., Sheridan, M., and Bursik, M.: Computing granular avalanches and landslides, Phys. Fluids., 15, 3638-3646, https://doi.org/10.1063/1.1614253, 2003.

Shen, W., Li, T., Li, P., and Lei, Y.: Numerical assessment for the efficiencies of check dams in debris flow gullies: A case study, Comput. Geotech., 122, 103541, https://doi.org/10.1016/j.compgeo.2020.103541, 2020.

Wang, W., Yin, Y., Zhu, S., Wang, L., Zhang, N., and Zhao, R.: Investigation and numerical modeling of the overloading-induced catastrophic rockslide avalanche in Baige, Tibet, China, Bull. Eng. Geol. Environ., 79, 1765-1779, https://doi.org/10.1007/s10064-019-01664-2, 2020.

Zhang, S. L., Yin, Y. P., Hu, X. W., Wang, W. P., Zhang, N., Zhu, S. N., and Wang, L. Q.: Dynamics and emplacement mechanisms of the successive Baige landslides on the Upper Reaches of the Jinsha River, China, Eng. Geol., 278, 105819, http://dx.doi.org/10.1016/j.enggeo.2020.105819, 2020a.

C3: l.52: If a remember well, this estimation is for non-seismically triggered landslides.

R3: As the reviewer said, this estimation is for non-seismically triggered landslides, so we have modified this sentence as follows:

Landslides present a significant hazard for humans, the number of fatalities resulting from non-seismic landslides between 2004 and 2016 averaged 4,000 per year (Froude and Petley, 2018).

C4: l.55-58: You should be more specific about the « new methods ». If you mean the combination of simulation and seismic data, this is not really new (cf references above).

R4: We have explained the innovation of this research method compared with other methods. Please refer to the reply to C2.

C5: l.92: It is not clear what « the two main approaches » refer to. The reader is led to believe that you mean « block model » and « numerical simulation », while I guess you refer to two numerical approaches.

R5: Thank you for the useful comment. According to C6, we have now added a third method and modified the sentence to "there are issues with each of the following three main approaches."

C6: l.99: I would also mention thin-layer models as a third approach. It is formally a continuum approach, but the equations are averaged over the depth of the landslide. They are less precise than full 3D models (continuous or discrete), but allow faster runs (see refs above).

R6: Thank you for your constructive comments. As instructed, we have now added the third approach in manuscript. "The thin-layer model, it is based on the thin-layer approximation and depth-averaging of the Navier–Stokes equations without viscosity, but a main issue is low computational accuracy (Moretti et al., 2012, 2015; Yamada et al., 2016, 2018)".

C7: l.107-108: As stated in my comment on the abstract, it is not clear at this point how your work is different from previous studies combining seismic data inversion and numerical simulations (Moretti et al. 2012; 2015; 2020; Yamada et al. 2016;

2018). You mention in the abstract that you use both high frequency and long period seismic data, but this is not apparent in the introduction.

R7: The difference between this research work and previous research combined with seismic data inversion and numerical simulation and the innovation of this study please refer to our response to C2.

We have modified this part, as follows:

In this study, we use long period seismic signal to obtain the dynamic characteristics of Baige landslide, China, which occurred on October 10, 2018 (termed the “10.10” event). By the dynamic inversion results by long period seismic signal which can be used to quality the landslide reconstruction using numerical simulation, and the post-event field investigation and high frequency seismic signal analysis, we try to provide an improved characterization of the landslide movement process.

C8: l.114-122. I would be more specific on the contributions of previous studies on the Baige landslide. It would highlight the novelty of your work. Besides, I found at least one other article on the Baige landslide that you do not mention (An, Ouyang, et Zhou 2021).

R8: We thank the reviewers for their comments. Previous studies on the movement dynamics of the Baige landslide were mostly based on different numerical methods to invert its process. The calibration of DEM parameters is a very time-consuming process that relies heavily on experience. Previous studies are mostly based on trial-and-error methods, which require a lot of attempts, and the simulation of a landslide case may consume several days or even ten days. Based on this, we propose a new method to calibrate and optimize the input parameters based on information such as the velocity of seismic signal inversion, which can greatly reduce the calibration time required before obtaining reasonable simulation results.

We note the work of An, Ouyang, and Zhou (2021), which is cited in the manuscript, and compare it with our study. Their main innovation is to consider the evolution of the friction coefficient (one of the microscopic parameters) in DEM simulations and to calibrate the parameters by force-time curves from seismic signal inversions. It is noted that they carried out a total of 25 sets of simulations in the paper before determining the most appropriate parameters, and this is not considering the calibration time of other DEM parameters. This is almost unacceptable in applications when carried out landslide dynamic simulations, and it would take a month to determine a microscopic parameter on a workstation with high computational efficiency. However, we must acknowledge the significance of the study by An, Ouyang, and Zhou (2021), who provided new ideas for the study of landslide dynamics mechanisms and, from a scientific point of view, may help to reveal the physical mechanisms underlying the hyperkinetic nature of remote landslides.

For the Baige landslide, the mobility of the landslide is limited (H/L = 0.5) due to topographic constraints, so it is acceptable to ignore the resistance variety, and previous studies have shown that ideal simulation results can be obtained even without considering the variation of resistance (Fan et al. 2019; Hu, Yu, and Zhou 2020; Ouyang et al. 2019; Mao et al. 2021).

Our study provides a complete set of DEM micro-parameter calibration methods based on seismic signals, in which the parameters were firstly calibrated by the deposit range and then quantified by the evolutionary process of seismic signals. This is one of the main innovations of our research.

Reference:

An, H. C., C. J. Ouyang, and S. Zhou. 2021. 'Dynamic process analysis of the Baige landslide by the combination of DEM and long-period seismic waves', Landslides, 18: 1625-39.

Fan, Xuanmei, Fan Yang, Srikrishnan Siva Subramanian, Qiang Xu, Zetao Feng, Olga Mavrouli, Ming Peng, Chaojun Ouyang, John D. Jansen, and Runqiu Huang. 2019. 'Prediction of a multi-hazard chain by an integrated numerical simulation approach: the Baige landslide, Jinsha River, China', Landslides, 17: 147-64.

Hu, Yu-xiang, Zhi-you Yu, and Jia-wen Zhou. 2020. 'Numerical simulation of landslide-generated waves during the 11 October 2018 Baige landslide at the Jinsha River', Landslides, 17: 2317-28.

Mao, Jia, Xunnan Liu, Chong Zhang, Guoxin Jia, and Lanhao Zhao. 2021. 'Runout prediction and deposit characteristics investigation by the distance potential-based discrete element method: the 2018 Baige landslides, Jinsha River, China', Landslides, 18: 235-49.

Ouyang, Chaojun, Huicong An, Shu Zhou, Zhongwen Wang, Pengcheng Su, Dongpo Wang, Duoxiang Cheng, and Jinxing She. 2019. 'Insights from the failure and dynamic characteristics of two sequential landslides at Baige village along the Jinsha River, China', Landslides, 16: 1397-414.

C9: l.133: You also have Digital elevation models and ortho-photographs. They should be mentioned, with their source, in the Data section, not in the Simulation section (l.200 – 202).

R9: We thank the reviewer for this comment. We have now moved the data source from numerical simulation into the “Study area and data source”:

“We used terrain data from Ouyang et al. (2019), comprising a 10 m resolution pre-landslide Digital Elevation Model (DEM) from 2017, and a 5 m resolution post-slide DEM obtained through Unmanned Aerial Vehicle (UAV) photogrammetry in 2018.”

C10: l.135-136: You should detail your criterion of a good azimuth coverage. It is only slightly more than 180°, so one could argue it is not that good… Did you also have a criterion on the distance, explaining why you do not use stations to the south-west of the landslide?

R10: Maybe the word ‘good’ is not appropriate here, we changed it to ‘adequate’. To be honest, we have no criterions of azimuth coverage and distance limitation. According to our experiences and previous studies, good inversion results can be obtained using a couple of high signal-to-noise ratio station records within a few hundred kilometers. We don't have seismic data to the south-west of the landslide. Therefore, we chose to use the stations described in the text.

References:

Moretti, L., Allstadt, K., Mangeney, A., Capdeville, Y., Stutzmann, E., and Bouchut, F.: Numerical modeling of the Mount Meager landslide constrained by its force history derived from seismic data, J. Geophys. Res.-Sol. Ea., 120, 2579–2599, https://doi.org/10.1002/2014JB011426, 2015.

C11: l.137: Add a reference for the probabilistic PSD, or explain it, it is not clear to me how « probabilities » are associated to PSD.

R11: We provided references for the PSD calculation, as follows:

“We used the probabilistic power spectral density (PSD) technique (McNamara and Buland, 2004) to characterize the background seismic noise.”

References:

McNamara, D. E., Buland, R. P. 2004. Ambient Noise Levels in the Continental United States. Bull. Seismol. Soc. Am. 94, 1517–1527. https://doi.org/10.1785/012003001.

C12: l.138: « low background noise », you should be more specific and quantitative. What is the criterion of a low background noise ? Besides, you only show the PSD of one station, so we have to take your word that other stations also have a low background noise.

R12: We used the probabilistic power spectral density (PSD) technique (McNamara and Buland, 2004) to characterize the background seismic noise level in the study area, which can be represented using one station record. The record quality for each seismic trace was evaluated by the signal-to-noise ratio.

The main seismic energy is distributed between the new high noise model (NHNM) and the new low noise model (NLNM) (Peterson, 1993), indicating that the study area has a relatively good seismic observation environment.

C13: l.167: 0.006 – 0.2 Hz. This frequency bandwith contains only low frequencies, while you mentioned high frequencies in the abstract. Or maybe I'm missing something (what is your definition of low and high frequencies ?).

R13: The frequency band of 0.006 – 0.2 Hz is used in the landslide force history inversion. To avoid misunderstanding, we deleted high frequencies in the abstract, adjust the structure of the text and moved the descriptions to the Results section.

C14: l.174 – 175: Are your particles spheres ? Can there be overlap between particles?

