Stability of shale at a slope

AKM Badrul Alam¹, Yoshiaki Fujii², Naveel Islam³, Md Abdur Rahman³, Ashiq Al Hasan¹, Md Abid Hasan¹
¹ Petroleum and Mining Engineering Department, MIST, Bangladesh.
² Faculty of Engineering, Hokkaido University, Japan
³ Civil Engineering Department, MIST, Bangladesh
rock.mist.badrull8@gmail.com

Abstract. The road-construction and nature create rock slopes along the Anticlinal Folded Belt in the eastern part of the Chittagong hill tracts, the northern margin of Surma Basin, and some eastern parts of Sylhet, Bangladesh. The total number of death due to slope failure in these regions is 622 from 2000 to 2017. Shale outcrops occur in several parts of the hilly region where rock fragments are on the roads at the slope base, and slope failure is common in these regions. This research aimed to find out the mechanism of formation of the rock fragments and the slope failure at a shale slope by water immersion, slake durability, direct shear, and triaxial compression tests. The rock is very unstable in the presence of water and, wet and dry cycles where water is absorbed along with the clay layer and breaks along with the layer. The gradient of the slaking index is 20 SI%/cycle in the 1st, 2.5 SI%/cycle in the 2nd, and 1.17 SI%/cycle in the 3rd stage which reveals that the rock degrades immediately upon exposure to wet and dry cycle. The ten shale pieces before the durability test became more than 300 pieces after the test. From the image analysis, it reflects that the average area decreased by 98% with increased aspect ratio, circularity, and roundness. The strength decreased to around 75% by wetting having low cohesion and internal friction of 105 kPa and 24.2° respectively. Effective countermeasures for slope failure should be investigated.

Keywords: Slake durability, Slope stability, Strength of shale.

1 Introduction

The road-construction and nature create rock slopes along the Anticlinal Folded Belt in the eastern part of the Chittagong hill tracts, and the northern margin of Surma Basin, and some eastern parts of Sylhet (Fig. 1a), where a large number of people live due to scarcity of land area in Bangladesh. Shale outcrops occur in several parts of the hilly regions where rock fragments are on the roads at the slope base (Fig. 1b), and slope failure (Fig. 1c) is a common phenomenon in the geo-environment. The total number of death due to slope failure in the regions is 622 from 2000 to 2017 [1] having an increasing trend. This research aimed to find out the mechanism of formation of the rock fragments and the slope failure in shale by water immersion, slake durability, direct shear, and triaxial compression tests.
Fig. 1. The geological formation of exposed rock and the location of the studied area. (a) Geological formation of exposed area [2, modified], (b) Rock fragments at the base of a shale slope (c) Slope failure at a shale slope
2 Methodology

The sample was characterized by various methods. The grain size analysis of the rock sample was performed by Sieve and Hydrometer analysis following the standard of ASTM D 7928 – 17 [3] and then compared with the Wentworth Scale which is the most widespread use for the classification of grain matter (Udden 1914; Wentworth 1922). Moreover, the organic content by ASTM D 2974 – 14 [4] and the specific gravity by ASTM D 854 – 14 [5] of the rock were determined. The XRF analysis was carried out on the clay size fraction by Rikagu ZSX Primus. The studied rock then correlated with the stratigraphic succession of the area to determine the geologic setting of the studied rock.

The slake durability test was carried out by the standard testing method of Franklin and Chandra which is recommended by the International Society for Rock Mechanics [6] and standardized by the American Society for Testing and Materials. In the slaking test, 10 rock pieces of about 40–60 g each were prepared and rotated for 10 min in a test drum made of a standard sieve mesh of 2 mm. The drum was half immersed in a slaking bath at 25°C. The wet samples were then dried at 105°C. The slaking index (SI) corresponding to each cycle was calculated as the percentage ratio of final to initial dry weights of rock in the drum after the drying and wetting cycles. The image analysis was carried out on the rock pieces before and after the test to characterize them by circularity, aspect ratio, and roundness which were calculated by the following formula with the help of image analysis by imageJ [7].

\[ \text{Circ} = 4\pi \times \frac{A}{P^2} \]  
\[ \text{AR} = \frac{a}{b} \]  
\[ \text{Round} = 4 \times \frac{A}{\pi \times a^2} \]

Where, Circ is circularity, AR is aspect ratio, Round is roundness, \( A \) is area, \( P \) is perimeter, \( a \) is major axis, \( b \) is minor axis.

