Mineralogy-based Evaluation of Ring Shear Strength of Clayey Soils from Thrust-zone Landslides in Nepal

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1. Introduction

Large-scale landslides and frequently occurring rain-induced slope failures are one of the destructive natural disasters in Nepal, where the geology is characterized mostly by sedimentary and metamorphic formations uplifted and weakened by the collision of tectonic plates. Owing to the problem of landslides and slope failures apart from the financial difficulties, Nepal has a poorly maintained highway network. Up until today, the capital city of Kathmandu (Fig.1) and its neighboring settlements, which have an estimated population of 2.5 millions, are connected with the rest of the country by only one trunk road, which frequently suffers landslide damages. Despite being a major national road playing probably the most important role in the nation's economic development, the landslide damage response is almost non-existent mainly due to lack of funds and insufficient investigations. For a proper management of the road network, it is all important to deal with the landslide problems, and to deal with the landslides, it is essential to understand the landslide mechanism.

As a part of the efforts to understanding Nepal landslides, Yatabe et al. (2005) have investigated a large part of the major national highways in Central Nepal, and have prepared a landslide distribution map along the investigation route, as indicated in Fig.1. Based on the findings of their investigations, this paper puts forward the results of laboratory tests on the soil samples collected from some of those landslide sites, and looks into the landslide occurrence and distribution along the highways from clay mineralogical point of view.

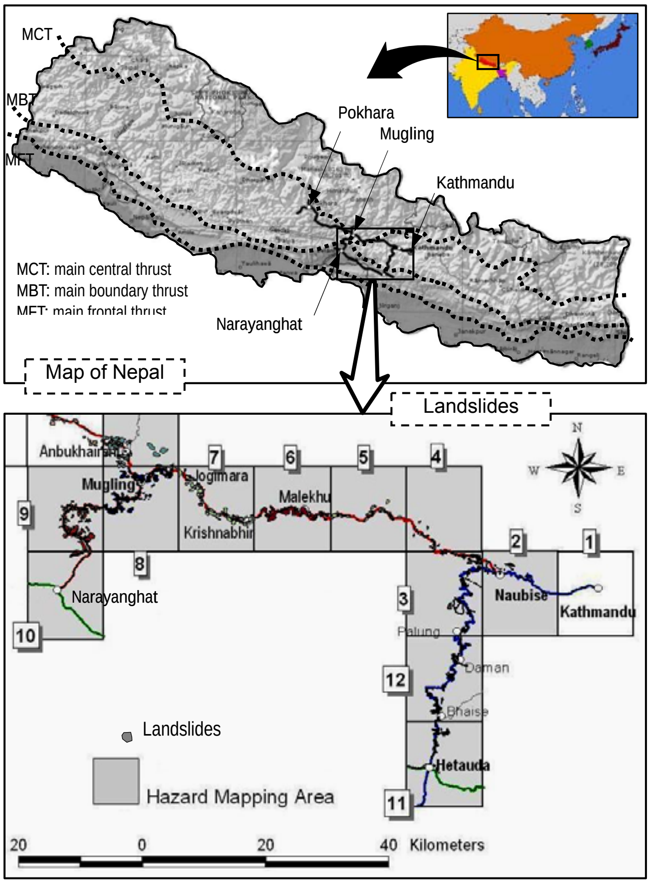

Fig. 1: Geo-physical map of Nepal and the landslide distribution along major national highways (Yatabe et al. 2005).

2. Brief geological background of Nepal

The geology of Nepal is largely characterized by rippled sedimentary strata separated by three major thrust faults in east-west direction (Fig.1, map of Nepal). Depending on the degree of thrust upliftment, the geomorphology of each geological zone is different. The general trend is that greater the thrust, greater is the scale of mountains formed. Most parts of these geological formations consist of sedimentary and metamorphic rocks with highly decomposed top layers that are easily eroded by rainwater. Investigations and experiences have revealed that the geological conditions of the mountains and hills between main central thrust (MCT) and main boundary thrust (MBT) as well as main boundary thrust (MBT) and main frontal thrust (MFT) are comparatively weak and cause landsides and related failures. In addition, the human intervention due mainly to settlements and development activities, such as road building, over these zones has become one of the major factors inducing landslides.

