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Exploring Joint Orientation Effects on the Failure of the Interbedded Rock Slope Using UDEC

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Abstract: In Taiwan, the lives of residents and passersby in mountainous areas are frequently threatened by disasters such as rockfalls and landslides. These disaster-prone areas are mostly interbedded slopes composed of different lithologies, and differential erosion often occurs due to differences in their weathering resistance. Therefore, this study is based on geological survey results of an oblique slope with differential erosion in Miaoli County, Taiwan, to simulate the effects of varying joint orientation on slope failure and to explore whether specific failure patterns occur.

Keywords: ***Differential erosion, Interbedded slope, Orientation.***

Introduction

Interbedded sandstone and shale slopes are a common feature of the Western Foothills Belt in Taiwan (Hung, 2002). In hot and humid climate, the shale layer beneath the sandstone layer gradually erodes by weathering, leaving the sandstone layer with extremely steep slope or overhanging rock slope, leading to frequent collapses and rockfalls (Figure 1). Admassu and Shakoor (2015), Cano and Tomás (2013) and Wyllie and Mah (2004) suggest that differential erosion is one of the reasons for the frequent occurrence of rockfalls. Based on field survey, this study used UDEC to simulate failures of interbedded slope within Miaoli County, Taiwan, and explored the effect of the orientation randomness of a single joint on the slope failure induced by differential erosion.

Methodology

Geological survey

The slope under study is an oblique slope composed of the Kuantaoshan Sandstone Member of the Kueichulin Formation (Kck), interbedded with thin shale. Lin (2023) investigated five sets of discontinuities, including four sets of joints and one set of bedding. Among these, the strike of J4 (joint code) is like that of the slope (Figure 2).

Numerical model

This study built a UDEC basic model based on the A-A' section of the study area's point cloud and field survey data (Figure 3). To simulate differential erosion-induced collapses, following Liu (2025), the simulation was divided into several steps. At each step, the shale layer near the slope is removed to a depth of 0.3 m before the next step. The orientation is assumed to follow a Fisher distribution. Representative joint values were used to generate the UDEC basic model.

Figure 1, A collapse incident in 2022/08/29.

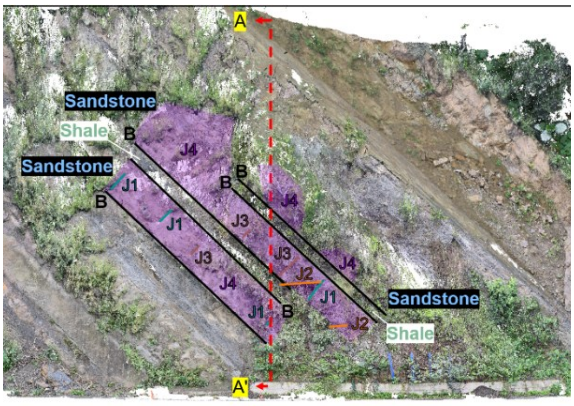

Figure 2, Point cloud showing joint sets.

Oblique slope failure affected by differential erosion

Simplified on-site simulation

The results show that the leading cause of slope failure is shale erosion, which weakens the support of the sandstone below, causing some sandstone blocks to become overhanging and fall. Calculation of the sandstone area destroyed at each step reveals three large-scale collapses exceeding 10 m^2. Sandstone blocks rotate or slide along J4 when the shale erodes to within 0.3 m of J4, or when the shale beneath is completely eroded. The slope geometry after collapse at each step shows that J4 will become the slope surface, J3 is in the minority, and J1 and J2 do not affect the slope geometry.

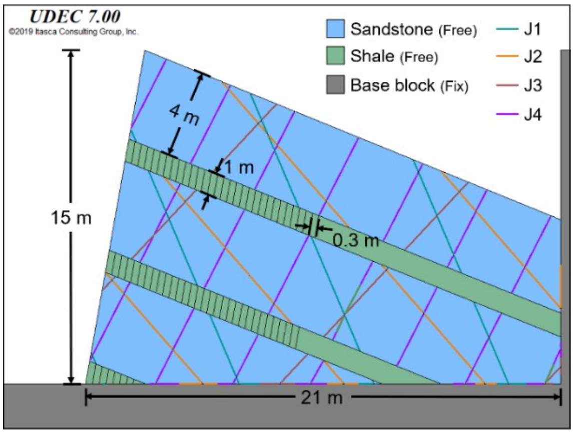

Figure 3, UDEC basic model.