R14: Thank you for your constructive comments. These particles are spherical and can overlap with a small intersection when they are in contact with each other, as used in traditional discrete element method (Cundall and Strack, 1979).

Reference:

Cundall, P. A., and Strack, O. D. L. 1979, A distinct element model for granular assemblies, Géotechnique, 29, 47-65.

C15: l.180 and onwards: It would be helpful to state explicitly the parameters that need to be set in the model. In this perspective, Table 1 could be added directly in this section. Besides, some parameters in this table are not explained in the main body of the text, such that their role is not clear. For instance, what is the difference between the internal friction coefficient, and the intergranular friction coefficient?

R15: Thank you for the useful comment. The internal friction coefficient is the macroscopic parameter of rock and soil, and the intergranular friction coefficient refers to the friction coefficient between the particles of the model sphere and the sphere. We modified Table 1 to add data sources, as follows:

Table 1. Macro- and micromechanical parameters of Baige landslide material used in the discrete element model.

Parameter	Value	Reference
Young modulus E	20 GPa	Laboratory test (Zhou et al. 2019)
Poisson's ratio υ	0.2	Laboratory test (Zhou et al. 2019)
Uniaxial compressive strength C_u	30 MPa	Laboratory test & Calibrated
Uniaxial tensile strength T_u	3 MPa	Laboratory test & Calibrated

Internal friction coefficient μ_i	0.46	Laboratory test & Calibrated
Density ρ	2400 kg/m^3	Zhang et al. (2019)
Normal stiffness k_n	486 GN/m	Calculated (Liu et al., 2013)
Shear stiffness k_s	270 GN/m	Calculated (Liu et al., 2013)
Breaking displacement x_b	1.3 mm	Calculated (Liu et al., 2013)
Initial shear resistance F_{s0}	3.28 GN	Calculated (Liu et al., 2013)
Intergranular friction coefficient μ_p	0.0897	Calculated & Calibrated
Average damping coefficient C_{damp}	1.06×10^5	Calibrated

Parameter	Value	Reference
Young modulus E	20 GPa	Laboratory test (Zhou et al. 2019)
Poisson's ratio υ	0.2	Laboratory test (Zhou et al. 2019)
Uniaxial compressive strength C_u	30 MPa	Laboratory test & Calibrated
Uniaxial tensile strength T_u	3 MPa	Laboratory test & Calibrated
Internal friction coefficient μ_i	0.46	Laboratory test & Calibrated
Density ρ	2400 kg/m^3	Zhang et al. (2019)
Normal stiffness k_n	486 GN/m	Calculated (Liu et al., 2013)
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Breaking displacement x_b	1.3 mm	Calculated (Liu et al., 2013)
Initial shear resistance F_{s0}	3.28 GN	Calculated (Liu et al., 2013)
Intergranular friction coefficient μ_p	0.0897	Calculated & Calibrated
Average damping coefficient C_{damp}	1.06×10^5	Calibrated

C16: l.208-209: By « cell size », do you mean particle size ? What do you mean by « real-world » time?

R16: Thank you for your constructive comments. It means particle size. « real-world » time refers to the duration of the actual landslide event."

C17: l.210-239: This paragraph is difficult to follow because you go forth and back between the different steps of the parameters calibration. However, the flow-chart of Fig. 5 is clear. Thus, I recommend you write again this part. If I understand well, there are three steps : 1) choice of some parameters without calibration (explain how they are chosen), 2) Calibration of some parameters by reproducing the extent of the deposits, 3) Calibration of the last 2 parameters by reproducing the inverted force. Just explain these three steps, in three successive paragraphs. Besides, you should give more details on the calibration method : is it simply trials and errors ? What is the range of initially tested parameters ? In the following points I have some more specific questions.

R17: We thank the reviewer for this helpful comment. As instructed, we have now modified these paragraphs as follows:

"We used the dynamic inverted from seismic signals and deposition characteristics as references for the DEM simulation. Initial macro parameter values, such as Young modulus, Poisson's ratio, were based on results of laboratory tests on Baige landslide materials from Zhou et al. (2019), using the macro and micro conversion formula proposed by Liu et al. (2013) (see Appendix 1 for details), the micro parameters, such as Normal stiffness, Shear stiffness, Breaking displacement, Initial shear resistance, of DEM input can be obtained. As elastic modulus and mechanical properties in laboratory tests are usually higher than those in large-scale rock masses in the field (Darlington et al., 2011; Hencher et al., 2014; Hoek, 2000), Liu et al. (2019) used MatDEM to simulate Xinmo landslide, set Young's modulus and strength to about 40% of the test value, and obtained appropriate simulation results. Therefore, we used 40% of the test value in our simulation.

The second step is to use the geometry of the deposits as a reference to adjusted to obtain reasonable simulation result. For the discrete element method, the geometry of the deposits is affected by the bond strength between particles and the friction coefficient (An et al., 2020), which correspond to the fracture displacement, initial shear force, and friction coefficient between particles in MatDEM. Other parameters, such as normal stiffness and tangential stiffness, remain constant during the simulation. Accuracy of the final landslide accumulation was evaluated by the critical success index (CSI) proposed by Mergili et al. (2017), calculated as:

$$CSI = \frac{TP}{TP + FP + FN} \qquad (13)$$

where, TP (true positive) is intersection area from both simulation and filed observation, FN (false negative) is the deposition area observed from field that simulation cannot covered, and FP (false positive) is the additional deposition area from simulation where no deposition is observed from site. CSI ranges between 0 and 1, and the higher the value, the more accurate the simulation; when CSI is 1, the simulated accumulation range coincides with the observed. An et al. (2021) conducted 25 simulations by changing the parameters such as static friction coefficient, thermal weakening friction coefficient and normal bond strength. The results showed that only 8 cases had CSI > 0.6 and the highest CSI was 0.83. In addition, among the 15 groups of results simulated by Mergili et al. (2017), the maximum CSI is 0.59. Therefore, in this study, the criterion is chosen as CSI > 0.6, it can be considered that the simulated accumulation characteristics are basically consistent with the actual situation.

The third step is to use the landslide motion velocity and displacement characteristics inverted by the seismic signal as a reference to back-calibrate parameters that affect the kinematic characteristics of the landslide, such as friction and average damping coefficients. A flow chart of the method is shown in Fig. 5, and the final values of the parameters are shown in Table 1.

The accuracy of simulated and inversed landslide velocity and displacement was preliminarily evaluated by the relative errors of several key points δ. Then, the variance S^2 between the simulated value and the inversion value per second was calculated, and the difference between the two groups of data in the landslide process was analyzed in detail. Related error δ and variance S^2 were calculated as:

$$\delta_x = \frac{X_s - X_i}{X_i} \qquad (14)$$

$$S^2 = (X_s - X_i)^2 \qquad (15)$$

where, X_s is the simulated value and X_i the inversed value. X can be replaced by landslide duration T, peak velocity V_{max}, time when peak velocity achieved T_{vmax}, and peak displacement D_{max}.

C18: l.210-211: I don’t understand what you mean in this sentence. How do you determine deposition characteristics from seismic signal ? You should be more specific than just using the word « characteristic ». What do you mean by « reference for the discrete element landslide motion simulation » ?

R18: Thank you for the useful comment. The corrected statement is shown in below:

“We used the dynamic inversion from seismic signals and deposition characteristics as references for the DEM simulation”.

And “characteristic” refers to the elevation difference of DEM real terrain before and after landslide.

C19: l.212-213: « accumulation state », « the range of landslide accumulation » : do you mean the geometry of the deposits?

R19: We thank the reviewer for this helpful comment. It means the geometry of the deposits. We have modified the corresponding contents in the manuscript.

C20: l.212-215: You state that the fracture displacement, the initial shear force, and the friction coefficient between particles relate to the bond strength between particles and friction coefficient. Why do other parameters not relate to them (e.g., elastic modulus and stiffness)? I would add a small explanation in addition to the reference.

R20: We thank the reviewer for the constructive comment. It can be seen from the macro and micro conversion formula that the Young's modulus and Poisson's ratio have little effect on the results. We add the macro and micro conversion formula in the Appendix 1, as follows:

$$K_n = \frac{E}{\sqrt{3(1-2v)(1+v)}} \tag{A1}$$

$$K_s = \frac{E(1-4v)}{\sqrt{3(1-2v)(1+v)}} \tag{A2}$$

$$X_b = \frac{2K_n + K_s}{2\sqrt{3}K_n(K_n + K_s)}T_u d \tag{A3}$$

$$F_{s0} = (\frac{1}{4} - \frac{\sqrt{3}}{4}\mu_p)C_u d \tag{A4}$$

$$\mu_p = \frac{-3\sqrt{3} + \sqrt{3I}}{3 + 3I}, I = [(1+\mu_i)^{0.5} + \mu_i]^2 \tag{A5}$$

where Kn and Ks are the normal and shear stiffness of the particle, respectively; E is Young's modulus; v is Poisson's ratio; X_b is breaking displacement; T_u is uniaxial tensile strength; d is particle diameter; F_{s0} is initial shear resistance; μ_p is intergranular friction coefficient; C_u is uniaxial compressive strength; μ_i is internal friction coefficient.

C21: l.218-220: You should add a reference here, and explain why there is such a difference between laboratory and field scale parameters. You should also justify the 40% value, where does it come from?

R21: Thank you for the useful comment. It is generally accepted that there is a significant reduction in strength with increasing specimen size (Darlington et al., 2011). Hoek (2000) suggests this reduction in strength is due to the increased probability that failure of rock grains will occur as the specimen size increases. Therefore, elastic modulus in laboratory tests is usually higher than those in large-scale rock masses in the field (Hencher et al., 2014). As for the value of this quantity, it is related to the shape and volume of the selected sample, and the difference may reach several times to tens of times (Hencher et al., 2014). Regarding the numerical simulation results of the hazard, they are mainly related to the size of the spherical unit. No quantitative research results on the differences between the strength characteristic values and the results of indoor tests and field measurements at the numerical simulation scale have been reported. Liu et al. (2019) used MatDEM to simulate Xinmo landslide, set Young's modulus and strength to about 40% of the test value, and an excellent simulation result is got when using this threshold. In our study, the landslide scales, element radius are similar to this work, therefore, we take reference to Liu et al (2019), and used 40% of the test value in our simulation. We have supplied the reference in manuscript.

