Slope stability and engineering characteristics of rock mass at the boundary of slate and schist: Study of Southern Cross-Island Highway in southeastern Taiwan

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ABSTRACT: The slopes in the study area had suffered from frequent collapses. To investigate the relationship between slope instability and the engineering parameters of the rock masses at the boundary of slate formation and Tananao schist formation, interpretation of the spatial distribution of collapses from multi-temporal remote sensing images, investigation of slope instability mechanism, surveying and geological mapping, and evaluation of engineering parameters of rock masses have been performed and reported in this article. The outcomes indicate that the Q values of the rock masses at the boundary of slate and schist are lower than those of the surrounding rocks, resulting in areas prone to rock slides, debris slides, and rock fall. The adaptive structures, such as axial faults, pre-existing shear, and dense fractures near the axis of a mesoscale fold, cause rock fragmentations, which are often the source of rock debris and rock fall.

Keywords: slate, schist, landslide, slope instability, fold.

1 INTRODUCTION

Lithology and geological structure determine the engineering characteristics of a rock mass, and the exposed position, scale, and structural influence range of rock mass will affect slope stability. Metamorphic rocks contain complex structures and often present anisotropic fabrics, therefore, the understanding of factors affecting slope stability is lower than that of sedimentary rocks (Stead & Wolter 2015). More case studies are needed to explore the rock mass engineering properties of all kinds of metamorphic rock.

This study collected remote-sensing images and UAV-produced orthophotos from 1952 to 2021 and produced digital terrain models (DTM). The spatial distribution of slope collapses was interpreted in multi-period images, and types of collapse as well as rock mass classification were verified and obtained through in-situ investigation. Eventually, the influencing factors of slope collapse in metamorphic rocks are discussed thoroughly.

2 STUDY AREA

The study area is in the eastern section of the Southern Cross-Island Highway (No.20 highway) in southeast Taiwan, from Wulu to Lidao in Haiduan Township, Taitung County. The strata include the Pilushan Formation (part of the slate belt, Eocene) and the Kaolin Schist (part of Tananao Schist complex, Late Paleozoic - Mesozoic), and the study area is between the slate and schist belts. The lithology of the Pilushan Formation is dominated by slate, intercalated with metasandstone. The lithology of the Kaoling Schist is mainly quartz-mica schist, mixed with intercalated quartz schist, chlorite schist, and marble (Central Geological Survey 2013).

The main river system in the study area includes Halibosong River, Massupoerh River, Malilan River, Lidao River, and Xinwulü River (Figure 1). Typhoon Morakot in 2009 caused massive collapse in the upper reaches of the Xinwulü River, resulting in the aggradation of the river below the middle course and raise in the riverbed elevation (Lo et al. 2021).

