Study on the Impact of the Debris Flow in Bujiaoyida Gully on Tunnel Entrance Stability

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Abstract. Taking the threat of debris flow disasters to the tunnel entrances along the Chengkun Railway as a backdrop, this study combines field data with numerical simulation using the discrete element software PFC^{3D}.The complex process of debris flow impacting tunnel entrances is highly destructive and consists of three stages: impact, overflow, and deposition, each presenting varying threats to structural safety. The results indicate that numerical simulations analyzed the accumulation patterns of debris flow impacts and their effects on portal stability under different spatial relationships, revealing that the force initially increases and then decreases, while the accumulation shape is closely related to the protective state.

Keywords: Mudslides; Tunnel entrance; Numerical simulation

1 Introduction

Debris flow is a common geological disaster in mountainous areas, consisting of a solid-liquid two-phase fluid made up of water, mud, sand, and gravel. Its characteristics include suddenness, short-duration high intensity, extreme destructiveness, and significant hazards. Debris flows release large amounts of materials and energy upon impact, causing severe damage to mountainous infrastructure such as tunnels, bridges, and embankments[1].

Domestic and international experts have conducted in-depth studies on debris flow disasters through numerical simulations[2]-[6]. Zuo Xiong et al.[7] utilized PFC2D software to simulate the initiation mechanisms and motion processes of debris flows under rainfall conditions. Zhang et al.[8] combined physical and numerical simulations to validate the instability patterns and failure mechanisms of granular slopes under varying environmental conditions. Zheng et al.[9] utilized three-dimensional particle flow simulation technology to explore the initiation process and intrinsic mechanisms of debris flows in depth. Although other debris flow simulation software have their own advantages, PFC usually provides more powerful features and flexibility in terms of particle simulation accuracy, computational efficiency, and user-friendliness. Currently, numerical simulations of debris flows primarily focus on analyses or evaluations over entire watershed areas, often targeting single channels and individual debris flow

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events[10]. However, existing studies often limit themselves to the characteristic values of debris flows, neglecting their potential hazards to nearby buildings and transportation facilities. Therefore, this study employs the particle flow numerical simulation software PFC3D to establish a numerical model for debris flows, investigating the scale, movement characteristics, and impact on tunnel entrance stability of the Bujiaoyida Gully debris flow.

2 Research Area Engineering Background

The study area is located in the right bank of the Nizhi River in Azjue Township, Bujiaoyida Gully Basin, which is located in the southwestern part of Sichuan Province, and the geographic coordinates of the opening of the 0# transverse hole of the Teke Tunnel are: east 102°51′33″, north 29°06′52″.

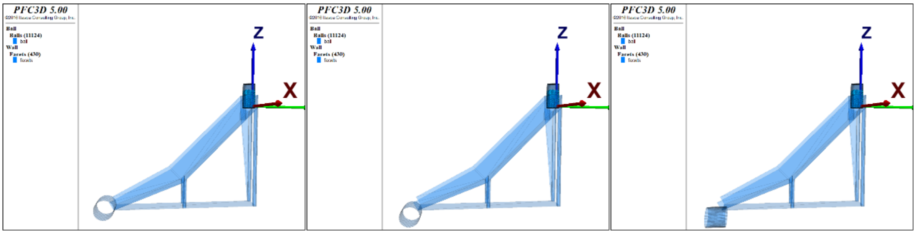
The Bujiaoyida Gully has a total length of 2.6 km and is formed by two tributaries that converge in a "Y" shape at the main gully, with a height difference of up to 1842 m and a watershed area of approximately 7.55 km^2. The gully mouth has developed accumulation topography, with adverse geological phenomena present; the slopes are steep, and the landform is in a youthful stage.

Bujiaoyida Gully is located in the Niriji River watershed, characterized by a monsoonal subtropical climate with abundant rainfall. Mudslide disasters can be triggered by rainfall of 40mm or more in the ditch, and the abundant rainfall provides water and power for mudslides.

3 Construction of a Numerical Model for Debris Flow Impact on Tunnel Entrances

Under the same gradation and chute slope conditions, the debris flow movement process caused by heavy rain was simulated, and the impact force variation law of different azimuth openings was compared and analyzed. In PFC3D, the modeling simulated the mudslide material source set a slope of 35° similar to the actual. The modeled stacking platform is 16.38×11.47m, the width of the chute is 3m, the length is 20m, and the baffle is set in front of the chute. The diameter of the hole is 3m, and the center of the hole circle is 0.5m from the exit of the chute. the hole is divided into three positions: pressure top, half pressure top and side punch cutting. As shown in Figure 1.