Reference:

Darlington, W.J., Ranjith, P.G., and Choi, S.K.: The Effect of Specimen Size on Strength and Other Properties in Laboratory Testing of Rock and Rock-Like Cementitious Brittle Materials, Rock Mech Rock Eng, 44, 513, https://doi.org/10.1007/s00603-011-0161-6, 2011.

Hencher, S. R., Richards, L. R.: Assessing the Shear Strength of Rock Discontinuities at Laboratory and Field Scales, Rock Mech Rock Eng, 48, 883-905, https://doi.org/10.1007/s00603-014-0633-6, 2014.

Hoek E (2000) Rock engineering course notes by Evert Hoek. http://www.rocscience.com/education/hoeks_corner.

Liu, C., Fan, X., Zhu, C., and Shi, B.: Discrete element modeling and simulation of 3-Dimensional large-scale landslide-Taking Xinmocun landslide as an example, J. Eng. Geol, 27, 1362-1370, https://doi.org/10.13544/j.cnki.jeg.2018-234, 2019. (In Chinese).

C22: l.220 – 221: It is not clear, at this point of the manuscript, how you estimate the velocity and displacement of the landslide, from the inverted force. It is mentioned in the Results section, but it should be explained in the Method section.

R22: The descriptions on how to estimate the velocity and displacement of the landslide from the inverted forces are moved to the Methodology section.

C23: l.233: How did you choose your « key points » ? How many are there ?

R23: We thank the reviewer for the constructive comment. Here we are not expressing it clearly. Here δ is a symbol, which can denote landslide duration T, peak velocity V_{max}, time when peak velocity achieved T_{vmax}, and also peak displacement D_{max}. Compared with the previous judgment of the accuracy of landslide simulation results using only the accumulation morphology, the complete process characteristics of landslide motion are better represented from the above four dimensions, thus ensuring the accuracy of both the results and the process. We have modified the original description as follows.

"The accuracy of simulated and inversed landslide velocity and displacement was preliminarily evaluated by the relative errors of several key points δ."

C24: l.236: shouldn't s2 be the sum of $(Xs-Xi)^2$?

R24: Thank you for your constructive comments. It is not the sum, the variance s^2 between the inversion value and the simulated value calculated and compared in each second, the results are show in Fig 12 as follows.

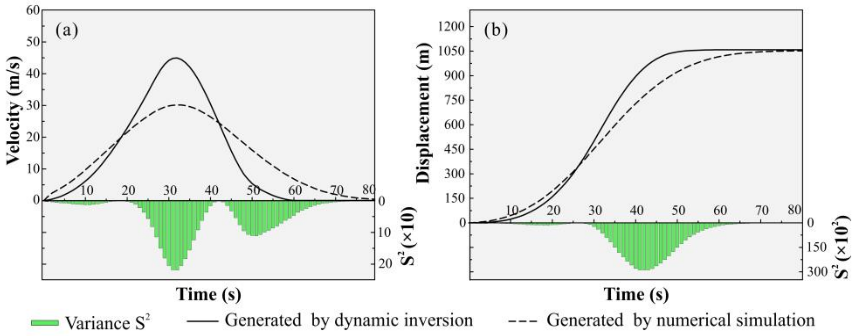


Fig. 12. Comparison of landslide characteristics simulated using discrete element model with inversion results. (a) Average velocity; (b) Average displacement.

C25: l.249-250: In the methodology you said you deconvolve the seismic signals to obtain displacements. But here you mention velocities. If displacements are used only for inverting the source force, this should be stated clearly. It would be very helpfull in Fig. 1 to display clearly the different stages of the landslide (initation, sliding, blockage and deposition).

R25: Seismic signals recorded at seismic stations are converted to displacement and then deconvolved to obtain landslide forces; and the inverted forces are used to estimate sliding velocity and displacement of the sliding mass.

C26: l.253: « The main driving force of the landslide is gravity » . Well, isn't it always the case ? What else could it be ? « the landslide surface » : do you mean the surface of the sliding mass, or the surface on which the mass slides ?

R26: We thank the reviewer for this comment. This sentence is inaccurate, and "the landslide surface" means "the surface on which the mass slides". We have modified this sentence as follows:

"The driving force of the landslide is gravity, and the surface on which the mass slides is inclined at about 35°."

C27: l.254-255: « … and the SNR of the V component (…) appears high ». I don't see the link with velocity changes in the longitudinal direction. Do you mean that the landslide movement has a significant dip (35°), which implies important vertical velocities in seismic records ?

R27: There is a text error here, it should be the acceleration curve, the relationship between SNR and acceleration change. It can be understood in this way that the environmental noise level is certain, and the acceleration is large, and the amplitude of the acceleration signal is larger, so that the difference between the amplitude of the acceleration signal and the amplitude of the noise is large, that is, a large SNR.

C28: l.252: « south-east-to-south », do you mean in the south-south-east direction, or from the south-east to the south (which is strange). To avoid confusion, you could give an azimuth. Besides, from Fig. 1 it seems the landslide went to the East until it reach the valley bottom. So I don't understand the direction « south-east-to-south » you give.

R28: We have modified this part, refer to the reply of comment 6.

C29: l.255-256: Throughout the manuscript, I think « deposition stage » could me accurate than « accumulation stage ». At least, it seems more natural and self-explanatory to me. And from Figure 1, I have the impression that the landslide propagates to the North and to the south-East once it has reached the valley bottom. So I don't understand the « easterly direction » you mention.

R29: Thank you for your advice. We have modified "accumulation stage" to "deposition stage"...Indeed, as the reviewers found, after the deposition stage of the landslide body began to accumulate in the river, it mainly slides along the river, so in the ⑥~⑦ stage, the seismic signal amplitude in the North direction is the largest, and the two are confused when writing. We have corrected the original text as follows:

During the deposition stage, the main horizontal movement direction of landslide body changed from east-west to north-south, and from north-south limited to east-west limited. The morphology of the landslide channel means that the landslide stage has a large east-west component and a small north-south component, and in the deposition stage, it reverses. This feature is consistent with the high SNR of the N component of the landslide signal and low SNR of the E component.

C30: l.265-271: This passage should be in the Methodology section. Besides, it should be more detailed : how do you relate the seismic signal to the landslide velocity and mass ? « Roughly determined » is too vague…

R30: Indeed, the part on signal propagation could go into the Methodology section. However, we believe that the defects in our direct analysis of landslides with signals can be better explained here, so that readers can better understand. We think that separating the two parts does not work very well.

The seismic signal is obtained by digitizing the physical signal of the sensor, and its amplitude is positively correlated with the seismic amplitude of the sensing chip in the sensor, and the seismic amplitude of the sensing chip in the sensor is related to the vibration acceleration of the observation point, and the vibration acceleration is determined by the landslide. As a result, the acceleration of landslide vibration is related to the size and sliding velocity of the landslide.

C31: l.272-276: This passage should at the beginning of the Results section, to introduce the seimic signals with their description. By « three phases of velocity », do you mean three phases of acceleration ? It is not clear to me : 1) how you determine the points of velocity changes as they do not always correspond to maxima or minima, and you did not pick some extrema, 2) why these « velocity changes » in seismic signals necessarily correspond to transitions from acceleration to deceleration phases for the landslide.

R31: Indeed, as the result of the analysis, it should be placed at the beginning of the Results section; but we would like to introduce it in the order of signal characteristics, analysis results, etc., which can help the reader to draw more clearly how we got the result, as well as the characteristics of the materials used, make the author more convincing.

There is an obvious misalignment of the translation syntax here, we are using the acceleration curve instead of the velocity curve, the acceleration corresponds to the force, and we use the moment when the force changes direction as the key point.

C32: l.278: I think the fact that the seismic signal is longer than the event itself results from seismic wave scattering, rather than from « superimposition of vertical and horizontal waves ».

R32: In fact, both have effects, scattering leads to longer time, and the superimposition of vertical and horizontal waves leads to longer time, too (Peterson, 1993; McNamara and Buland, 2004). Regarding this part, We have made modifications as follows:

"…what's more, the signal is mixed by longitudinal wave that stack with transverse wave, which makes the ending time picked by seismic signal much latter than the actual time. All these make the time of the landslide derived from the original seismic signal would be lagged and longer, compared to the real time. A more accurate landslide time can be determined by……"

McNamara, D. E., Buland, R. P. 2004. Ambient Noise Levels in the Continental United States. Bull. Seismol. Soc. Am. 94, 1517–1527. https://doi.org/10.1785/012003001.

Peterson, J. R. 1993. Observations and modeling of seismic background noise, U.S. Geological Survey Open-File Report 93-322. https://doi.org/10.3133/ofr93322.

C33: l.281: Be more specific, the inversion of what ?

R33: The modifications are as follows:

landslide force history inversion.

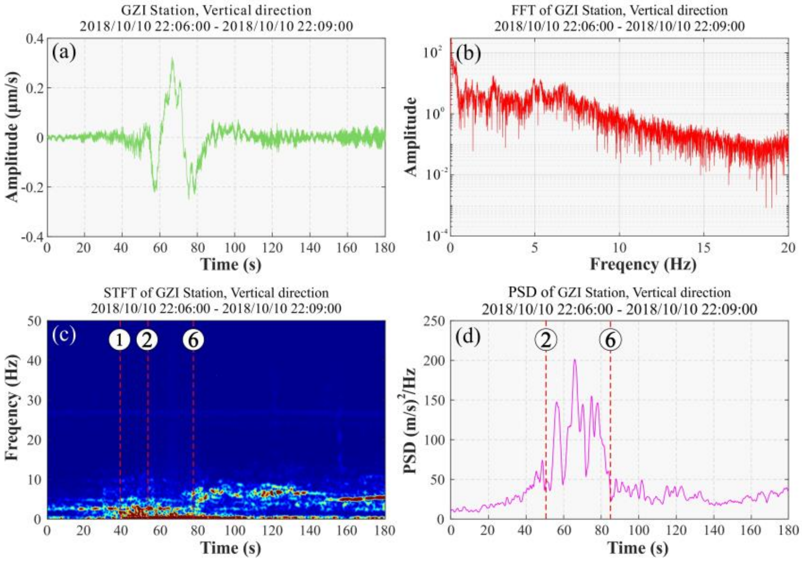
C34: l.282: « The analysis here », do you mean the analysis made before, or the analysis that will be done afterwards ?