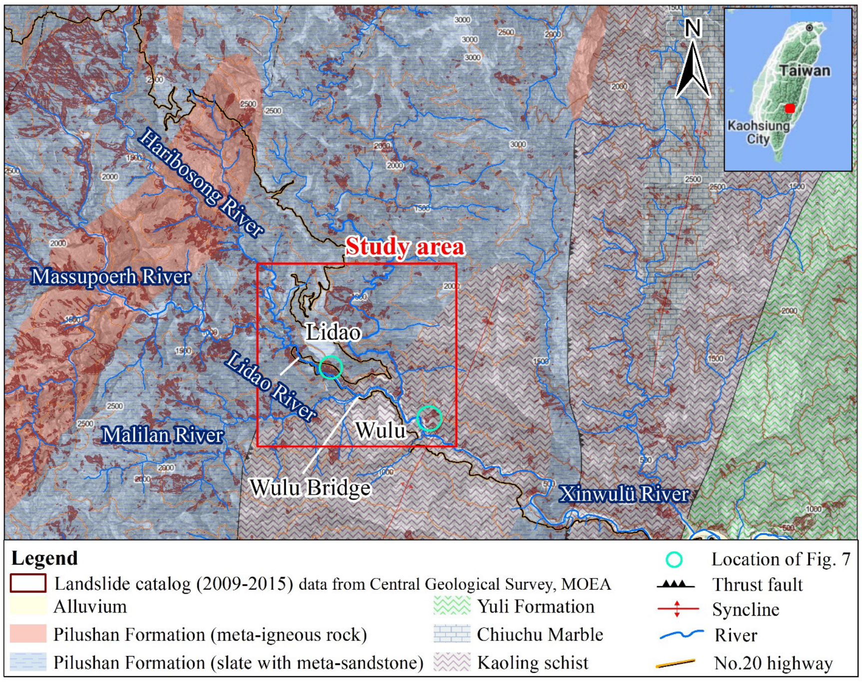

Figure 1. Landslide catalog and geological map of the study area.

3 DISTRIBUTION AND TYPES OF LANDSLIDES

The catalog of historical landslides from 2009 to 2015 shows that the scale and number of landslides in the slate belt are higher than those in the schist belt. In the schist area, landslides are mostly linear and located at the toe of the slope and along the erosion gullies. The locations of landslides in the slate zone are near the slope top and toe, and the distribution area and shape are relatively irregular. There are also several large collapses that almost cover the whole slope.

4 INVESTIGATION OF GEOLOGICAL AND ROCK MASS ENGINEERING PROPERTIES

This study carried out a surface geological survey along the No.20 highway, and drew a route geological map, investigated discontinuities (Ulusay & Hudson 2007), and evaluated Q-system at the outcrop and lithologic boundary zone of different lithology (Barton et al. 1974, 2002). Finally, we discussed the characteristics of landslide development with different lithology in this area, and how regional structure affected the development of landslides.

4.1 *Geological mapping and geological survey*

On the east side of the Wulu Bridge, the exposed lithology is mainly quartz-mica schist with well-developed schistosity (Figure 2), and the strike is northeast-southwest dipping to the north. The boundary between the slate and schist belts is 300 m west of the Wulu Bridge, where the terrain bends and the stream turns. Erosion gullies develop on the slope, and shear zones with a width of more than 20 m can be found at the toe of the slope (Figure 3). This is the location of the slate and schist belt in this study, which is consistent with previous studies by Stanley et al. (1981).

The lithology within the slate belt consists of slate, phyllite, and metamorphic sandstone of various thicknesses (Figure 4). The slate strikes about N20°-30°E and dips 70°-85° to the north, but it also dips to the south, depending on the influence of regional folds. The attitude of the metamorphic sandstones is influenced by regional scale folding and is highly variable.

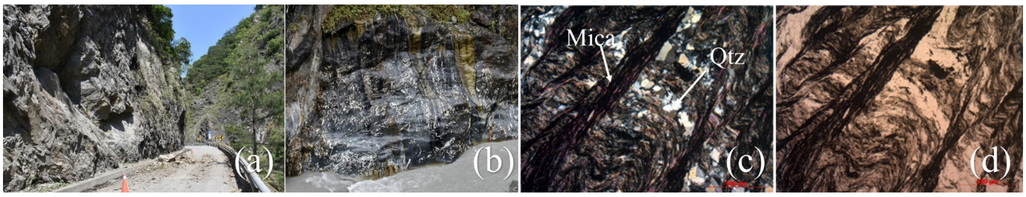

Figure 2. (a)Weathered and (b) fresh quartz-mica schist. (c) and (d) are microscopic features of schist.