Effect of orientation

The results of the basic model show that the slope geometry is mainly affected by J3 and J4. Therefore, the orientations of J3 and J4 are changed for simulation (Table 1). The results of changing J3 show that J3-1 and J3-2 exhibit similar trends in timing and failure area. Compared to J3-3, while J3-1 and J3-2 experience more failures, each failure covers a relatively minor area, and there is a pattern of 7-9 steps of large-scale collapse. The results of varying J4 show that J4-1 failed at a depth of 0.45 m below the base of the block. J4-2 and J4-3 failed when the shale retreat depth exceeded the rock mass's center of gravity. The collapse area shows that J4-1 has a pattern of two consecutive large-scale collapses. J4-3 presents multiple groups of collapse events; each group of events consists of two large-scale collapses followed by 1 to 2 non-collapse steps. There is also a pattern of a group of collapse events occurring in 7 steps (Figure 4).

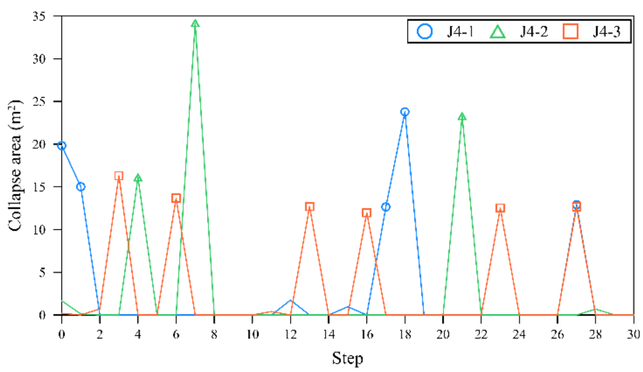

Figure 4, Sandstone collapse area of J4-1 to J4-3.

The slope occurrences of various models at every 10 steps were overlapped to observe the changes in slope geometry. The results show that J3-1 and J3-2 are prone to forming an overhanging rock slope. J3-3 differs little from the basic model, only making the slope steeper when in self-weight balance. The slope geometry of J4-3 remained unchanged during self-weight, while J4-1 and J4-2 appeared to be overhanging rock. Regardless of the angle of J3 or J4, J4 will dominate the slope surface after each step of slope failure, and the slope geometry will change with the angle of J4 (Figure 5).

Conclusion

In various models, joint sets nearly parallel to the slope surface will form the failure boundary when the slope collapses, and the slope surface after collapse will change with the angle of these sets of joints. The remaining joint set had no significant impact on slope collapse. However, the joint sets that are nearly parallel to the slope surface do not exhibit a specific failure time at different angles; however, the failure area shows that most angles exhibit specific failure patterns.

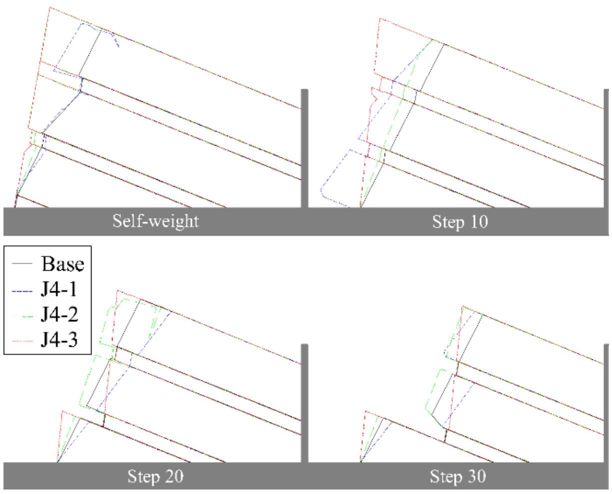

Figure 5, Comparison of slope geometry for J4.

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