R34: We are sorry that we did not make it clear, and we have modified it as follows:

“The analysis of the velocity curve recorded at seismic stations is to help understand the overall characteristics of the landslide and help verify the rationality of the subsequent Green's function stress inversion results.”

C35: l.287 – 305: This passage is somehow a repetition of what has been said before. You analyze the spectrum content to identify acceleration and deceleration phases, but if I’m not wrong you had similar results from direct observations of the seismic signals (though, as stated above, it is not clear how you draw these conclusions). Besides, the link between the two parts is not completely clear because the 7 times spotted in Fig 6 are not reported in Fig 7.Thus, I was a little lost, as the loigcal links between paragraphs is not clear.

R35: Fig.7 only annotates the key time points that are easily found from PSD curves and time spectrum. The notes in Fig.7 are rewritten and the key moments are explained. Rewrite as follows:



“Fig. 7. Seismic signals of the Baige landslide as recorded at seismic station GZI. (a) Vertical seismic signal; (b) Frequency spectrum; (c) Time-frequency spectrum and the key times picked frequency from it, that is, start time, 1st acceleration and 3rd deceleration, from left to right respectively; and (d) Power spectral density (PSD) curve and the key times picked from it, that is 1st acceleration and 3rd deceleration.”

C36: l.298: « in the longitudinal direction », what do you mean ? How do you relate a direction to a PSD curve?

R36: The reason for using the vertical PSD for the analysis is that, after the previous analysis, we believe that the vertical curve signal-to-noise ratio, amplitude and other factors are the best for the analysis of the landslide process.

C37: l.306-309: Do you have references to support this affirmation?

R37: According to the statistics in our previous research, when water is involved, that is, debris flow or high-density flow, the frequency of the seismic signal is relatively high, and its main frequency range can reach 3~50Hz, and more than 5Hz (Yan, et al, 2021; Yan, et al, 2017). "Clear difference" refers to the frequency of the seismic signal of the flood discharge event after the second landslide in Baige, and the difference between the curve mentality and the current landslide; because there are relatively many studies on the seismic signal of floods and debris flows, so this time the seismic signal for the second flood event was not added. In the revised manuscript, we have added a description of the second landslide seismic signal frequency information. We changed the paragraph of the original Line306-310 as follows:

According to Yan et al (2021), the frequency of landslide hazard seismic signals is usually low (0~5 Hz), and the morphology in the time-frequency domain and time domain presents single-peak or double-peak characteristics, while the frequency of flood or high-density flow seismic signals is usually high (5~50 Hz), and the morphology in the time-frequency domain and time domain mostly presents the characteristics of flat. Combined with this landslide seismic signal has relatively low frequency (0–1 Hz) and the single-peak feature in time and time-frequency characteristics, apparently different from the spectrum (main frequency :15~30 Hz) of the outburst flood signal triggered by the second landslide on October 12, 2018 (An et al, 2021). So, we think there was no flood discharge during the landslide process.

Reference:

Yan Yan, Yifei Cui, Dingzhu Liu, et al. Seismic Signal Characteristics and Interpretation of the 2020 “6.17” Danba Landslide Dam Failure Hazard Chain Process [J]. Landslides, 2021, 18(6): 2175-2192. https://doi.org/10.1007/s10346-021-01657-x.

Yan Yan, Peng Cui, Su-chin Chen, et al. Characteristics and interpretation of the seismic signal of a field-scale landslide dam failure experiment [J]. Journal of Mountain Science, 2017, 14(2): 219–236. https://doi.org/10.1007/s11629-016-4103-3.

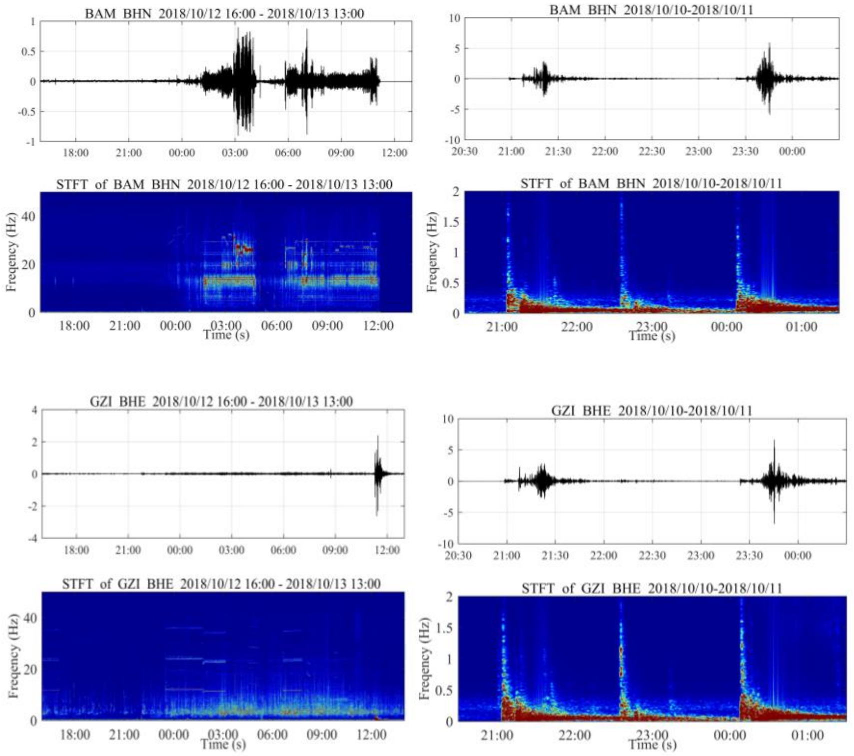
C38: l. 309 – 310: You should be more specific than just stating that there is a « clear difference », especially as there are no figure to support this statement.

R38: According to the statistics in our previous research, when water is involved, that is, debris flow or high-density flow, the frequency of the seismic signal is relatively high, and its main frequency range can reach 3~50Hz, and more than 5Hz (Yan, et al, 2021; Yan, et al, 2017). "Clear difference" refers to the frequency of the seismic signal of the flood discharge event after the second landslide in Baige, and the difference between the curve mentality and the current landslide; because there are relatively many studies on the seismic signal of floods and debris flows, so this time the seismic signal for the second flood event was not added. In the revised manuscript, we have added a description of the second landslide seismic signal frequency information. We changed the paragraph of the original Line306-310 as follows:

批注 [Y1]: Please provide reference of this paper

批注 [yY2R1]: 已修改

According to Yan et al (2021), the frequency of landslide hazard seismic signals is usually low (0~5 Hz), and the morphology in the time-frequency domain and time domain presents single-peak or double-peak characteristics, while the frequency of flood or high-density flow seismic signals is usually high (5~50 Hz), and the morphology in the time-frequency domain and time domain mostly presents the characteristics of flat. Combined with this landslide seismic signal has relatively low frequency (0~1 Hz) and the single-peak feature in time and time-frequency characteristics, apparently different from the spectrum (main frequency :15~30 Hz) of the outburst flood signal triggered by the second landslide on October 12, 2018 (An et al, 2021). So, we believed there was no flood discharge during the landslide process.



C39: l.315: You should give these empirical relations in the Methodology section.

R39: We have moved the descriptions related to the empirical relations to the discussion section.

C40: l.330-335: This should be in the methodology section, and the method must be clarified I think. It is not clear to me how you infer « sliding trajectories » from satellite data, and how you « minimize discrepancies » between these observations and inverted positions (and you did not mention satellite data in the Data section, this should be corrected). What is exactly that you invert ? The mass and the initial position (the displacement being then deduced from Newton's law)?

R40: Thank you very much for the suggestion. We moved this part to the Methodology section.

C41: l.336: You already have a masse estimation at l.316, this is confusing. I would only keep one in the Results section, and discuss it in the Discussion section by comparing it to other estimations.

R41: Thank you very much for the suggestion. We moved the descriptions related to the empirical relations to the discussion section.

C42: l.337-338: From this sentence I understand that the displacement is deduced from the result of the method explained l.330-335, but isn't displacement a direct result ?

R42: Thank you very much for pointing this out. What we did is that we first estimated the sliding mass by minimizing the predicted and actual displacements and then estimated acceleration and velocity distributions over time. This is explained in the revised Methodology section, as follows:

"Once the landslide force history $\boldsymbol{f}$ was inverted, based on Newton's third law of motion, the forces acting on the sliding mass could be obtained by multiplying the inverted force history by -1 (Kanamori and Given, 1982; Yamada et al., 2013; Gualtieri and Ekström, 2018). And then the forces acting on the sliding mass can be used to calculate its velocity and displacement distributions for a given mass (Li et al., 2019c; Yu et al., 2020), or to estimate the sliding mass by minimizing discrepancies with independently derived sliding trajectories (Hibert et al., 2014), using the following equations".

C43: l.344-352: You should add more references to the figures and subfigures to illustrate better your description of acceleration/ deceleration phases. They could be indicated more clearly in Fig. 8 (I guess it is the dashed vertical lines, but it is not said in the caption). Besides, the link with the acceleration/deceleration phases observed in the seismic signals is not clear.

R43: Thank you very much for pointing this out. We added captions in Fig. 8. We also added references in the descriptions to the figures and subfigures.

C44: l.352: « the relative high frictional force », what do you mean ? High in comparison to what ?

R44: We are truly sorry for the relative high frictional force description in the original text. The description is based on the analysis of the inversion results. However, we didn't have a comparative analysis and now we have deleted the description.