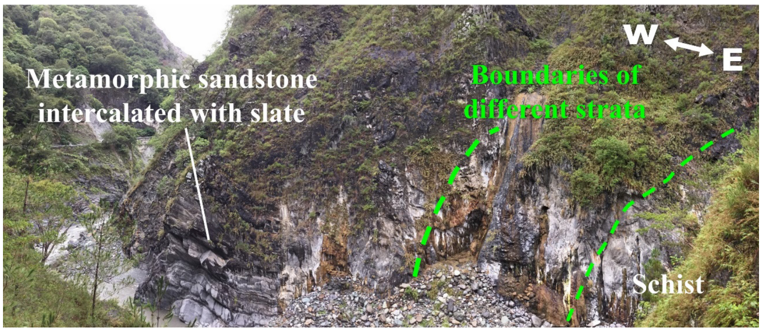

Figure 3. Boundary between slate and schist belts.

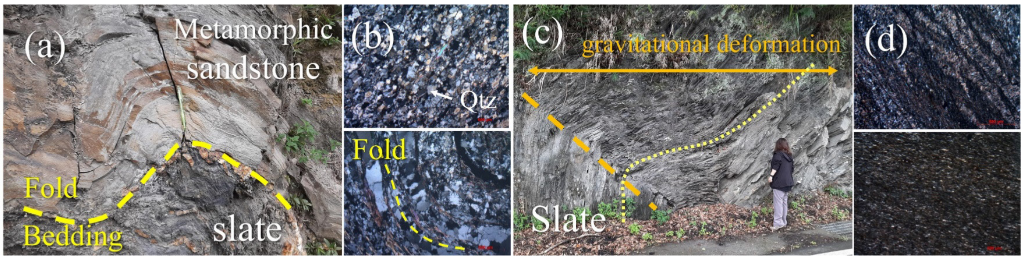

Figure 4. Outcrops and microscopic features within the slate belt. The lithologic composition of the outcrops consists of (a) (b) metamorphic sandstone interbedded with slate and (c) (d) slate.

4.2 *Folds and enveloping surface of folds*

Many folds can be seen in the slate belt of the study area, and the strike is clearly identifiable as roughly parallel to the axial plane of the fold. Slates and metamorphic sandstones are mostly interbedded to intercalated with each other. The wavelengths and amplitudes of the smaller embedded folds and the larger fold follow the same trend, consisting of poly-harmonic folds (Figure 5).

There are a series of mesoscale folds in slate and metasandstone, which form a curved surface tangent to all folds, a surface that contains all crestal lines or trough lines in a single folded surface, which is called an enveloping surface of fold (Figure 6).

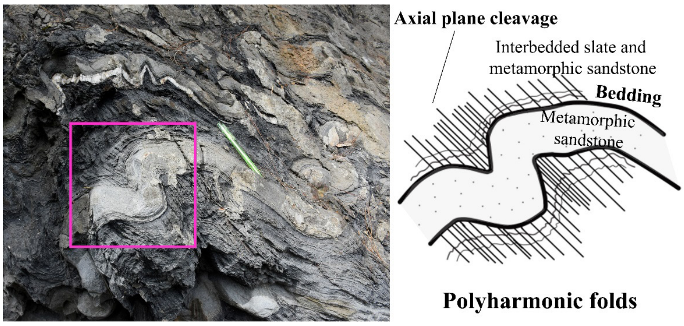

Figure 5. Fold patterns of slate and metasandstone in the slate belt.