The strength of the shale was determined by direct shear and triaxial test of the dry or wet conditions. Direct shear tests were carried out on 63.5 mm diameter and 20.0 mm height specimens at room temperature (25°C) and atmospheric pressure on dry or wet conditions. After 24 h consolidation at 50 kPa, 100 kPa, 200 kPa, 400 kPa normal stresses, the shear displacement of 0.2 mm/min was applied on the direct shear test to determine the internal friction and cohesion and to see the change in strength of wet and dry conditions. Moreover, a triaxial test was carried out on 24 h consolidated specimen at the effective confining pressure of 630 kPa with an axial displacement rate of 0.0049 mm/min on the 38.50 mm diameter and 76.00 mm height specimen at room temperature (25°C).
3 Results and Discussion

3.1 Rock characterization and stratigraphic setting

The rock is composed of mainly silt (76 wt%) and clay (16 wt%) size particles with fine sand of 8 wt% (Fig. 2). The organic content \((n = 2)\) is 3.6% and the specific gravity is 2.63 \((n = 2)\). From the XRF analysis, it was found that higher K2O around 4.5 wt% (Fig. 3) is present in the sample which reveals the presence of illite. The fissility along pertaining surfaces that is the tendency to split along flat planes was observed in the rock samples (Fig. 4). It is found that the rock is silty shale with illite clay of low-grade organic content. It is of Bhuban Formation of Late Miocene age found from the stratigraphic correlation (Table 1) of the area.

![Fig. 3 Grain size analysis of the rock sample from sieve and hygroscopic analysis.](image1)

![Fig. 4. The elemental composition \((n = 2)\) of the rock from XRF analysis.](image2)
Fig. 5. Fissility in the rock block.

Table 1. Stratigraphic correlation [8]

| Formation      | Lithology                                                | Age          | Study area |
|---------------|----------------------------------------------------------|--------------|------------|
| Dihing        | Sand stones, peddy sandstone and clay                    | Recent       |            |
| Dupi Tila     | Grey to yellowish caly stone, sand stone, silt stone etc.| Pleistocene  |            |
| Girujan clay  | Unconsolidated clay stone, silty shale and sandstone with calcareous concretion | Upper Pliocene |            |
| Tipam Sandstone | Yellowish to brown sandstone and very subordinate shale.  | Pliocene     |            |
| BokaBil       | Alteration of silt stone and shale with calcareous band. | Upper Miocene|            |
| Bhuban        | Siltstone, silty shale, sandy shale and sand stone.      | Lower Miocene| Silty shale|
| Barail        | Sandstone with shale, sand stones are very fine grained, poorly sorted containing heave mineral | Oligocene    |            |

3.2 Immersion test

A rock block was submerged into distilled water at room temperature and atmospheric pressure. The block was broken into pieces after 21 h (Fig. 5a). Water was being absorbed along the fracture at the beginning found from the close observation (Fig. 5b). After water absorption, the fracture opened up in 16 h and the thin layers were peeling off at the rock surface (Fig. 5b).
3.3 Durability test

The slake durability tests were performed on two sets with ten shale pieces each. The Slaking Index (SI) curve is divided into three stages. The SI is 35 to 84% at 1 to 4th cycles; at 5 to 10th cycles, the SI ranges from 12 to 35%; whereas it is from 5 to 10% for 11 to 16th cycle (Fig. 6). The SI is very steep 20 SI%/cycle in the first stage, moderately steep 2.5 SI%/cycle in the second stage, and very gentle slope 1.17 SI%/cycle for 3rd stage of the shale, and it is moderately steep in the case of sandstone. The ten shale pieces before the durability test became more than 300 pieces after the test, having an increment of 29 times (Fig. 7a). From the image analysis, the average area of the particle size of 18.94 cm² before the SI test became 0.44 cm² after the test i.e., the area decreased by - 98%; circularity of 0.69 before the test became 0.82 after the test having an increase of 19%; aspect ratio of 1.68 before the test became 1.53 after the test having a decrease of -9%; roundness 0.66 before the test became 0.72 after the test having an increase of 9% (Fig. 7b).

3.4 Strength test

In dry conditions, 4 direct shear tests were carried out and the strength ranges from 456 kPa to 579 kPa having an average value of 523 kPa (Fig. 8a). On the other hand, the strength was 113 kPa and 152 kPa having an average value of 133 kPa in the wet condition. The average strength decrease due to water was 390 kPa (75%). Major effective principal stress of 1888 kPa at the minor effective principal stress of 630 kPa was observed in the triaxial test of the rock with 105 kPa cohesion and 24.2° internal friction.
Fig. 8. Fragments number and characteristics before and after the durability test. (a) Number of fragments (b) Characteristics of the fragments; AR- aspect ratio, Cric.- circularity, Round- roundness.

4 Conclusion

The studied rock is shale composed of silt, clay, and fine sand size particles containing illite. The rock is very unstable in presence of water because water is absorbed along the clay layer and breaks along it. The rock degrades immediately in contact with the wet and dry cycle. The particles were relatively rounded with an increase in

Fig. 9. Strength of the rock and the specimens. (a) Strength of the rock  (b) Specimens after the direct shear test in dry and wet conditions.

number after degradation in the wet and dry cycles. The strength decreased to around 75% by wetting having low cohesion of 105 kPa and internal friction of 24.2°. Effective countermeasures for slope failure such as installation of protecting sheets, cover plants, shotcrete, etc. should be investigated.

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