C45: l.354-356: Are these stages deduced from the simulation, from seismic data or from the inverted force ?

R45: These stages are deduced from the simulation, and the sentence has now been modified as: "According to the results of numerical simulation the movement process of the "10.10" Baige landslide can be divided into three stages".

C46: l.361: What do you mean by « variance results » ? Variance of what ? Is it the s2 mentionned in the Methodology section ? It should be more explicit.

R46: Yes, «variance results» means variance s^2 (we have unified it into S^2). The meaning of this sentence is to see from the change of variance, in the sliding stage, the variance result is small, and the difference between the simulated and the inversion results of average velocity and average displacement at this stage is small.

C47: l.362: « after which they match », well in Fig.12 I wouldn't say that the inverted and modeled velocities match after t=18s.

R47: This statement is incorrect and does not mean that the results of inversion and simulation after t=18 s are consistent. The sentence has been modified as follows: "Due to the small particle friction coefficient (0.0897), simulated average velocity and average displacement growth rate are both higher than that determined in the inversion until 18 s, but their variation trends are similar."

C48: l.401-402: You should reformulate. Reading the sentence we think you compare your volume estimations to the estimations of Chao et al. (2016) and Ekström and Stark (2013), while you actually compare your volume estimations to topographic surveys estimations. I would simply say that your volume estimation depends on the frequency bandwidth, it would me less misleading. Besides, write frequency bandwidths in Hz or s, but not both, it is otherwise difficult to compare them.

R48: Thank you very much for pointing this out. We modified this part to make it more readable. We indeed compared our mass estimations to the estimations of Chao et al. (2016) and Ekström and Stark (2013).

C49: l.411 – 412: Well, if with a different frequency bandwidth you have a better volume estimation and similar estimations of the trajectories, the advantage of using a higher frequency bandwidth is not clear. I understand that it allows to model sharper increases/decreases of the force, but isn't it more interesting to have a better estimation of volume?

R49: In fact, the estimation of the sliding mass/volume by comparing the observed displacement with that derived from force inversion does not depend much on high frequencies, because the high frequencies are suppressed when double integrating with respect to time. However, when empirical equations were used to estimate the volume/mass, the effect of frequency became strong (Hibert et al., 2014; Moore et al., 2017).

References:

Hibert C, Ekström G, Stark CP (2014) Dynamics of the Bingham Canyon Mine landslides from seismic signal analysis. Geophys Res Lett 41:4535–4541. https://doi.org/10.1002/2014GL060592

Moore JR, Pankow KL, Ford SR, et al (2017) Dynamics of the Bingham Canyon rock avalanches (Utah, USA) resolved from topographic, seismic, and infrasound data. J Geophys Res Earth Surf 122:615–640. https://doi.org/10.1002/2016JF004036

C50: l.419-423: I would have liked a more detailed discussion on the calibration method : choice of parameters calibrated for deposits and then dynamics, influence of calibrating dynamics before deposits, method of calibration (trial and error, gradient descent, …), sensitivity of results to parameters variations, … You also state that combining deposits and dynamics helps improve the simulation results, but we have to take your word. What would you have obtained if you had only ised deposits ? To what extent would the modeled dynamics be different ? Besides, there are no details on the ressources needed to run simulations. How long is one simulations ? How many needed to be run for the calibration step?

R50: The parameter calibration of DEM is one of the most critical aspects of motion simulation. There are many parameters that affect the calculation results of DEM, and usually the simulations are performed by trial-and-error method, by changing one of the parameters and fixing the others to observe their effects on the simulation results. This is the simplest but time-consuming method because the number of key parameters of different DEM contact models vary from a few to a dozen, and some of them are interacting with each other, which, together with the large scale of landslide simulation, leads to a single simulation usually taking a long time (7.8 hours for a single simulation project on a work station (Intel® Core™ i9-12900, GeForce RTX™ 3090), both in terms of the number of trials and errors and the trial-and-error period. Therefore, for the same case, novices usually spend days or even months to obtain satisfactory parameters, while experienced researchers can quickly adjust to the best parameters based on simulation results, which is a process full of experience and challenges.

Our innovation is to propose a set of simulation methods based on the parameters obtained from seismic signal inversion combined with numerical simulation parameters calibration. In this method, the initial input is the density of the landslide determined from the field sampling. Then the Young's modulus and Poisson's ratio, as well as the initial intra-geotechnical friction coefficient, uniaxial tensile and compressive strength parameters were inputted. Because the indoor experiments can only obtain the macroscopic mechanical properties of the soil, while the DEM simulation uses microscopic contact parameters, the macroscopic-peripheral parameter transformation equations proposed by Liu et al.,2019 are further used to obtain the corresponding microscopic normal and tangential contact stiffness, contact damage critical displacement, initial shear resistance, and contact friction coefficient, so that the first simulation is started. For the simulation results, the accuracy index CSI>0.6 was used as the threshold value for judgment, which is a summary of previous studies. When the Young's modulus and Poisson's ratio of the material are determined. Due to the scale effect between internal friction coefficient and strength index, when CSI<0.6, the parameters of μ_i, C_u, T_u is adjusted until the accuracy index exceeds the threshold value, when means the simulation results are consistent with the landslide accumulation pattern.

The deposits morphology only reflects the characteristics of the simulation results. To further characterize the motion process, the friction coefficient μ_p and the damping coefficient C_dump are selected for adjustment, which have been valid to have less effect on the deposit’s morphology of landslides. By adjusting these two parameters, we apply four key metrics in calculations (landslide duration T, peak velocity $V_{\max}$, peak velocity corresponding to time $T_{v\max}$, and peak displacement $D_{\max}$） to constrain the simulation results, and these parameters can be obtained by inversion of the ground vibration signal from a real record of landslide motion. Based on these methods, we constrained both the temporal and spatial characteristics of the simulation, and when these error values are acceptable, we consider the simulation results to be representative of the actual landslide process.

Using the above method, the calibration of variables from constant parameters, to variables affecting the spatial depositional morphology, and variables affecting the time series process is achieved. The initial values of the calibration are given by Liu et al, 2019, and which are adjusted according to the simulation results. Finally, the dynamic process is constrained based on the pileup morphology and seismic signals.

The accuracy of the landslide dynamic with time evolution process will not be determined using only the calibration of the accretion morphology, because different velocities, evolutionary processes may produce similar accretionary landforms, especially for mega-landslides like Baige, which occur next to deep-incised valleys.

It should be noted that the innovation of this study is the proposed calibration method that can obtain the appropriate DEM micro parameters faster and more accurately. In this method, the constraint by seismic signal has a significant effect and ensures the accuracy of the simulation process. However, in terms of the time required to simulate one case, there is no difference with the traditional method. In addition, several key issues, such as friction weaking, base entrainment, particle breakage, are not considered in the DEM, which resulted the difference between DEM simulation and seismic inversion. Nevertheless, it has a tremendous contribution to the traditional landslide dynamics with DEM simulation, because previous work has shown that the biggest challenge of DEM simulation is precisely the rapid selection of reasonable microscopic parameters.

C51: l.432-434: I don’t understand, if you do not model fluidization, shouldn’t you under-estimate the velocity, instead of over-estimating it ?

R51: As shown in Fig. 12, the velocity of numerical simulation under-estimates peak velocity. Here the expression is wrong, we have modified the sentence as follows：“Reduction in the friction coefficient means the landslide moves faster, however, this factor is not considered in the current inversion model, so it under-estimate the velocity”.

C52: l.436-497: It is not clear, in this section, what you deduce from your inversion and simulations, what you deduce from field observations and/or previous studies, and what you hypothesize. Clarifying these points would help highlight your contribution to the understanding of the Baige landslides dynamics, in comparison to previous studies. For instance, you go through a lot of details for the initiation stage, and I don't always understand how you can deduce them from your results.

R52: This study is carried out in the form of a combination of three methods: seismic signal analysis, dynamic inversion, and numerical simulation.

Simply by analysing seismic signals, we can only qualitatively get four stages of the landslide process: (a) Stage 1 – initiation; (b) Stage 2 – main slip; (c) Stage 3 – crawling up against the slope (blocking); (d) Stage 4 – falling back and accumulation (deposition).

Simply by dynamic inversion, we can only quantitatively obtain the force, velocity, displacement, and acceleration curves of the landslide process (Fig. 8) and the Reconstructed horizontal trajectory (Fig. 10).

Through calibrated numerical simulation results, we can reconstruct the landslide process, with comparison of dynamic inversion and final deposition with detailed discussion on the difference and possible reasons behind this.

Therefore, we reconstructed the landslide process through the combination of three methods: seismic signal analysis, dynamic inversion, and numerical simulation (Fig. 14).

C53: l.504-533: In these paragraphs you only state relatively broad statements, without references : in this perspective, it helps understanding the contribution of your work, but it would be more helpful in the introduction. In the discussion, I would expect that you compare more specifically your work to previous studies on the Baige landslides, so that the reader can see if your description is in agreement with what has already been done, if your work sheds lights on some points that previous studies had overlooked, or if you disagree with previous interpretations. Besides, you could also discuss other landslides where you think your methodology could help better constrain their dynamics.

Another point that could be discussed is the difference between your work and previous works using seismic data to calibrate numerical models (Yamada et al. 2016; 2018; Moretti et al. 2015; 2012; 2020). If I'm correct, they compared the force inverted from seismic signal, to the force provided by simulations, whereas to you compare trajectories. Do you expect the results to be different?

R53: We appreciated the reviewer for this comment. Our study is different from that of An et al., (2021); Moretti et al., (2015); Yamada et al., (2018). Their study mainly focuses on the force-time curves derived from the seismic signal to constrain and optimize the numerical simulation, so that the simulation results is closer to the actual situation. In contrast, our study combines three methods: ground seismic signal analysis, kinetic inversion, and numerical simulation, which help us better reconstruct the landslide dynamic process, that is, our results combine the advantages of the three methods, so that we can obtain more profound and richer information about the disaster dynamic process than previous study.

