

Studies of Rock Characteristics and Timing of Creep at Selected Landslide Sites in Taiwan

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Abstract.—A study was conducted to investigate the causes of and rock characteristics at three landslide sites in the Tesngwen Reservoir watershed of southern Taiwan. Research methods used included the petrographic microscope, X-ray diffraction (XRD), scanning electron microscope (SEM), inductively coupled plasma spectroscopy (ICP), constant head permeameter in triaxial apparatus, surface extensometer, and seismic exploration by wave-refraction processes. Chemical analyses of the rock indicated a higher Na than K content at all three landslide sites; iron normally occurs as Fe³⁺. The relationships between percolation velocity (V) and gradient (I) were developed for the different sites. A prediction equation for the timing of landslide failure was also developed from surface extensometer measurements.

Introduction

Managers of many watersheds in Taiwan are concerned about landslides due to heavy torrential rains during the May through October typhoon season, steep topography, young and weak geological formations, erodible soils, and improper land uses. Many methods exist to mitigate these situations. However, land instability and land use capability are core concerns, which are successfully addressed through sound soil and water conservation practices.

With a design capacity of 650,000,000 m³, the Tesngwen Reservoir located in southern Taiwan is the largest reservoir on the island. Serious landslides occur frequently at many locations around this reservoir. Generally, factors affecting these landslides are naturally occurring. Taiwan is located in an active tectonic area; the collision site between the Philippine Sea Plate and the margin of the Eurasian Plate (Lin, 1991). The topography and lithology reflect the interaction of the tectonic system with exogenetic processes. The purpose of this study was to investigate the causes of and rock characteristics at three landslide sites on this watershed.

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Methodology

Landslides often reflect the interaction of natural and human factors. A hillslope-material rupture mechanism model addresses the importance of this interaction (Lee, 1982). The methodology of this study followed this model using rock-petrographic microscope methods and the recognition, identification, and rupture timing of landslides of Taiwan.

The proposed concept is based on the nature and mechanism of landslides using direct boring core and surface geologic data. Landslides are caused by natural and environmental processes including the original landmass, hillslope material, and landforms. Techniques used in this study include petrographic microscope, X-ray diffraction (XRD), scanning electron microscope (SEM), inductively coupled plasma spectroscopy (ICP), constant head permeameter in triaxial apparatus, surface extensometer (Hoek, 1981), and seismic exploration by wave-refraction processes. These methods emphasized reliability rather than statistical precision by careful sample selection and pretreatment measurements. A prediction model and seismic prospecting for the rupture timing and macrostructure of landslide were also developed.

Results

Field observation and lab techniques were used to analyze landslide properties, to obtain petrographic characteristics, to predict creep rupture timing, and to explore the depth of the slide layer. Landslide mechanisms were established in the Tsengwen reservoir watershed using landslide investigation data. Three landslide sites at Da-Pang, Ta-Tou and Mao-Pu-Tse, were arc-creep failure types. The occurrence of these landslides was caused by a combination of natural and environmental factors.

Petrographic analysis is useful to investigate the origin of rock material. Certain sets of rock-forming minerals are

associated with rock core. Overlays and unconformities are suspected from certain discontinuities in the mineralogical composition of samples taken at different depths in a given landslide profile. The presence of sericite in rock specimens at these landslide sites may indicate altering rock deposit. Evidence of sericite and feldspar may be critical to explain some rock characteristics (table 1 and figures 1 through 3). The shape, size, and spacing of primary mineral grains may also be related to changes caused by weathering and rock-material development. Clay minerals (matrix) may force primary or skeletal rock-forming mineral grains to separate. Clay minerals control the rupture surface of the rock core at landslide sites. The condition of resistant minerals also answers some questions related to these landslides. Petrographic microscope techniques allow observation of rock-forming mineral in the process of alteration in the landslide profiles. Stages of

weathering can be followed, and the source of secondary mineral (sericite) can be observed (Carroll, 1970; Cady, 1986; Wang, 1964).

