Numerical investigation of large-slope planar failure considering entrainment effects: New insights into the 2009 JWS event

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Research Background

- A rock avalanche is an extremely rapid, flow-like movement of fragmented rock from a large rock slide or rock fall
- Numerical simulation can analyze the failure mechanisms of geotechnical materials
- Erosion can greatly enhance the destructive potential of the rock avalanche by increasing its volume and impact force

Research Motivations

- The planar failure mechanism and moving process of the JWS rock avalanche are needed to investigate in detail
- No mechanical condition has been specified for the shoveling effect and shoveling mode of erosive rock avalanche gain or loss

Study area and Research Framework

Figure 1 shows the locations and geological map of the JWS rock avalanche. The stratigraphy in the area is underlain by the Lower Permian Maokou Group (P1m) and the rock types are dark gray and gray limestone with flint concretions. The Lower Permian Qixia Group (P1q) and the rock types is a 25 m-thick layer of dark gray limestone.

To build the 3D DEM model, the geometric data of the slope surface was surveyed by photogrammetry, and that of stratigraphy was obtained by field investigation and survey, the flowchart for simulation is shown in Figure 2.

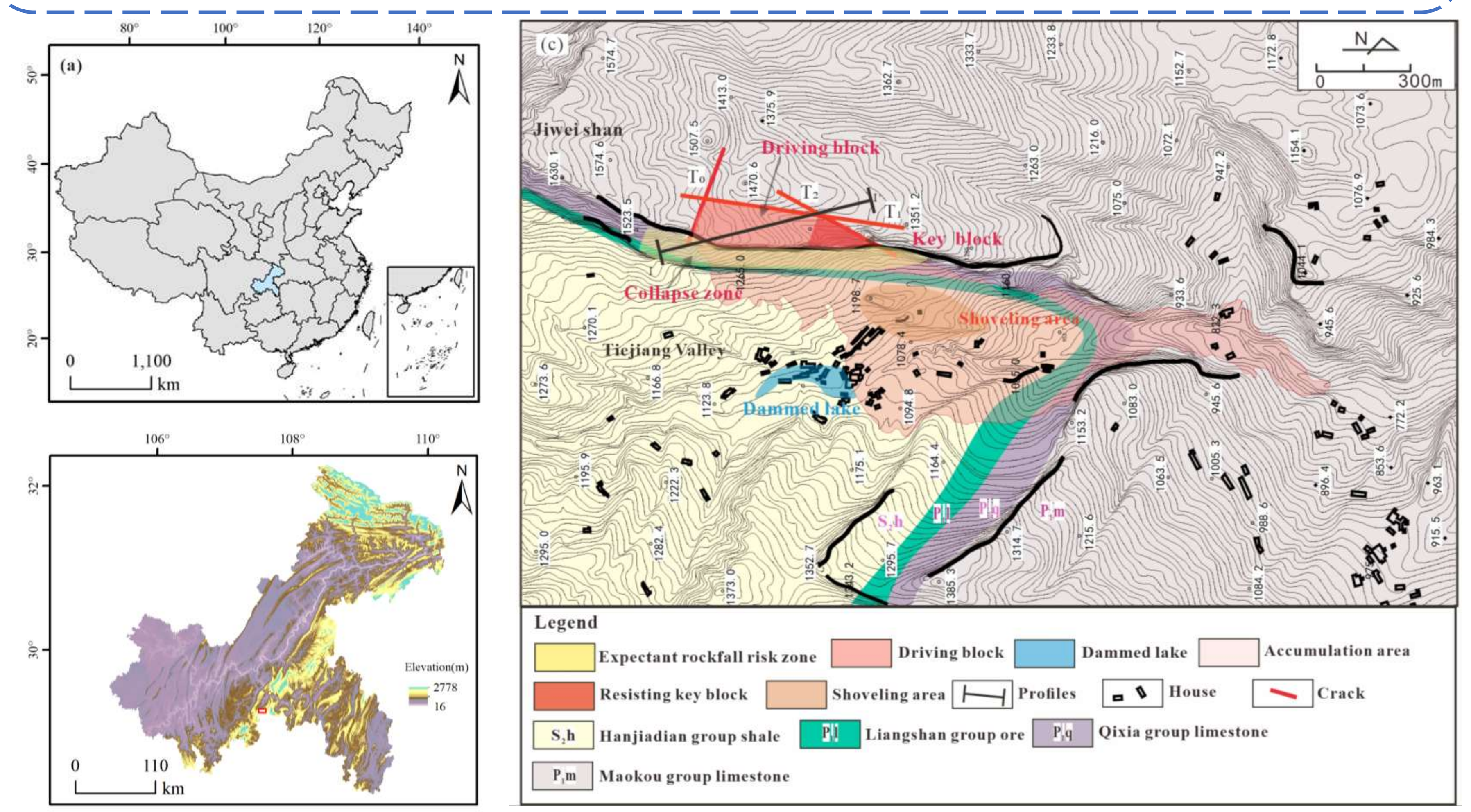

Figure 1. The Location and Geological map of the study area. Modified of Liu et al. (2025)

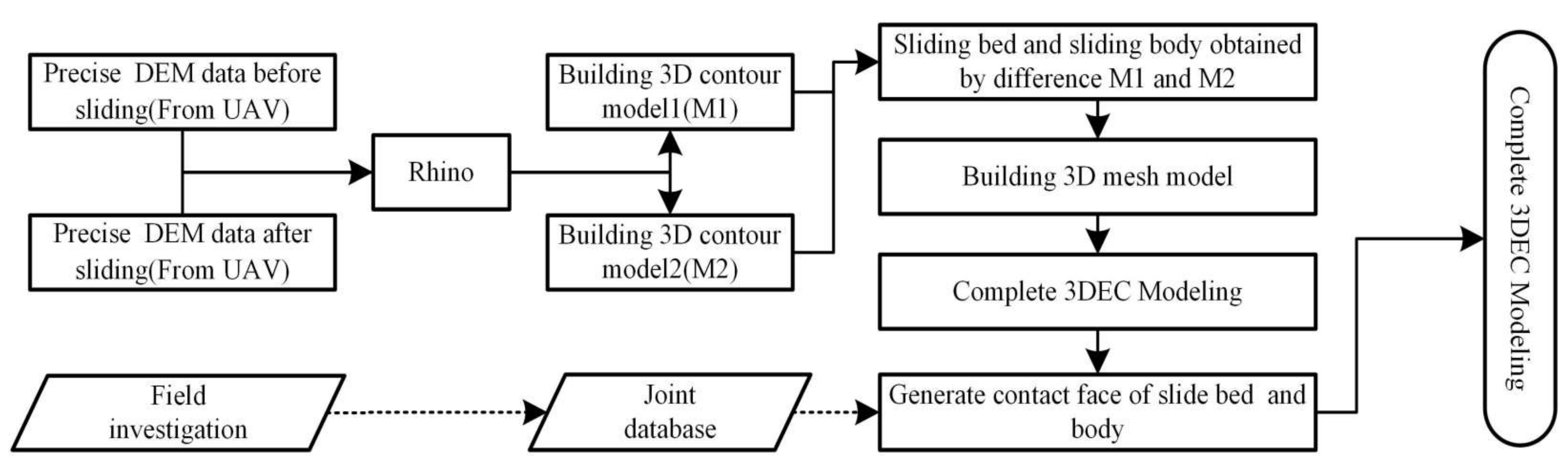

Figure 2. The flowchart for simulation of JWS landslide. Modified of Liu et al. (2024)