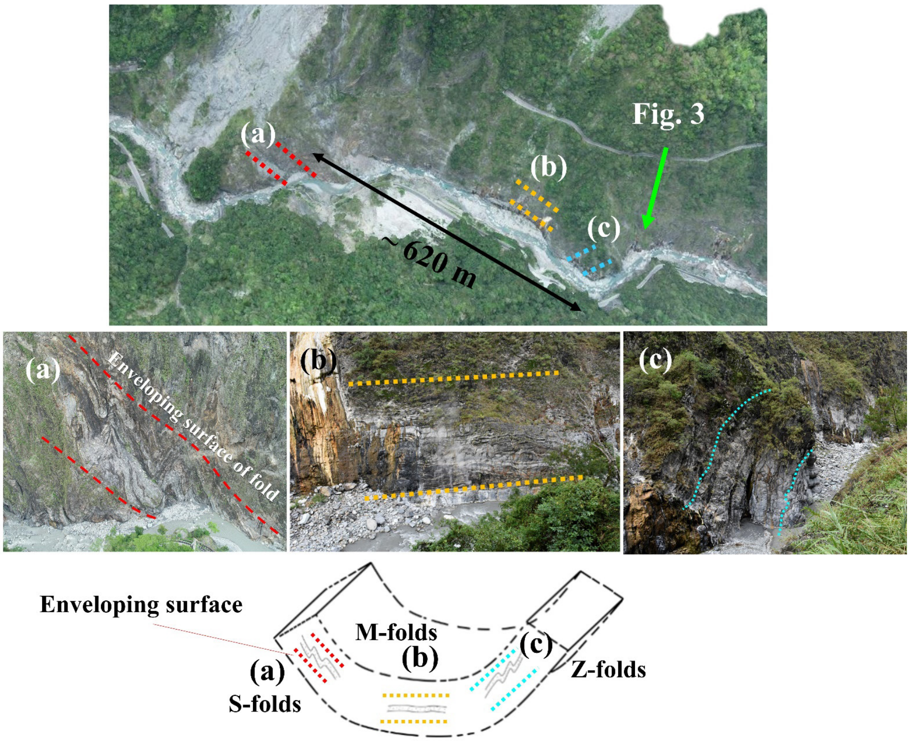

Figure 6. Enveloping surface of fold with wavelength of more than hundreds of meters.

4.3 Investigation of engineering characteristics of rock mass

All the lithologies in the study area contain at least three sets of discontinuities. The foliation (including slaty cleavage and schistosity) is well-defined in the outcrop. Survey results from different locations are affected by differences in lithological composition, topography, and proximity to structures, resulting in varying degrees of difficulty in identifying discontinuous surfaces. The joints of schist are not easy to distinguish, and the attitude has obvious differences within several meters, and the continuity is low.

5 DISCUSSION

5.1 Landslide characteristics and distribution

Of all slope movements, strip type debris slides are the most common. Such movements are widespread within the whole study area but are the most frequent in northeast-southwest and northwest-southeast patterns. These landslides mostly occurred near creeks, gullies, and where landform concaves (Figures 1 and 7), showing that river and surface erosion have great influence on the slope stability (Tsao et al. 2020; Lo et al. 2021).

There are few large landslides in the schist area, most of the landslides are shallow debris fall, topple, and slides, herein referred as debris collapses and slides. In the slate belt, there are more large landslides, especially where folds and faults are nearby (Figure 7). Such phenomena can be explained by the properties of slate. The time-dependent deformation characteristics and anisotropy of slate are easily affected by gravitational deformation and water softening, which reduce the strength of rock masses and cause slope instability.

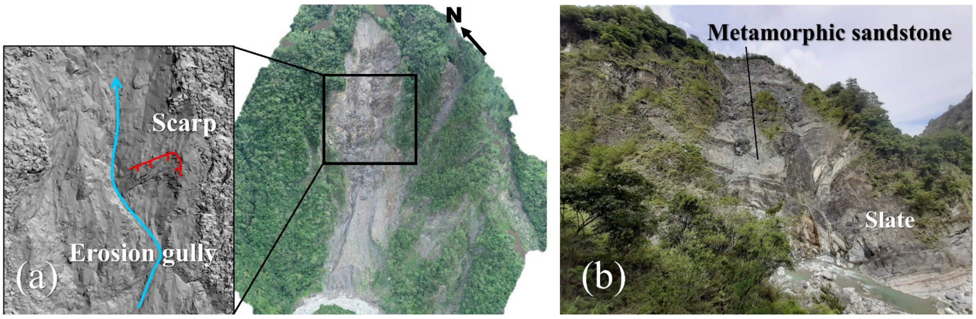

Figure 7. Landslide cases within the (a) schist and (b) slate belt in the study area.