In our study of the Baige landslide, we gave the detailed description of the dynamic process of landslide evolution, as shown in Figure 14, where we divided the landslide into four stages: (a) Stage 1: initiation; (b) Stage 2: main slip; (c) Stage 3: crawling up against the slope (blocking); (d) Stage 4: falling back and accumulation (deposition). In previous studies, this dynamic process cannot be clarified by simple signal analysis, ground seismic signal inversion, or numerical simulations.

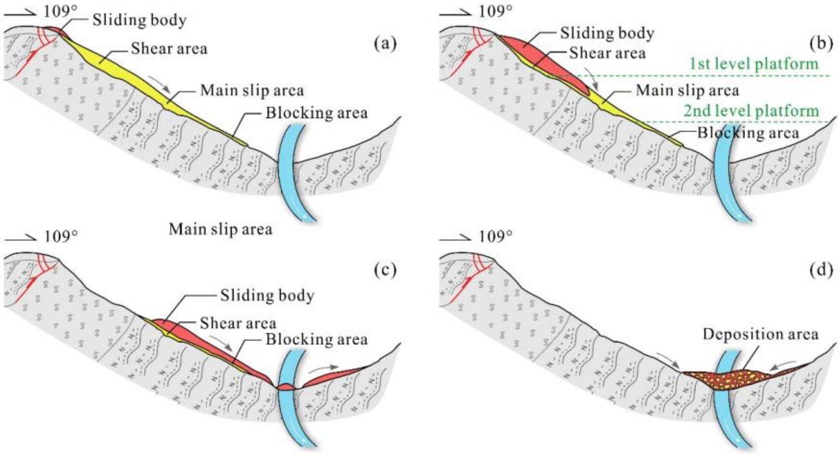


Fig. 14. Schematic diagram of the Baige landslide model. (a) Stage 1 –initiation; (b) Stage 2 – main slip; (c) Stage 3 – crawling up against the slope (blocking); (d) Stage 4 – falling back and accumulation (deposition).

As for An et al. (2021), the results of numerical simulations are constrained to be optimized by force-time curves derived from the inversion of ground seismic signals. In our study, the simulation results are constrained and optimized by 1) the velocity-time curve and displacement-time curve of ground seismic signal; and 2). the CSI index of landslide accumulation pattern.

We have now added a comparison with relevant studies in the discussion, as follows:

“Compared with the study of An et al. (2021), which mainly focuses on force time history inversion, we further added the velocity and displacement characteristics retrieved from seismic signals to conduct dynamic quantitative constraints on dynamic parameters and improve the credibility of numerical simulation, so as to carry out efficient simulation of landslide process. The improved simulation allows in-depth analysis of frequency motion characteristics of the landslide, such as speed change, characteristics of each stage, etc. These characteristics can also be used to verify and optimize the landslide process to improve analysis results.”

Reference:

An, Huicong, Chaojun Ouyang, et Shu Zhou. 2021. « Dynamic Process Analysis of the Baige Landslide by the Combination of DEM and Long-Period Seismic Waves ». Landslides 18 (5): 1625-39. https://doi.org/10.1007/s10346-020-01595-0.

Moretti, L., K. Allstadt, A. Mangeney, Y. Capdeville, E. Stutzmann, et F. Bouchut. 2015. « Numerical Modeling of the Mount Meager Landslide Constrained by Its Force History Derived from Seismic Data ». Journal of Geophysical Research: Solid Earth 120 (4): 2579-99. https://doi.org/10.1002/2014JB011426.

Moretti, L., A. Mangeney, Y. Capdeville, E. Stutzmann, C. Huggel, D. Schneider, et F. Bouchut. 2012. « Numerical Modeling of the Mount Steller Landslide Flow History and of the Generated Long Period Seismic Waves ». Geophysical Research Letters 39 (16): n/a-n/a. https://doi.org/10.1029/2012GL052511.

Moretti, L, A Mangeney, F Walter, Y Capdeville, T Bodin, E Stutzmann, et A Le Friant. 2020. « Constraining Landslide Characteristics with Bayesian Inversion of Field and Seismic Data ». Geophysical Journal International 221 (2): 1341-48. https://doi.org/10.1093/gji/ggaa056.

Yamada, Masumi, Anne Mangeney, Yuki Matsushi, et Takanori Matsuzawa. 2018. « Estimation of Dynamic Friction and Movement History of Large Landslides ». Landslides 15 (10): 1963-74. https://doi.org/10.1007/s10346-018-1002-4.

Yamada, Masumi, Anne Mangeney, Yuki Matsushi, et Laurent Moretti. 2016. « Estimation of dynamic friction of the Akatani landslide from seismic waveform inversion and numerical simulation ». Geophysical Journal International 206 (3): 1479-86. https://doi.org/10.1093/gji/ggw216.

C54: l.507-508: Quantify what you mean by low-frequency and high-frequency.

R54: We generally think that low-frequency corresponds to the frequency range of <1Hz, and high-frequency corresponds to the range greater than 1Hz.

C55: l.520-521: I think it is not clear enough, in the manuscript, how the analysis of the high frequency content (i.e. above XX Hz ?) of seismic signals improves your understanding of the landslide dynamics. In the Results section you give successive descriptions of the landslide dynamics, from raw seismic signals, from the inverted force, and from the simulation. However the comparison between these different descriptions is not very clear.

R55: The frequency range is delineated in detail, and the rewritten paragraph reads as follows:

The low-frequency (0~0.2 Hz) component of dynamic parameters, as provided by dynamic inversion, can guide the all band frequency motion, concentrating the high frequency (>0.2 Hz) movement, analysis of the landslide process, which helps to reduce ambiguity.

C56: l.524: « there are often multiple solutions ». You did not illustrate it in your work. You show the result of your calibration process, but you do not quantify its benefits in comparison to simpler methods (e.g. using only depoits).

R56: For the simulation results, we adopted the accuracy index CSI>0.6 as the judgment threshold, and further adjust the simulation parameters according to the dynamic characteristics. But simple calibration methods could not ensure that CSI>0.6 (An et al. 2021; Mergili et al. 2017).

The deposits morphology only reflects the characteristics of the simulation results. The accuracy of the landslide dynamic with time evolution process will not be determined using only the calibration of the accretion morphology, because different velocities, evolutionary processes may produce similar accretionary landforms, especially for mega-landslides like Baige, which occur next to deep-incised valleys.

Using the method of this study, the calibration of variables from constant parameters, to variables affecting the spatial depositional morphology, and variables affecting the time series process is achieved. we apply four key metrics in calculations (landslide duration T, peak velocity V_{max} , peak velocity corresponding to time T_{Vmax} , and peak displacement D_{max})to constrain the simulation results, and these parameters can be obtained by inversion of the ground vibration signal from a real record of landslide motion. Based on these methods, we constrained both the temporal and spatial characteristics of the simulation, and when these error values are acceptable, we consider the simulation results to be representative of the actual landslide process.

We have also added to the manuscript as follows:

“When static parameters such as pre- and post-landslide topography are used to select parameters and constrain results of numerical simulation, there are often multiple solutions. The accuracy of the landslide dynamic with time evolution process will not be determined using only the calibration of the accretion morphology, because different velocities, evolutionary processes may produce similar accretionary landforms (An et al. 2021; Mergili et al. 2017), especially for mega-landslides like Baige, which occur next to deep-incised valleys.”

Reference:

An, H. C, Ouyang, C. J, Zhou, S.: Dynamic process analysis of the Baige landslide by the combination of DEM and long-period seismic waves., Landslides, 18, 1625-1639, https://doi.org/10.1007/s10346-020-01595-0, 2021.

Mergili, M., Emmer, A., Juřicová A., Cochachin, A., Fischer, J. T., Huggel, C., and Pudasaini, S. P.: How well can we simulate complex hydro-geomorphic process chains? The 2012 multi-lake outburst flood in the Santa Cruz Valley (Cordillera Blanca, Perú)., Earth Surf Process Landf, 43, 1373-1389., https://doi.org/10.1002/esp.4318, 2017.

C57: l.44: It is not clear what « each method » refers to.

R57: “each method” refers to the three methods of “Seismic data analysis”, “Seismic signal inversion” and “numerical simulation” used in this study.

C58: l.120 : Use scientific notation for the volume (1.96 x 107 instead of 1960 x 104)

R58: Thank you for the useful comment. As instructed, we have modified 1960 x 10^4 to 1.96 x 10^7 as follows:

“Based on Digital Elevation Model (DEM)differencing, total landslide volume was calculated as c. 1.96×10^7 m^3.”

C59: l.122: If you give the altitude of the deposition zone, you should also give the altitude of the initiation zone.

R59: We thank the reviewer for this helpful comment. “The altitude range of the initiation zone is 3523-3730 m.”.

C60: l.147-149: Isn’t this sentence a repetition of the first sentence of the paragraph ?

R60: We didn't express it accurately enough. We have modified this paragraph as follows:

“We used short-time Fourier transform (STFT) and PSD to quantitatively analyze the seismic signals for Baige landslide (Yan et al., 2020a, 2020b). A time-frequency domain transform of the seismic signal using STFT allowed information on both the time and frequency domain distributions of the seismic signal to be obtained. The power of each unit of frequency for each frequency band component that corresponds to a specific moment was estimated based on the PSD of the seismic signal in the frequency domain.”

C61: l.166-169: This paragraph on signal processing should be at the beginning of the section, before you explain force inversion.

R61: Thank you for your advice. We have moved this paragraph on signal processing to Section 4.2 Dynamic inversion of Landslide, please refer to C28 of Reviewer 1.

C62: l.182: where does the « 9+ » come from ? Is it a typo ?

R62: “ 9+” This should be a clerical error. We have modified to “K_s is the tangential stiffness; and X_s is the tangential displacement”.

C63: l.370: Shouldn’t it be s^2 instead of R^2 ?

R63: Both R^2 and s^2 refer to variance in this manuscript, we have unified it into S^2.

