Slope stability analysis along the road between Yinmabin and Kalaw in Mandalay region and Shan state, Myanmar

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Abstract. Slope stability analysis along the road between Yinmabin and Kalaw, in Mandalay Region and Shan State was carried out aiming to gain preventive measure for the landslide due to the lack of consideration on landslide hazards and associated risk. The rocks comprise the sedimentary rocks of Plateau Limestone Group, Loi-an Group and Kalaw Red Bed, and the Yinmabin Metamorphics. Notably, four types of landslides such as rockfall, debris flow, creep and slump have been identified along this road. Rockfall is the commonest landslide mainly occurs along the manmade road cuttings generating potential threats to human life triggered by heavy and prolong rainstorm. Slope Mass Rating (SMR) values indicated that Yinmabin Metamorphics is the most vulnerable to landslide. Three types of failures such as wedge, plane and toppling failures are confirmed by kinematic analysis. Moreover, a total of three landslide hazard zones is interpreted based on geological and geotechnical parameters. These zones are described as Landslide Hazard Zone I (west of Yinmabin), Zone II (eastern part of Yeboon and western part of Kyatsakan) and Zone III (the area between Nampandet and Wetphuye). Remedial measures have been proposed to mitigate the hazard.

Keywords: Slope stability analysis, landslide, slope mass rating, kinematic analysis

1. Introduction
The landslide hazards along highway area are threatening to people using the road. The present study mainly aims to conduct the analysis of the landslide hazards along Thazi-Taunggyi road where the research road is situated between Yinmabin, Mandalay Region and Kalaw, Shan State (South). The rocks are mainly composed of sedimentary, metasedimentary and igneous rocks which include rock sequences of Yinmabin Metamorphics (Paleozoic), Lebyin Group (Carboniferous to Lower Permian), Plateau Limestone Group (Middle Permian to Middle Triassic), Loi-an Group (Jurassic), Pyinnyaung Formation (Upper Jurassic to Cretaceous), Kalaw Red Beds (Cretaceous), Older Alluvium (Pleistocene) and Alluvium (Holocene).
1.1. Past Landslides

The road consists of hilly terrain with steep slopes and geologically unstable structure. Landslides occur in all rock types of igneous, sedimentary and metamorphic rocks which were exposed along the road between Yinmabin-Kalaw. Deforestation has been increasing due to over exploitation. Moreover, natural and manmade hillside cutting causes more landslides. Rainy season generally starts in May and ends in October. However, light showers can be expected before May and after October. Heavy rainfall can be considered as a triggering factor as most of the big landslides occur in August 2011, 2017 and 2018 which happens to be the highest rainfall months.

Four kinds of landslide mainly occurred at 33 slope sites along the road in the form of rockfall, debris flow, creep and slump. The landslide localities map is described in Figure 1. The most common type of landslide found along the road is rockfall associated with the cutting slopes along the road side. Rockfalls are found at the slope location (1), (2), (3), (4), (5), (6), (9), (12), (13), (14), (15), (20), (21), (26) and (28) as shown in Figure 2. These slopes composed of phyllite, limestone, sandstone and shale alternate unit, siltstone and conglomerate. The other debris flows event occurred at location (11), (18), (22), (23), (24) and (31). The large debris flow occurred in August 2017 at the western part of the Pyinnyaung at location (10) which is also cutting slope as illustrated in Figure 3. The dimension of the landslide is 53 m wide, 50 m long and 100 m flow line from the slope. They are composite slopes, and one debris flow also occurred at location (19) which is natural slope. Creep is observed at location (7), (8), (16), (17), (25), (27), (29) and (30). Most of this creep is formed by erosion of the stream bank of Myittha Chaung and Taung Wun Dwin Chaung located at the sides of the road which is shown in Figure 4. Slumps are found at location (32) and (33) where the top soil cover is thick deriving from the siltstone unit of the Kalaw Red Bed as illustrated in Figure 5.

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**Figure 1.** Location map with landslide distribution of the research area.
2. Methodology

Landslide classification adopted for this research is that proposed by Cruden and Varnes [1]. The Rock Mass Rating (RMR) was computed according to Bieniawski [2], with adding rating values for five parameters: i) strength of intact rock, ii) Rock Quality Designation (RQD), iii) spacing of discontinuities, iv) condition of discontinuities, and v) water inflow through discontinuities and/or pore pressure ratio.