5.2 Location of changes in engineering properties of rock mass

In the study area, the Q value of fresh and complete schist exceeds 50 (Figure 8); while after weathering, the foliation detaches prominently (Figure 2a), the superficial quartz-mica schist was weakened and softened, and the Q value reduces to 8-15. Weathered schist is prone to shallow debris collapses and slides, in which failure surfaces were controlled by the combination of foliation and the axial plane of folds.

At the boundaries of slate, phyllite, and metasandstone, the Q-values are usually much smaller (around 0.1-53). The differences occur at factors including RQD, Jn, and Jr (Figure 8). In the slate belt zone, the Q-values vary according to the proportion of slate and metasandstone, and give the Q-values of 6-28. Area with thicker metasandstone shows higher Q-value. If the interbedded slate and metasandstone are affected by folds and faults, debris collapse and slides can easily happen.

6 CONCLUSION

The eastern section of the No.20 highway in Taitung County, Taiwan, passes through the boundary of slate belt and schist belt, and is a section of the No.20 highway where collapses have been frequent for many years. Based on results of this research, the following conclusions were obtained:

1. Rock masses close to the boundary of the schist and the slate belt in the study area present lower Q-values than the others. The differences in factors within Q-value are obvious in RQD and Jr. There are more fractures in the rock mass, and landslides often occur in this location.
2. The lithology of the slate belt in the study area includes slate, phyllite, and metasandstone, and there are various combinations in the proportion of interbedding. The variation in rock engineering properties is generally less pronounced than where structures (e.g., folds and faults) are exposed.
3. Fold axis, fault, interlayered shear fractures, and dense fractures on the mesoscopic scale are likely to cause fractured rock masses, and are often the source of debris collapses and slides.
4. Quartz mica schist in the study area consist of wavy schistosity and centimeter-degree folds, while the continuity of discontinuities is mostly poor, except for the foliations. The fracture surface of the rock masses mostly developed along the foliation, and produces stepped fracture surfaces with discontinuities perpendicular to foliation or axial surface of folds.

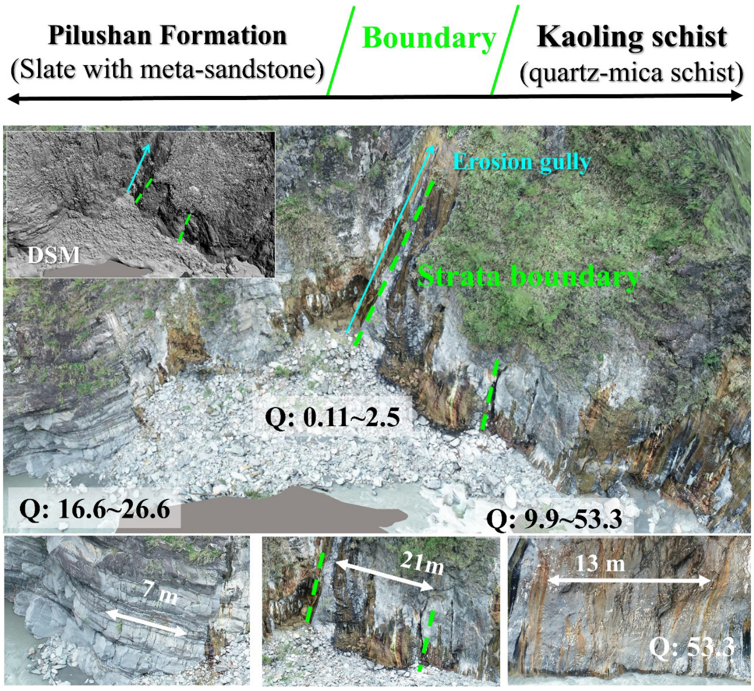

Figure 8. The difference of Q value between the boundary of slate and schist belt. The rock mass is broken at the junction of lithology and there is an erosion gully developed.

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