C64: l.378: « the velocity variance » -> The variance of velocity residuals

R64: Thank you for the useful comment. As instructed, the sentence has now been modified as follows: “The variance of velocity residuals has a secondary peak around 50 s, while the displacement variance decreases gradually.”

C65: l.421-422: I don’t think these notations are explained in the main body of the article.

R65: We have explained these notations in Figure 5. To facilitate understanding, these notations have been explained in the main body of the manuscript as follows:

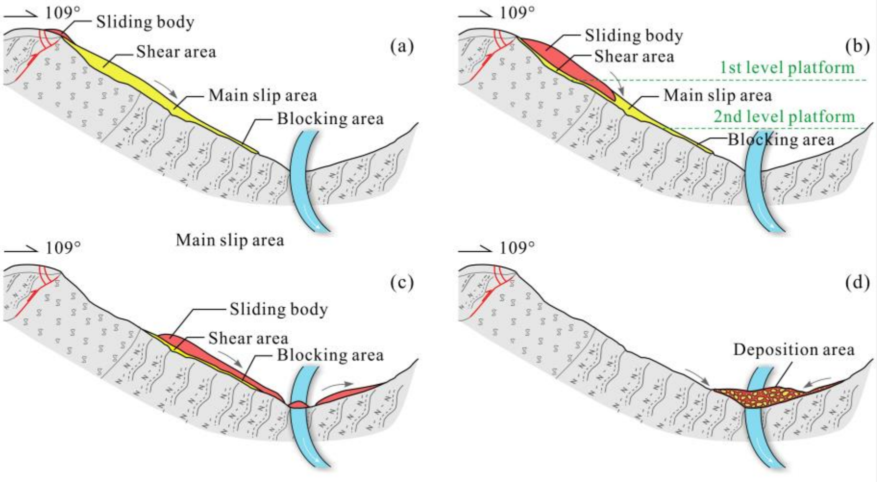
(δT_{vmax}: error of time corresponds to peek velocity from simulated and inversed; δD_{max}: error of peek displacement from simulated and inversed; δT: error of time of landslide from simulated and inversed; δV_{max}: error of peek velocity from simulated and inversed)

C66: l.424: « different landslide », there is a mistake I think, maybe « different landslide phases » ?

R66: This sentence is inaccurate and has been revised to “Differences in the kinetic characteristics of different landslide phases between the numerical simulation and inversion are highlighted using analysis of variance”.

C67: l.450: You should indicate the « first-level » and « second level » platforms on previous figures.

R67: We thank the reviewer for the constructive comment. As instructed, we have modified Fig. 14 as follows:



C68: Fig 1: Give the source of the DEM. (a) and (b), the date could be made more visible (e.g. in black with a wjite background). (c) Give the meaning of SA1, …, SA5. The small insets for I, II, III and IV are too small and without context and scale, they are hard to interpret. I would remove them or create another figure to improve readability. (d) Add the orientation. Are the distances to scale ? Finally, the acronyms DEM and AUV are not explained in the main body of the text.

R68: We thank the reviewer for the constructive comment. We have modified Fig. 1 as follows:

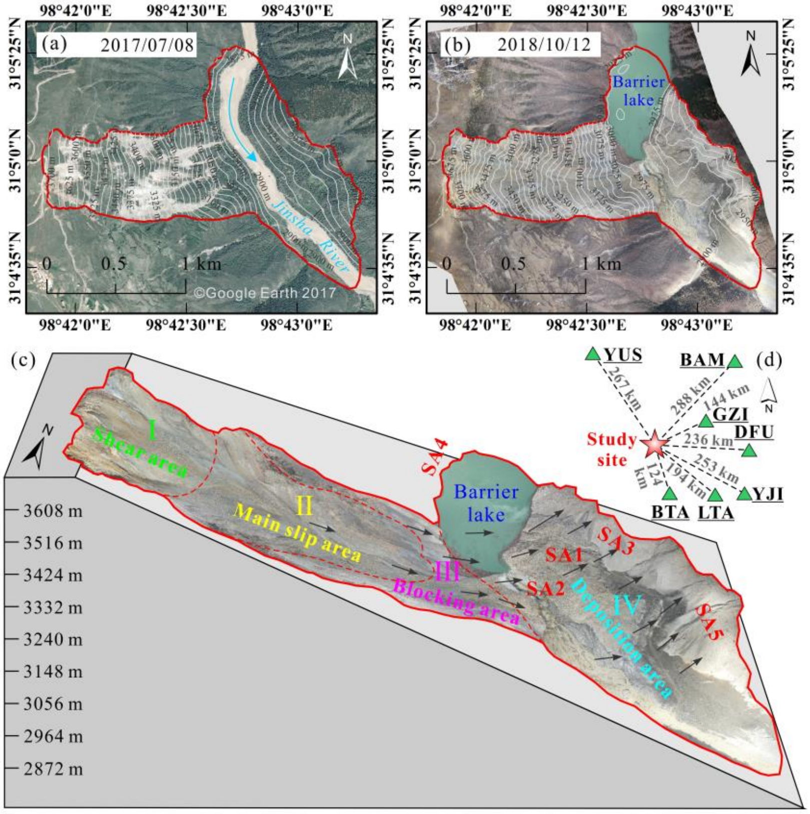


Fig. 1. Location of the study area. **(a)** DOM of Baige landslide 2017; **(b)** DOM of Baige landslide after the 2018 event; **(c)** Schematic cross-section with remote sensing overlay showing key features of the Baige landslide (SA1 and SA2 is a secondary slip zone formed by small fragments at the top of the dam body lose stability; SA3 is the left bank of the river, scoured by landslide debris; SA4 is a small area of the right bank, scoured by landslide debris; SA5 is the downstream left bank, which is affected by the landslide body mix with the sandblasting water); **(d)** Location of the Baige landslide (red star) relative to seismic stations (green triangles) used in the study. The remote sensing image map data of Fig 1.a. is from the © Google Earth 2017, and the data of Fig 1.b. and Fig 1.c. are from the authors' own Unmanned Aerial Vehicle (UAV) photography measurements.

C69: Fig 2: (a) I would mention, at least in the caption, the main geological periods corresponding to each symbol. Or you could simplify the figure by regrouping some geological units by periods.

R69: Thank you for your suggestion, but the geological age and stratigraphic name are too long. The uppercase letter in the legend is the abbreviation of the geological age symbol, which is briefly explained in the caption as follows:

Fig. 2. Geology of the study area. **(a)** Geological map of the Baige landslide area (Q_{3-4}^{al-pl}: Quaternary Holocene Upper Pleistocene; T_3a, T_3b, T_3j, T_3w, T_3jn, T_3l, T_3x^2, T_3x^1: Upper Triassic; C_2sh: Upper Carboniferous; P_txn^b, P_txn^a: Proterozoic; $n\gamma_5^{2b}$, δo_5^{2a}: Yanshan period; $n\gamma_5^1$, $\pi n\gamma_5^1$, $\gamma\delta_5^{2a}$, $\gamma\delta_5^1$, δ_5^1: Indosinian; $v\beta_4$, $\varphi\omega_4$, σ_4: Variscan; ws: Detached block; $\beta\mu$: Diabase-porphyrite; δo: Quartz diorite veins; γ: Granite veins; $\gamma\delta$: Granodiorite dikes; δ: Diorite veins.);

C70: Fig 3: Explain what white lines are. You could also try improve the grid lines (I’d try a lighter colour, with thinner lines) What is the subgraph, below the PSD graph, with the blue and green lines ?

R70: The white lines are new high noise model (NHNM) and new low noise model (NLNM) from Peterson (1993). The subgraph below the PSD is explained.

Thank you very much for the suggestion. We improved the fig in the revised manuscript.

C71: Fig 5: The subscript for \delta in the last diamond is very small and hard to read. The legend for the different kinds of \delta values in the grey box is also too small.

R71: Thank you for your constructive comments. We have explained the contents of the legend in the manuscript, so the repeated interpretation in the figure is deleted. The font under the graph has been enlarged. Figure 5 is modified as follows:

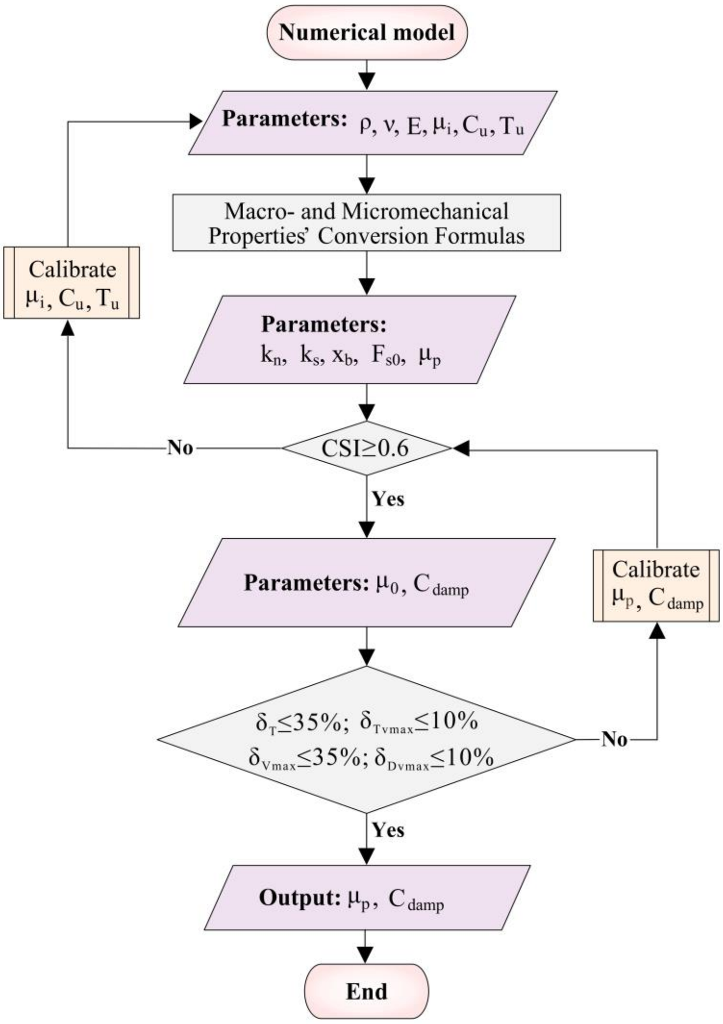


Fig. 5. Flowchart of the method of discrete element parameter adjustment based on seismic signal inversion.