Based on the original particle gradation, 1124 non-overlapping irregular particles were generated to simulate debris flow material sources, and the cave structure was simulated based on wall. A parallel bond contact model was used to simulate the cohesion and friction angle between the particles, achieving stable accumulation under gravitational influence and ultimately reaching a stable slope condition. This simulation utilized wall and ball calculation parameters as shown in Table 1.



(a) Side impact (b) Half pressure roof impact (c) Jacking impact

Fig. 1. Physical model of mudslide impacted cave entrance

Table 1. Fine-scale parameters of the soil in the source area of mudslide material

Wall			Ball					
normal stiffness	tangential stiffness	coefficient of friction	densities /(kg/m³)	normal stiffness	tangential stiffness	porosity	coefficient of friction	radius
0.17	0.17	0.2	1850	0.6	0.07	0.1	0.5	0.5-2

4 Patterns of Debris Flow Impact on Tunnel Entrances

4.1 Analysis of the Evolution Process of Impact Force

Key indicators for measuring impact force during the impact phase are the peak impact force, with the peak impact forces under various conditions shown in Figure 2.

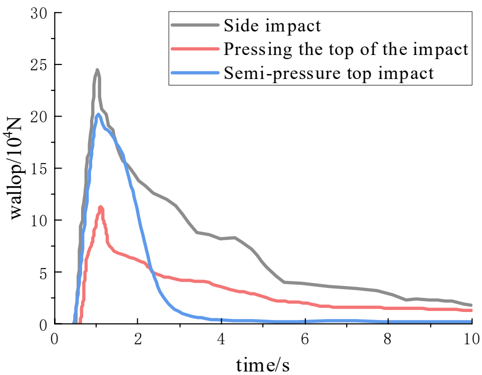


Fig. 2. Time course curve of overall impact force under different working conditions

(1) Debris flow on the frontal surface: the initial flow is free, and the peak impact of the secondary contact surface is 24.48x106N, causing initial damage. The damage may be exacerbated in the course of the injury, or the damage may be caused entirely. The structure is lifted in the Y direction, compressed in the X direction, the side wall is adducted, the side is squeezed on the side of the current, and the arch waist is expanded outward from the shoulder.

(2) At the half-pressure top, the mudslide 14.3m/s touched the structure, partly blocked the hillside and wall, and the remaining rushing road surface was silted up. The peak impact force was 11.23x106 N. The headward side was inwardly squeezed, the backward side was outwardly expanded, the X-direction offset was obvious, the deformation of the free end was large, and the near-fixed end was gradually reduced.

(3) The debris flow impacted the cave entrance, with an initial velocity of 20.5m/s and a peak impact force of 20MN. Then it hit the top of the cave door wall, quickly unloaded the impact force, no significant accumulation, and turned to static pressure to zero. The surrounding siltation debris flow slightly abrasively abrasives the roof of the structure, resulting in the spalling of the free-end wall.

4.2 Simulation Results of the Debris Flow Accumulation Process

After the landslide impact, the impact force on the cave entrance due to the collapsing debris rapidly diminishes. The force exerted on the cave entrance is transformed into the gravitational force and impact energy transmission for subsequent particles, resulting in minor up-and-down fluctuations. The specific impact forms and their accumulation effects are shown in Figure 3-5.

(1) The impact force in the mudslide increases first and then stabilizes, spreads rapidly to the sides when piling up, and the sidewalls of the cave are now overturned. The width of the jet varies little, and the backwash fills the blank area on the side.

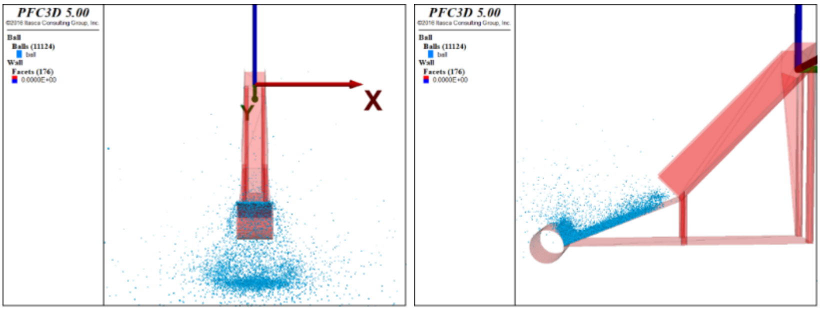


Fig. 3. Mudslide Lateral Impact Cave Accumulation Effects

(2) Under the semi-compression roof, the debris flow transitions to the cave impact, shortens the distance, and spreads to both sides. The leading edge decelerates, takes on a fusiform shape, the angle of entrapment decreases, and clusters in the center, filling the downstream void area.