The strength of the rock mass is measured experimentally using point load test. The volumetric joint count was measured using the following equation $J_v = 1/S_1+1/S_2+1/S_3+\cdots+Nr/5$, where $Nr$ means the numbers of random joints to determine RQD [3]. It is not possible to obtain good correlations between RQD and $J_v$. In 1982, the formula $RQD = 115 - 3.3 J_v$ was applied, which was presented by Palmström [4].

Spacing of discontinuities is the distance between them, measured along a line perpendicular to discontinuity planes. Determining the condition of discontinuities is not simple parameter, as it includes several parameters such as (i) roughness, (ii) separation, (iii) filling material, (iv) persistence and (v) weathering of walls. The groundwater which accounts for the influence of the water pressure, with particular reference to the underground excavation are classified either; completely dry, damp, wet and dripping or flowing.

Geomechanics classification of Rock Mass Rating (RMR) [2] system has been used to determine Slope Mass Rating (SMR) [3]. SMR is obtained from RMR by adding a factorial adjustment factor; depending on the relative orientation of joints and slopes and another adjustment factor depending on the method of rock slope excavation. Field observations and measurements of discontinuities using the following equation $SMR = RMR + (F_1 \times F_2 \times F_3) + F_4$ are the main method to determine SMR.

The stereographic method of kinematic analysis [5] and [6] is mostly useful for assessment of the stability of discontinuity planes. Slope orientation, discontinuity sets orientation and friction angle of the each formation in the research area are used for kinematic analysis as the three main parameters. Data of strike and dip values of slopes and discontinuities have been obtained from a discontinuity survey and pole plot, respectively.
3. Results and Discussions
A rock mass composed of a system of rock blocks and fragments separated by discontinuities forming a material in which all elements behave in mutual dependence as a unit. The main features constituting a rock mass are large variations in the composition and structure of rocks as well as in the properties and occurrence of the discontinuities intersecting the rock that lead to a complicated composition and structure of the rock mass. The determinations of RMR and SMR for geotechnical analysis and kinematic analysis for slope failures study are carried out in selected 54 sites along the road to find out the properties or characteristics of the rocks that are observed by field observation. The geotechnical and slope data are described in Table 1.