C72: Fig 6: Explain what the different numbers refer to. Change the x-axis not to repeat x-tick labels. The caption says the figure shows signal-to-noise ratio, but only velocity is given by the y-axis, if I'm not wrong.

R72: "shows signal-to-noise ratio", originally intended to express the signal-to-noise ratio qualitatively judged by only relying on the curve characteristics, but we could not express it accurately during translation, so we changed the legend to as follows: Time-domain acceleration signal (E \N\V direction) of the seismic generated by the Baige landslide at GZI seismic station, showing a relative high signal-to-noise ratio visually but different respectively.

C73: Fig 7: The spectral content is not coherent with you pre-processing step, where you filter signal between 0.006 and 0.2 Hz. What are the red dashed vertical lines ? (b) The FFT is weird looking, as if you had a continuous content in your signal. Did you detrend it ? Otherwise, consider using a log or semi-log scale. (c) The bandwidth considered here (y-axis) should be the same as in (b), for consistency. (d) What is the bandwidth used for the PSD ?

R73: Filtering 0.006~0.2 Hz is for dynamic parameter inversion, not for signal analysis. We use the full-frequency signal for analysis here. The red dashed vertical lines represent the time spectrum and PSD curve of the main stage of the landslide. We have de-instrumented the seismic signal.

C74: Fig 8: what are the dashed vertical lines ? You should explicit what you mean by « absolute value ». Is it the norm of the acceleration et velocity vectors ? For the displacement, is it the cumulated displacement (i.e. the curvilinear abscissa of the center of mass of the landslide) ?

R74: Thank you very much for pointing this out.

The dashed vertical black lines marked the landslide start and end times (the first and third ones) and the time that the sliding mass reached the maximum speed (the middle one). The explanation was added to the figure caption of Fig. 8 in the revised manuscript.

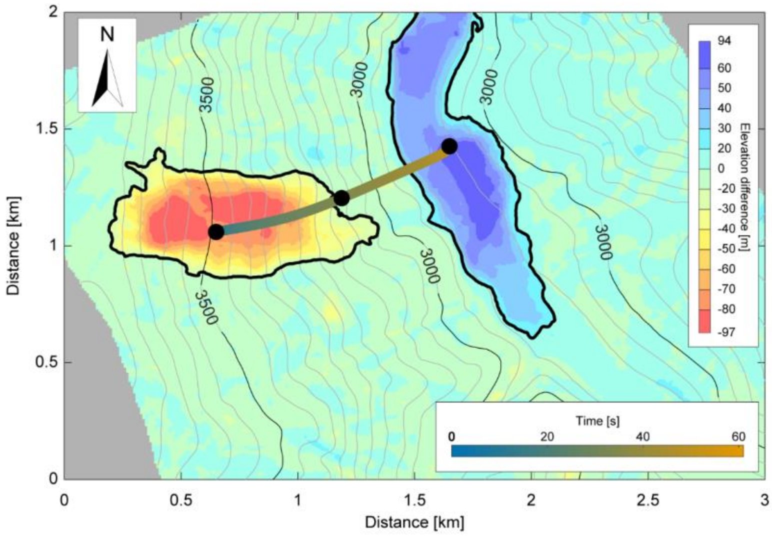
Yes, the absolute values are the norm of the acceleration et velocity vectors. The displacement is not the cumulated displacement; it is the distance relative to the origin.

C75: Fig 9: Maybe I missed it, but do you explain in the text why some seismic traces are not used ? If not, this should be included. In any case, a brief explanation would be welcome in the caption.

R75: Thank you for pointing this out. The original text explained why they were not used, which may have been deleted by mistake. The reason is simple. We calculated SNR of the processed seismic traces and chose the seismic traces with a SNR larger than 10 dB in the inversion. Seismic traces with a lower SNR were not used.

C76: Fig 10: I recommend using a colorblind friendly colormap for the time. The northern extent of the deposits is outside of the figure limit.

R76: Thank you very much for the suggestion. Fig 10 has now been modified as follows:



C77: Fig 11: Same remark, use a colorblind friendly colormap. It is not the same orientation as in previous maps. Where is the North ? You should also add a scale.

R77: The direction in Fig. 11 is different from that in the previous map, because the clockwise rotation is 90°, which is easy to read. The north pointer is in the upper left corner of Fig. 11 (a), and the scale is also identified in the lower right corner of Fig. 11a.

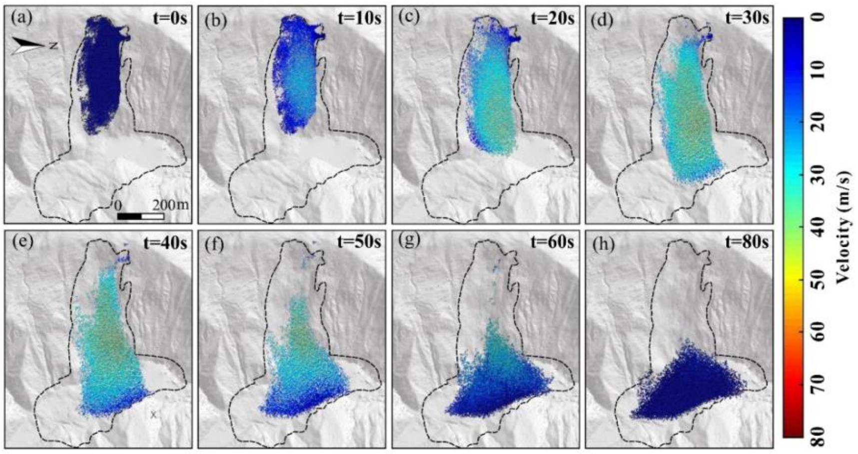


Fig. 11. Simulated landslide velocity distribution calculated in MatDEM. **(a)** t =0 s; **(b)** t =10 s; **(c)** t =20 s; **(d)** t =30 s; **(e)** t =40 s; **(f)** t =50 s; **(g)** t =60 s; **(h)** t =80 s. The digital terrain model (DTM) data of Fig 11. are from the authors' own UAV photography measurements.

C78: Fig 12: Use thicker lines and different line styles, to have a colorblind friendly figure. I think R^2 should be s^2, to be consistent with your notations in the main body of the text.

R78: Thank you for the useful comment. As instructed, Fig 12 has now been modified as follows:

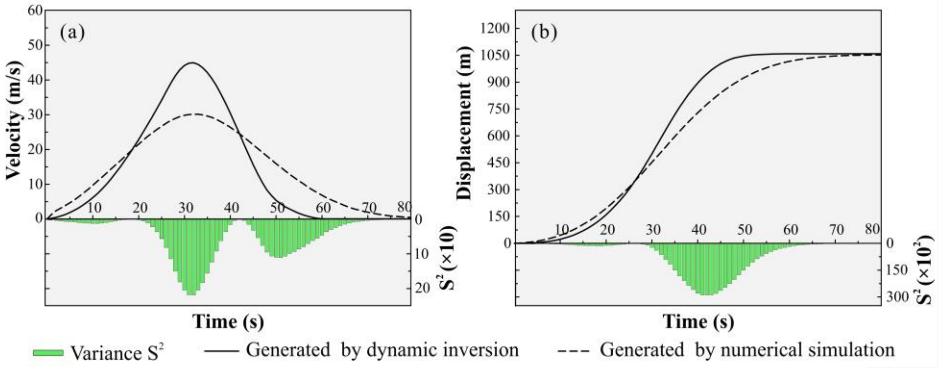


Fig. 12. Comparison of landslide characteristics simulated using discrete element model with inversion results. **(a)** Average velocity; **(b)** Average displacement.

C79: Fig 13: The northern extent of the deposits, in the river, displays a positive difference (more than 60 m). Shouldn't it be 0 at the edges of the deposits ?

R79: The difference between Fig. 13a and Fig. 13b is that this part is the barrier lake. In practice, the landslide formed a barrier lake after blocking the river. The figure 13a obtained by DEM difference can show this feature, but the influence of liquid phase is not considered in the numerical simulation, so the results obtained in the figure are different from the measured DEM.

C80: Table 1: You could add a column where you specify which parameters are deduced from laboratory measurements, and which parameters are calibrated.

R80: Thank you for the useful comment. As instructed, Table 1 has now been modified as follows:

Table 1. Macro- and micromechanical parameters of Baige landslide material used in the discrete element model.

Parameter	Value	Reference
Young modulus E	20 GPa	Laboratory test (Zhou et al. 2019)
Poisson's ratio υ	0.2	Laboratory test (Zhou et al. 2019)
Uniaxial compressive strength C_u	30 MPa	Laboratory test & Calibrated
Uniaxial tensile strength T_u	3 MPa	Laboratory test & Calibrated
Internal friction coefficient μ_i	0.46	Laboratory test & Calibrated
Density ρ	2400 kg/m^3	Zhang et al. (2019)
Normal stiffness k_n	486 GN/m	Calculated (Liu et al., 2013)
Shear stiffness k_s	270 GN/m	Calculated (Liu et al., 2013)
Breaking displacement x_b	1.3 mm	Calculated (Liu et al., 2013)
Initial shear resistance F_{s0}	3.28 GN	Calculated (Liu et al., 2013)
Intergranular friction coefficient μ_p	0.0897	Calculated & Calibrated
Average damping coefficient C_{damp}	1.06×10^5	Calibrated

C81: Table 2: It would be better to indicate the different phases between the given times, rather than above them (we do not know if the given times indicate the beginning or the end of the phase written above).

R81: We have changed the caption of the table to "Table 2. The beginning characteristic stage of the Baige landslide river blocking event picked by seismic signal recorded at GZI station".