Research Findings and Discussion

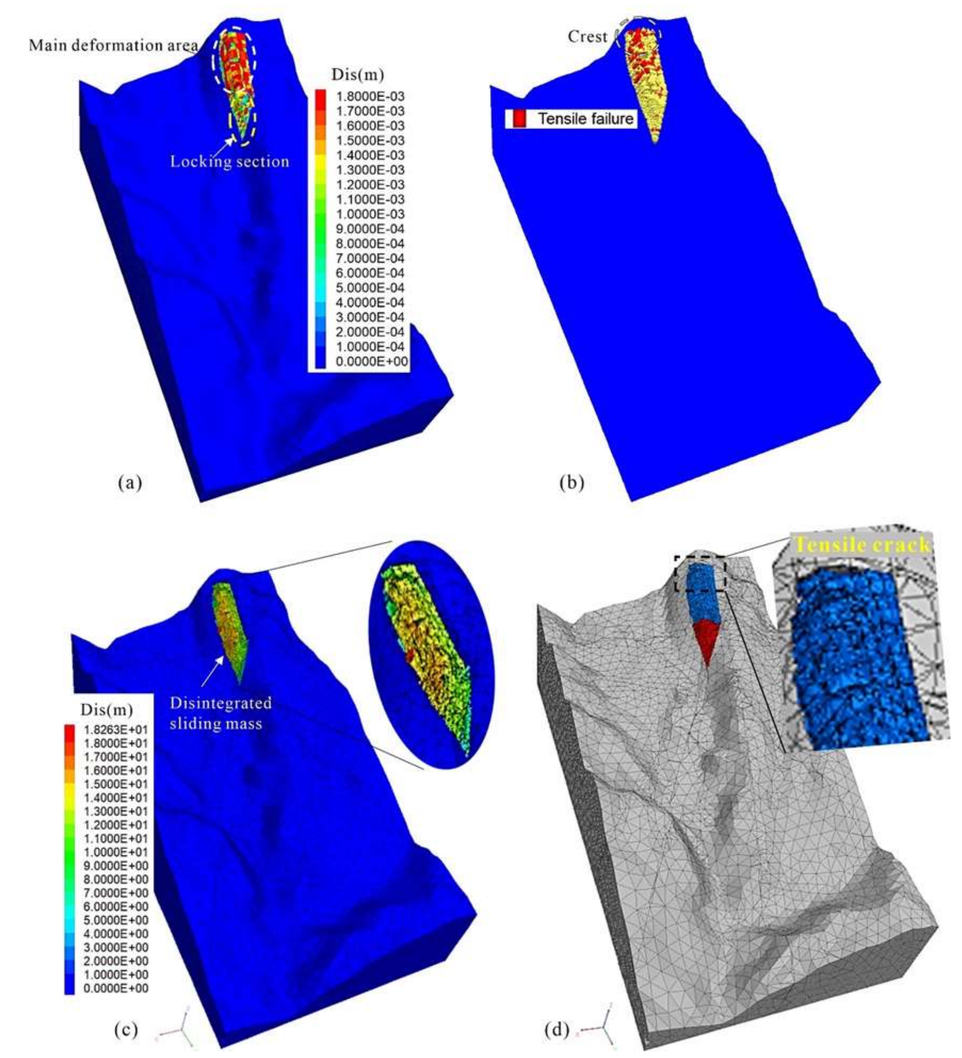

Figure 3. Results of JWS rock avalanche planar failure mechanism. Modified of Liu et al. (2025)

