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Half Tunnel Rockfall Simulation in Himalayas Region- A DEM Approach

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Abstract: Rockfall is a common geological hazard in the Himalaya, particularly along road cut slopes developed in steep mountainous terrain. Rapid infrastructure expansion and unscientific excavation, drilling, and blasting practices have significantly increased slope instability and overhanging rock masses. This study investigates rockfall characteristics along National Highway-05 between Tranda and Jeori in Himachal Pradesh, India. The rock mass mainly comprises schistose rock with more than three persistent joint sets under moderately weathered and damp conditions. Field data on rock mass properties and discontinuity geometry were collected and analyzed using distinct element modelling and rockfall simulation techniques. The study evaluated block trajectories, fragmentation behavior, and impact energy of falling rocks. Highly vulnerable blocks were identified for controlled blasting and stabilization, which can significantly improve long-term slope stability and road safety.

Keywords: ***Rockfall, Slope stability, Distinct Element Method (DEM), Rock mass characterization, Rockfall simulation, Controlled blasting, Schistose rock, Slope stabilization.***

Introduction

Rockfall is one of the most common geological hazards in the Himalayan region, particularly along steep road cut slopes constructed in mountainous terrain. Rapid infrastructure development and highway expansion in the Himalaya have significantly aggravated the problem due to improper excavation practices, inadequate slope stabilization measures, and unscientific drilling and blasting techniques (Kumar et al., 2022). In many cases, unstable rock masses remain hanging above highways after excavation because complete removal is technically difficult or economically expensive. Such overhanging rock blocks pose a serious threat to human life, vehicles, and construction machinery moving along these roads.

To reduce the risk of rockfall, various stabilization measures such as rock bolts, shotcrete, wire mesh, and retaining structures are commonly used. However, in many Himalayan road sections, these supports are either insufficient or partially implemented, resulting in continued instability of the slopes. Therefore, proper assessment and prediction of rockfall behavior are essential for long-term slope stability and sustainable road infrastructure development.

Conventional and numerical approaches for stability assessment

Traditionally, slope stability and support design have been based mainly on empirical rock mass classification systems. Although these approaches are useful for preliminary evaluation, they often fail to accurately represent the complex geological conditions and discontinuity-controlled behavior of Himalayan rock masses. Numerical modelling techniques provide a more reliable and detailed understanding of slope instability and rockfall mechanisms.

Several numerical methods are widely used in rock slope analysis (Verma et al., 2023), including the Finite Element Method (FEM), Finite Difference Method (FDM), and Distinct Element Method (DEM). These methods are advantageous because they can simulate complex geological conditions, discontinuities, block interactions, and failure mechanisms with fewer simplifying assumptions compared to conventional techniques (Singh et al. 2020). Numerical modelling is also economical and time-efficient for evaluating different stabilization alternatives and predicting future slope behavior.

Case study from National Highway-05, India

A case study was conducted along National Highway-05 between Tranda in Kinnaur District and Jeori in Shimla District of Himachal Pradesh, India. The study area is characterized by steep Himalayan terrain and highly fractured schistose rock masses. Field investigations revealed that the rock mass contains more than three distinct joint sets with high persistence. The slope was observed to be moderately weathered and under damp environmental conditions, which further reduced the stability of the rock blocks.

Rock samples and discontinuity data were collected from the site to characterize the geomaterial properties, joint geometry, and rock mass conditions. These parameters were used for distinct element modelling and rockfall simulation to understand the behavior of falling blocks from the overhanging slope sections.

Results and conclusion

The numerical simulation provided valuable information regarding the trajectory, velocity, fragmentation pattern, and impact energy of falling rock blocks. The analysis also identified highly vulnerable blocks that were close to failure and could potentially detach during rainfall, blasting, or seismic activities. Based on the simulation results, unstable rock blocks can be safely removed using controlled blasting techniques before catastrophic failure occurs.

The study demonstrates that numerical modelling combined with detailed geological characterization is highly effective for evaluating rockfall hazards in the Himalaya. Such approaches can significantly improve slope stabilization strategies, enhance road safety, and reduce risks to human life and infrastructure in mountainous regions.

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