3. Laboratory tests and clay mineralogy

Soil samples from more than 20 landslide and slope failure sites along the investigation route were tested in ring shear apparatus for drained strength and in X-ray diffractometer for constituent clay minerals. All samples tested in the ring shear apparatus passed 425μm sieve, the shearing was conducted over remolded, saturated, normally consolidated annular specimens of 8 cm inner dia, 12 cm outer dia, and 10-12 mm thickness. The average shear rate was fixed at 0.15 mm/min through the shear plane so as to let any developed pore-water pressures dissipate completely. Likewise, in X-ray diffraction (XRD) tests, all samples were examined by powder method (for overall constituent minerals) as well as oriented aggregate method (for constituent clay minerals).

The test results of 12 among the 20 tested samples are shown in Table 1. The results from the ring shear tests indicate that the angle of internal friction for the collected samples vary between 20 to 30 degrees, while the XRD test results show that the main constituent minerals of the soil samples are chlorite, micas, and quartz. Fig.2 shows a typical XRD pattern for the tested samples indicating the presence of these minerals. Also summarized in Table 1 are the x-ray diffraction peak intensities of the main minerals identified. Since, the presence of chlorite and micas in the tested samples is notably high, it is considered that the strength behavior of the collected landslide soil samples is greatly influenced by chlorite and mica contents. Assuming

Table 1: Results of x-ray diffraction tests (powder method) and drained ring shear tests.

Sample No.	ϕ_d (degree)	ϕ_r (degree)	Peak intensity of main constituent minerals (cps) Smectite	Chlorite	Micas	Quartz	Feldspar
3	29.06	28.21	–		200	640	–
4	28.58	26.89	–	100	200	420	40
5	22.04	21.00	–	300	1400	800	–
6	25.77	25.32	–	250	600	800	–
7	24.00	23.06	–	950	550	900	–
7-1	35.69	33.87	–	150	80	1500	–
7-2	26.05	25.32	–	450	450	650	–
8	22.39	20.96	–	2600	1200	200	–
10	26.88	26.63	–	500	400	700	–
11	31.15	30.34	–	200	250	800	–
15-2	26.44	25.22	–	1600	240	500	–
21-1	29.21	27.36	–		280	100	–

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the influence of other factors to be little, the peak intensities may be considered to represent relative amount of the constituent minerals in the tested samples. Although this is not an accurate method for quantitative analysis of the minerals, a quick and rough estimation of the constituent minerals can be made from the magnitude of peak intensity. The general trend for the shear strength of soil is that it decreases with the rise in percentage composition of clay minerals as well as other weaker minerals such as chlorites, micas, etc. This is because of lesser frictional resistance of these minerals against any applied stress, especially in presence of water. On the other hand, the shear strength increases with the rise in amount of non-clay minerals such as quartz, feldspar, etc. So, if the ratio is taken of the peak intensity for mica to that for quartz from Table 1 and plotted against the angles of internal friction, it is seen that the angles of friction follow a decreasing trend with the increase in the ratio (Fig.3).

To ascertain the effect of mica content on the strength behavior of soils, another set of ring shear and X-ray diffraction tests were conducted so that the decrease in soil strength with increased mica content could be simulated. The materials used were Toyoura sand powder passing through 75μm sieve and pure mica (muscovite) powder below 5μm (producer: Yamaguchi Mica Co. Ltd., Japan). The sand-mica mix samples were prepared in mix ratios of 10:0, 19:1, 9:1, 17:3, and 0:10, and tested under the same conditions as in case of landslide soils. The results of the ring shear tests are shown in Fig. 4a, and Fig.4b in terms of peak and residual angles of internal friction respectively. The figures are evident that the strengths of the mix samples decrease with the increase in percentage of mica powder.

Fig.5 combines the results of ring shear tests and X-ray diffraction analysis on the mix samples and indicates a clear drop in the angles of internal friction with the inclusion of greater percentage of mica content estimated in terms of the ratio of X-ray diffraction intensities for mica and quartz. This result more or less supports the relation between relative amount of micas in landslide soils of Nepal and heir strength behavior.