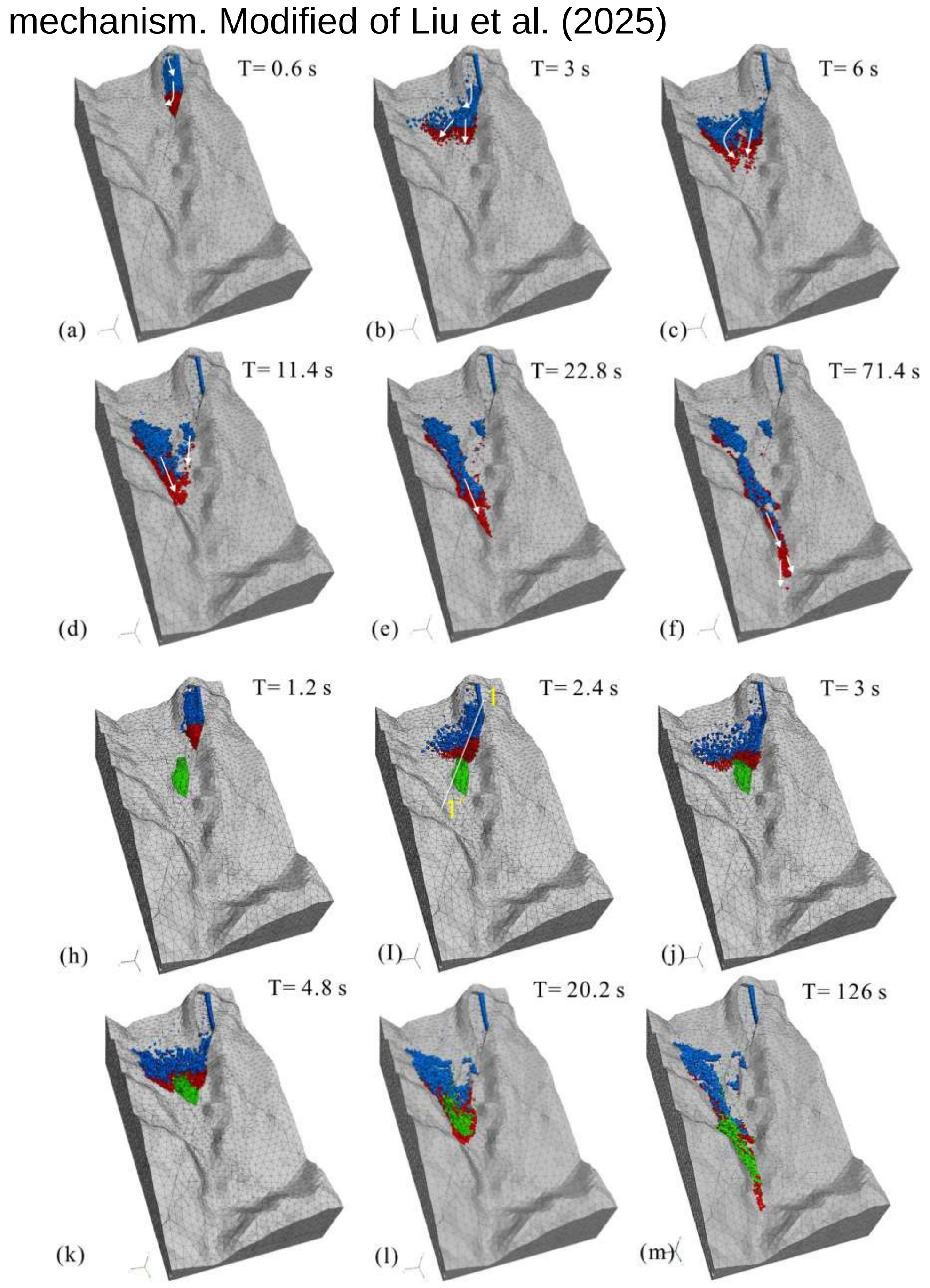

Figure 4. Failure process of the JWS rock avalanche without shoveling effect and considering shoveling effect. Modified of Liu et al. (2025)

A. Findings from initial simulation

- The planar-failure mechanism and movement process of the JWS rock avalanche were clarified through 3DEC simulations. The initiation of slope failure was demonstrated by block movement.
- Firstly, the initiation mechanism of rock avalanches is due to the long-term compression of the key blocks at the front end by the driving blocks at the crest, causing the key blocks to break along joints (Figure 3a).
- In addition, the back edge of the landslide is the main deformation zone, causing obvious plastic failure in the sliding mass. the tensile failure is the main failure at the crest of the rock avalanche (Figure 3b and d).
- when the location with the largest displacement in the sliding mass turned to the leading edge, the upper slide at the triangle corner slid as a whole without disintegration or obvious rotation. Which indicated that the sliding plane of the rock avalanche had been fully formed (Figure 3c).

B. Findings from movement simulation

- The movement was influenced by the throat region at the end of the gully zone. The gradual narrowing of the cross-section resulted in the formation of a local arch bridge in the simulation, with a mixture dominated by rocks.
- Subsequently, the shearing action, largely influenced by sliding friction, transitioned into an inertial flow characterized by collisions between polyhedrons.
- The entrainment on the hill in front of the slope toe to improve the lateral dispersion of the sediments.