| Site | Location                  | Rock Unit          | Geotechnical Analysis | Kinematic Analysis |
|------|---------------------------|--------------------|-----------------------|-------------------|
|      |                           |                    | RMR | SMR | \( \phi \) value from RMR | Mode of Failures |
| 1    | N20°45'3.0" E96°17'17.9" | Calc phyllite      | 39  | 39  | 25°                         | P               |
| 2    | N20°45'02.6" E96°17'15.7"| Calc phyllite      | 57  | 56  | 35°                         | W, P            |
| 3    | N20°45'03.4" E96°17'17.4"| Calc phyllite      | 55  | 12  | 35°                         | W               |
| 4    | N20°45'03.2" E96°17'17.8"| Calc phyllite      | 55  | 55  | 35°                         | W, T            |
| 5    | N20°45'02.4" E96°17'17.9"| Calc phyllite      | 60  | 60  | 35°                         | T, P            |
| 6    | N20°45'01.5" E96°17'22.2"| Calc phyllite      | 53  | 2   | 35°                         | W, P            |
| 7    | N20°45'04.2" E96°17'21.4"| Leucogranite       | 50  | 26  | 35°                         | W               |
| 8    | N20°45'09.3" E96°17'22.8"| Sandy Phyllite     | 53  | 41  | 35°                         | T, P            |
| 9    | N20°45'09.9" E96°17'23.1"| Sandy Phyllite     | 50  | 50  | 35°                         | T, P            |
| 10   | N20°45'10.0" E96°17'23.3"| Sandy Phyllite     | 39  | 47  | 25°                         | P               |
| 11   | N20°45'06.7" E96°17'23.6"| Sandy Phyllite     | 44  | 17  | 35°                         | W, T            |
| 12   | N20°45'11.0" E96°17'25.2"| Calc phyllite      | 64  | 63  | 45°                         | W, P            |
| 13   | N20°45'10.1" E96°17'27.4"| Calc phyllite      | 45  | 45  | 35°                         | W, T            |
| 14   | N20°45'10.9" E96°17'27.9"| Calc Phyllite      | 50  | 38  | 35°                         | P, T            |
| 15   | N20°45'10.0" E96°17'30.5"| Sandy Phyllite     | 45  | 45  | 35°                         | W               |
| 16   | N20°45'09.5" E96°17'34.3"| Sandy Phyllite     | 48  | 14  | 35°                         | W, T            |
| 17   | N20°45'09.1" E96°17'34.5"| Sandy Phyllite     | 53  | 52  | 35°                         | W               |
| 18   | N20°45'08.5" E96°17'35.0"| Sandy Phyllite     | 57  | 14  | 35°                         | P               |
| 19   | N20°45'07.6" E96°17'36.6"| Sandy Phyllite     | 48  | 48  | 35°                         | W               |
| 20   | N20°45'10.5" E96°17'39.2"| Sandy Phyllite     | 47  | 47  | 35°                         | W, P            |
| 21   | N20°45'10.9" E96°17'44.3"| Sandy Phyllite     | 58  | 57  | 35°                         | W               |
| 22   | N20°45'10.1" E96°17'47.0"| Sandy Phyllite     | 47  | 13  | 35°                         | T               |
| 23   | N20°45'10.3" E96°17'46.8"| Sandy Phyllite     | 47  | 47  | 35°                         | T               |
| 24   | N20°45'2.7" E96°17'45.0"  | Sandy Phyllite     | 50  | 49  | 35°                         | W               |
| 25   | N20°45'13.7" E96°17'46.9" | Phyllite           | 44  | 44  | 35°                         | W, P, T         |
| 26   | N20°48'26.2" E96°21'30.6" | Phyllite           | 63  | 70  | 45°                         | P, T            |
| 27   | N20°48'34.3" E96°21'42.4" | Phyllite           | 45  | 11  | 35°                         | W, P            |
| 28   | N20°48'35.6" E96°21'42.8" | Brecciated limestone | 45  | 44  | 35°                         | W, P            |
| 29   | N20°49'35.6" E96°24'32.9" | Brecciated limestone | 55  | 43  | 35°                         | W, P            |
| 30   | N20°49'38.6" E96°24'33.5" | Brecciated limestone | 55  | 43  | 35°                         | P               |
### 3.1 Slope Mass Rating

SMR addresses both planar sliding and toppling failure modes, no additional consideration is made for sliding on multiple joint planes. The description of the SMR Class is provided in Table 2.

#### Table 2. SMR Classes defined by Romana (1993).

| Class | SMR | Description       | Stability        | Failures          | Support               |
|-------|-----|-------------------|------------------|-------------------|-----------------------|
| I     | 81-100 | Very good        | Completely stable | None              | None                  |
| II    | 61-80  | Good              | Stable           | Some block        | Occasional            |
| III   | 41-60  | Normal            | Partially stable | Some joints or many wedges | Systematic |
| IV    | 21-40  | Bad               | Unstable         | Planner or big wedges | Importance/Correction |
| V     | 0-20   | Very bad          | Completely unstable | Big planner or soil like | Re-excavation |

A total of 54 sites have been selected covering the transportation route for SMR assessment. The results and rock types are described in Table 1. SMR values of the 54 sites ranged from Class II to Class V. The produced SMR class map is presented in Figure 6. The SMR Class IV and Class V sites hold significant threat to the commuters as well as the road infrastructure.

Sites 3, 6, 11, 16, 18, 22, 27 and 45 are assessed as completely unstable (Class V). It is possible that substantial planner failure can be expected for the stated sites. Besides, they are the most dangerous for slope stabilization according to SMR assessment. Sites 1, 7, 14, 31, 40, 41, 44, 46 and 50 are identified as unstable (Class IV) according to SMR assessment. There is a tendency of planner and wedge failures.
for the above sites. From field observation, smaller rock fragments involved in Class IV sites than Class III sites.

Sites 2, 4, 5, 8, 9, 10, 13, 15, 17, 19, 20, 21, 23, 24, 25, 28, 29, 30, 32, 33, 34, 35, 36, 37, 38, 39, 42, 43, 47 and 48 are assessed as partially stable (Class III). There are possible joint related planner and wedge failure in these sites.