4. Concluding remarks

The clay mineralogical investigation of the samples collected from major landslide sites identified along the Nepal highways resulted in greater composition of chlorite and micas in most samples. Particularly, the micas in the collected samples are considered to have weakened the soils in the landslide area leading to occurrence of landslides in various forms. Micas, particularly illite and muscovite are sheet-like clay minerals with specific surface in the range of 65 to 100 m^2/g which gives mica greater water absorption capacity. Moreover, illite particles tend to disaggregate considerably in water (Grim 1962) causing reduced particle-to-particle attraction leading to lesser frictional resistance. Finally, to elucidate further the mechanism of landslides and related problems in thrust zones of Nepal, various other studies including details in clay mineralogy and shear strength characteristics are of greater importance.

References

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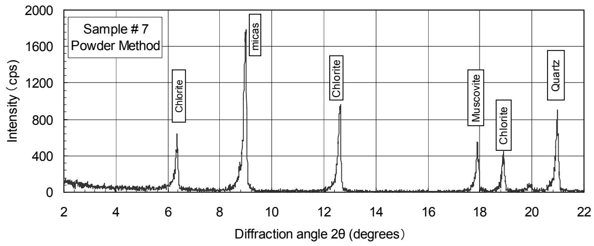

Fig. 2: A typical XRD pattern for the samples collected from landslide cites along the highways (location #7).

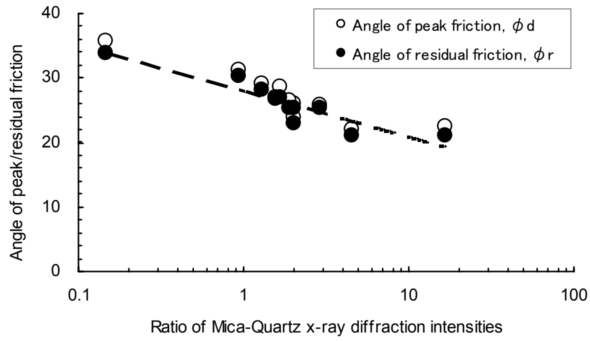

Fig.3: Variation of angles of internal friction with the peak intensity ratio

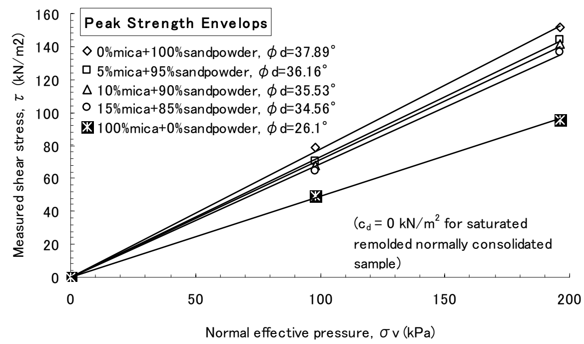

Fig.4a: Peak angles of internal friction for mica-sandpowder mixes.

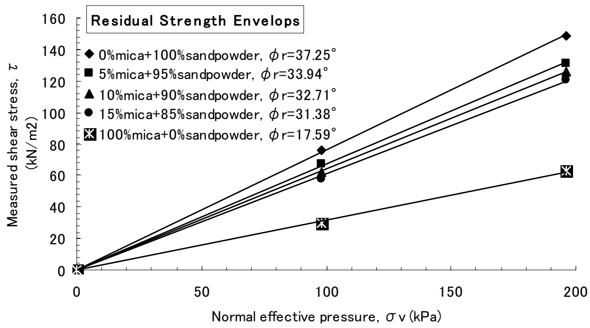

Fig.4b: Residual angles of internal friction for mica-sand powder mixes.

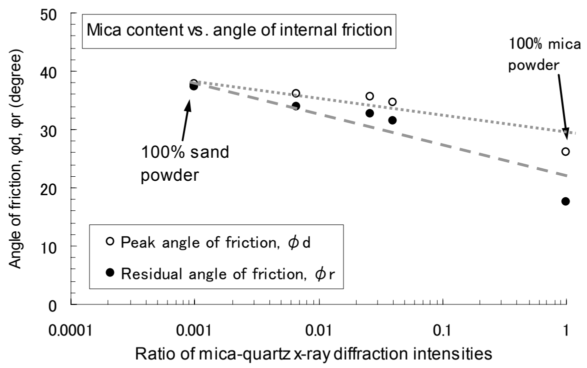

Fig.5: Change in internal friction angles with mica content.