C. In-depth Discussion of the Results

- Three erosion scenarios occurred, including plowing erosion, shearing erosion, and pushing erosion. As a result, the shoveling effect increases the accumulation depth, and the landslide dam formed at the outlet of the gully (Figure 6).
- Additionally, the accumulation of rock avalanche is greatly related to microtopography, which also illustrates the importance of refined modeling (Figure 4).
- Furthermore, the low friction angle caused the elastic energy of the rock blocks to release slowly during high-speed movement, contributing to the long runout of the rock slide.
- The deposit features of the JWS rock avalanche were characterized by the preservation of stratigraphic sequence and inverse grading (Figure 5). Moreover, numerical simulations reveal that the sliding distance of the block decreases with the increase of the volume (Figure 7).

Applicability and future work

- The discrete element method can simulate the damage and failure processes of brittle materials such as rock avalanche.
- At present, this study does not take into account multi-phase issues for different particle sizes after fragmentation/disintegration: big boulders and fine particles may behave mechanically differently, requiring multi-phase simulation with phase separation.

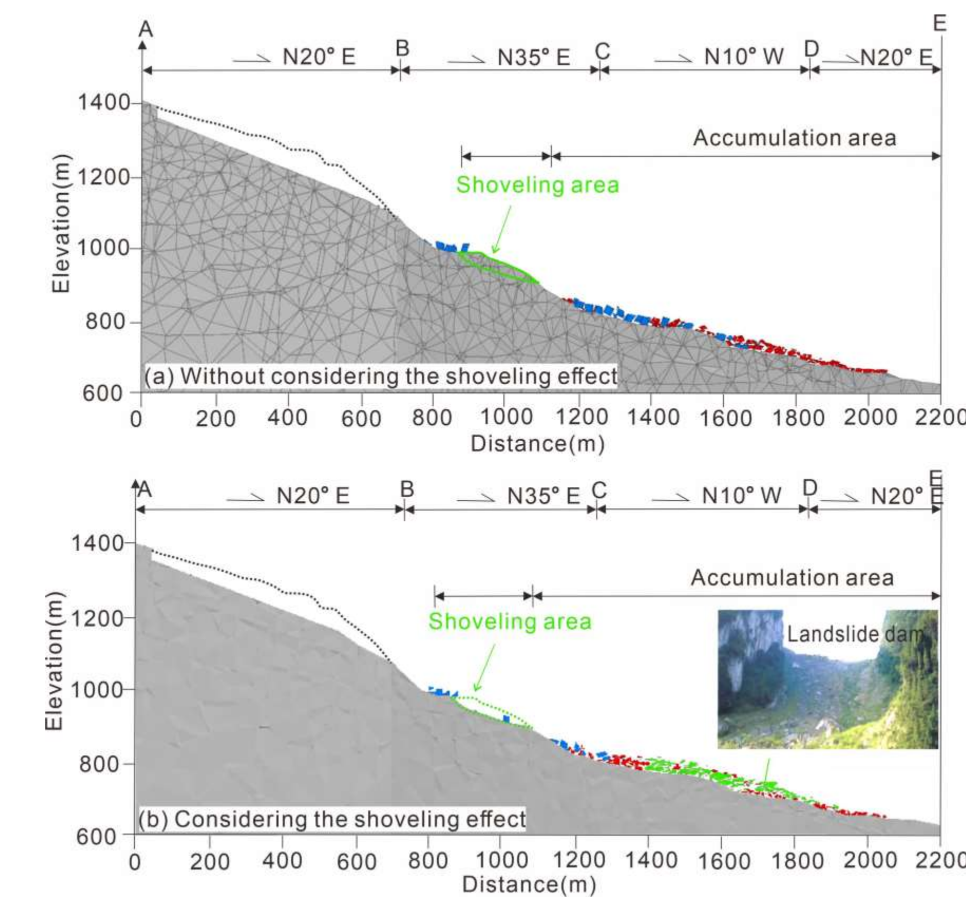

Figure 5. The section of the rock avalanche without considering or considering the shoveling effect. The green dashed line represents the entrainment area, where the majority of the eroded blocks accumulate in the narrow gully. Modified of Liu et al. (2025)