The SMR Class II sites are 12, 26, 49, 53 and 54, and have been assessed as stable slope. There is a very small possibility of block failures due to weathering. The low lying areas are overlain by the alluvium (sandy soil) where the slopes are generally gentle and stable.

3.2 Kinematic Analysis

According to kinematic analyses by Goodman [5] and Jeongi and Kulatilake [6], the following determinations have been made based on the relationship of discontinuities and slope faces using the stereographic projection as shown in Table 1 and analysis figure are illustrated in Figure 7. The slope face is shown as a great circle and the friction angle is represented by an interior circle. Kinematic analysis reveals that most of the sites can have one or combination of wedge failure, plane failure and toppling failure, with the exception of sites 22, 51, 52, 53 and 54.

**Figure 6.** SMR class map of the study area.

**Figure 7.** Example kinematic analysis of the research area.
3.3 Engineering Geological Mapping and Interpretation

Engineering geological map was produced based on the geological and geotechnical data, which include rock types, geological structures, geomorphological features, gully erosions, landslides, rock strengths, RMR and SMR as shown in Figure 8. The engineering geological map indicates that rockfalls are mostly found in the western part of the road especially west of Yinmabin, the area between Yebokson and Pyinnyaung and the area between Pyinnyaung and Kyatsakan. Debris flows and creeps originating in the composite slopes are located between Nampandet and Wetphuye area.

There are three landslide hazard zones which are characterized by the above geological and geotechnical parameters along the road. These zones are (1) Landslide Hazard Zone I (located in the west of Yinmabin), (2) Landslide Hazard Zone II (located in the eastern part of Yebokson and western part of Kyatsakan) and (3) Landslide Hazard Zone III (located between Nampandet and Wetphuye). Zone I consist of highly jointed, weak and very weak Yinmabin Metamorphic rocks. This zone has been assessed as unstable slope and completely unstable slope based on SMR assessment. Zone II consists of weak rocks (Low RMR) of Loi-an Group and is associated with Pyinnyaung fault zone. Majority of the sites are unstable slopes according to SMR assessment. Zone III comprises weak siltstone unit (Kalaw Red Bed) and some of the sites (less than six in number) are assessed as unstable slopes.

![Figure 8. Engineering geological map of the research area.](image-url)
4. Conclusions and Recommendations

The research area is composed of sedimentary, igneous and metamorphic rocks. Rainy season generally starts in May and ends in October. Heavy rainfall is highly controlled the landslide triggering in this area. Four types of landslide (rockfall, debris flow, creep and slump) occurred along the road.

Sites 3, 6, 11, 16, 18, 22, 27 and 45 exhibit lowest slope mass rating (Class V) which is identified as completely unstable condition. Sites 1, 7, 14, 31, 40, 41, 44, 46 and 50 are assessed as Slope Mass Rating (Class IV) which is identified as unstable condition. Joint analysis indicated that planner or wedge failures are imminent for those sites. Sites 2, 4, 5, 8, 9, 10, 13, 15, 17, 19, 20, 21, 23, 24, 25, 28, 29, 30, 32, 33, 34, 35, 36, 37, 38, 39, 42, 43, 47, 48 and 51 have been classified as Slope Mass Rating (Class III) which is considered as partially stable condition. Hence, these slopes are regarded as vulnerable to failure in the event prolong heavy rainfall. Reshaping of the slope geometry together with appropriate mitigation measures are suggested to help improve the stability and hazard reduction.

The sites in Landslide Hazard Zone I located at west of Yinmabin which are devoid of rockfall are mainly composed of residual soils. Some steep slope sites should be reshaped the slope geometry as well as installation of drainage system. Zone II with the exception of rockfall sites between the eastern part of Yebokson and western part of Kyatsakan where the sites are classified as completely unstable and unstable slopes and should also be reshaped. Slope inclination (<45°) is desirable together with grass plantation and surface drainage is also recommended. Mitigation measures including the reshaping of the slope inclination to less than 45° together with concrete buttress and subsurface drainage are recommended in Zone III located between Nampandet and Wetphuye.

Remedial and mitigation measures seem to be inadequate during the reconstruction and widening of Yinmabin-Kalaw highway. Additional risk assessment study is recommended for prioritizing the necessary mitigation measures and safety of the commuters.

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