(3) When the pressure top, the mudflow fast rushed to the top of the hole after unloading, almost no accumulation of static pressure near zero. After the impact of the speed to both sides of the expansion, the leading edge of the deceleration fan-shaped scattered, the inner sink to fill the downstream blank.

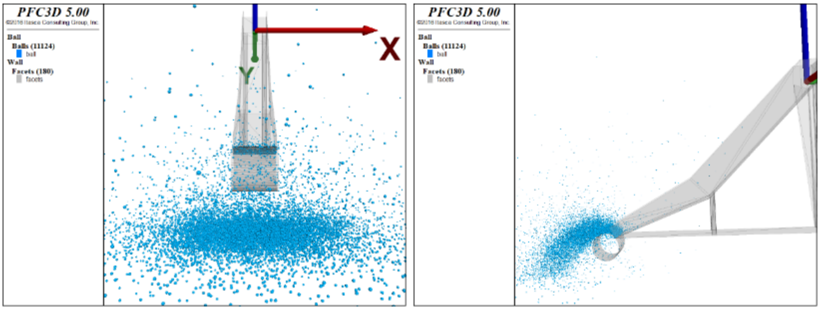


Fig. 4. Mudslide semi-compression roof impact cave stacking effect

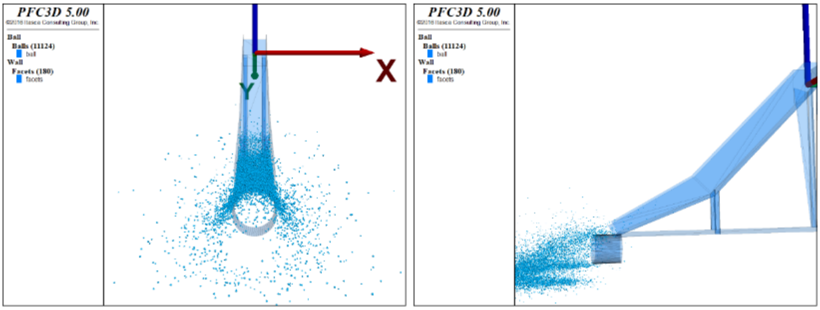


Fig. 5. Mudslide roof-impact cave stacking effect

5 Conclusion

Debris flow may not only directly damage the tunnel structure, resulting in tunnel collapse and deformation, but also may block the tunnel entrance, affect the construction progress and safety, wash out the construction facilities and mechanical equipment, and even threaten the life safety of construction personnel. Therefore, this study is based on the Chengkun Railway and utilizes field survey data to establish a three-dimensional numerical model of debris flow impact on tunnel entrances using the discrete element software PFC3D. The main conclusions are as follows:

(1) The mudflow force on the hole first increases and then decreases to stabilization, and the impact force is enhanced with the increase of contact area. The impact force is weaker in the semi-compression top, part of the mudflow is blocked and silted up, and the rest impacts the road surface.

(2) The damage pattern is the same, dominated by cracking and stripping, with significant displacement of the free end. On stacking, the pressure is maximum in fusiform shape at semi-compression top, fan spreading at compression top, and almost no stacking.

(3) Under the action of debris flow, the damage of tunnel opening is concentrated in the face, side wall, arch foot and top and bottom, and the stability is affected by the impact, velocity, accumulation pattern and structural characteristics. Enhanced protection, optimized design and drainage system can improve stability and safety.

(4) Although the PFC software has several advantages in simulating the effects of debris flow on tunnel openings, such as accurately simulating flow characteristics, predicting structural response and optimizing protective measures, there are still limitations such as model simplification, parameter uncertainty and insufficient consideration of multifactor coupling. In order to improve the accuracy and practicality of the study, it is recommended to combine the macro- and micro-scale simulation methods and conduct multi-factor coupling analysis.

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