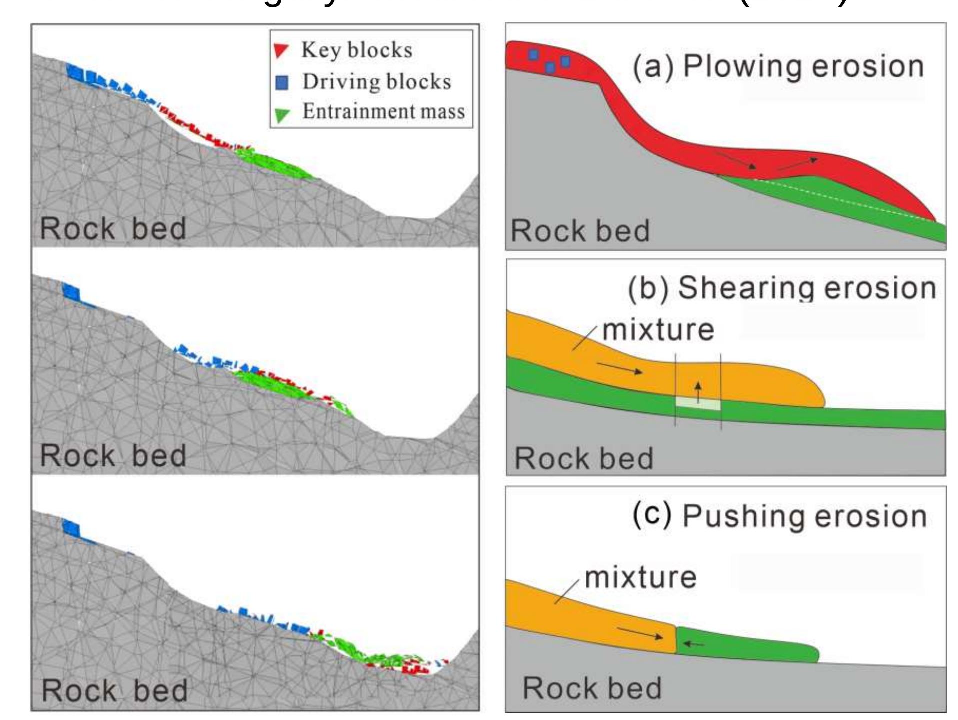

Figure 6. Three entrainment mode scenarios: plowing erosion, shearing erosion, and pushing erosion. Modified of Liu et al. (2025)

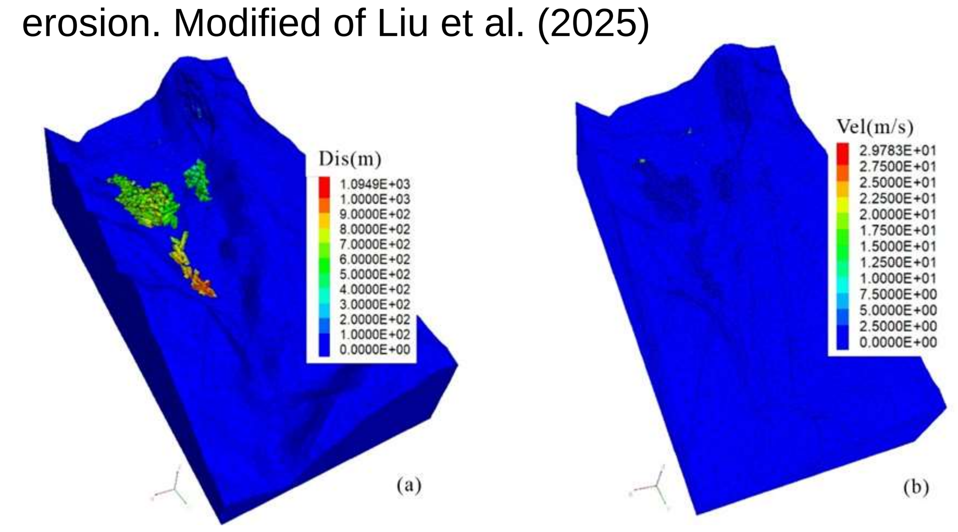

Figure 7. The simulation result of the JWS rock avalanche that the all joint spacing is 25 m. Modified of Liu et al. (2025)

Liu, Y., Haider, M., Lawrence, D., Li, T., Shen, W., Li, P., 2024. Failure mechanism and simulation for long run-out of the catastrophic rock landslide in the Shanyang Vanadium Mine, China. J. Mt. Sci. 21, 2905–2917. https://doi.org/10.1007/s11629-024-8706-9

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