Time-dependent behavior in hillslope material is referred to as creep landslide (Terzaghi, 1950; Saito, 1966; Roberts, 1977; Bates, 1987). In addition to the time factor, creep rupture is dependent on pore-water pressure, geostress, and temperature. Creep of rock detritus frequently occurs on hilly terrain. The motivating force is gravity, although lateral stress is sometimes important. The deformation mechanism is essentially one of plastic flow in which a slow downslope failure of the whole mass is combined with a vertical movement of fragments through the moving layer. Surface extensometers were used to measure displacements at different depths of a given profile at six landslide sites (figure 4).

Table 1. Mineral composition of rocks as determined by XRD method

Rock Samples	Quartz	Feldspar	Muscovite	Calcite	Illite	Chlorite	Kaolinite
Da-Pang LS							
TPL2-2	+++*	++	-	-	+	+	+
TPL2-6	+++	++	-	-	+	+	-
TPL3-5	+++	++	-	-	+	+	-
TPL3-6	+++	++	-	-	+	+	-
Ta-Tou LS							
TL5-4	+++	++	++	++	+	+	-
TL5-5	+++	++	-	++	+	+	-
TL6-2	+++	++	-	-	+	+	-
TL6-3(1)	+++	++	-	-	++	++	+
TL6-3(2)	+++	++	-	-	+	+	+
TB-7	+++	++	-	++	+	+	-
TB-8	+++	++	-	-	+	+	-
TD2-3a	+++	++	-	-	+	+	-
TD2-3b	+++	++	-	-	+	+	-
Mao-Pu-Tse LS							
MPL3-5	+++	++	-	-	-	-	-
MPL11-4a	+++	++	-	-	-	-	-
MPL11-4b	+++	++	-	-	-	-	-

*.+++ : dominant (38~58%) ; ++ : major (18~38%) ; + : minor (<18%) ; - : not detected (ND)

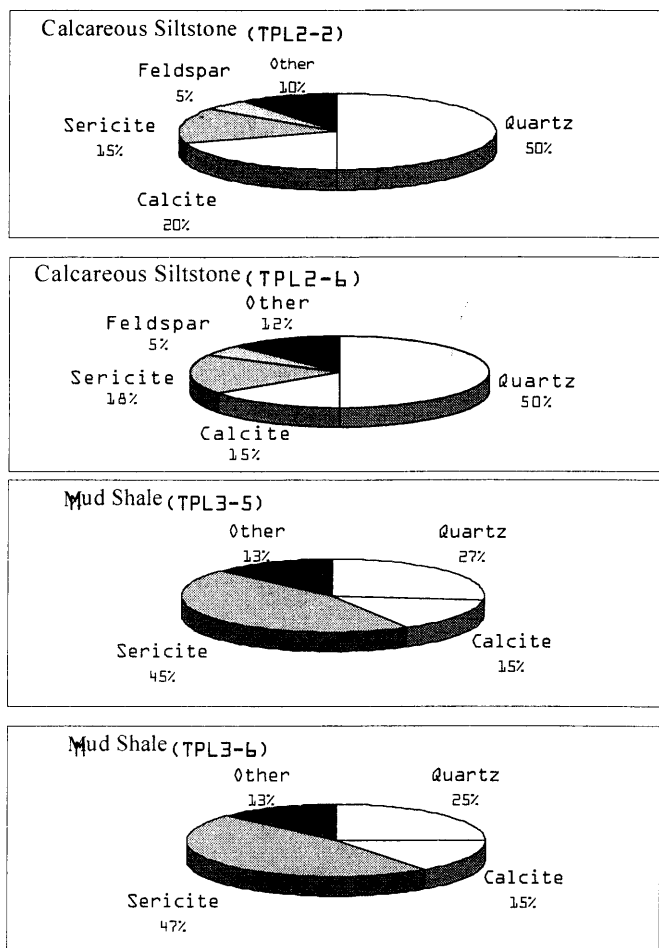


Figure 1. Relative abundance of mineral composition of rocks at Da-Pang landslide (volume %).

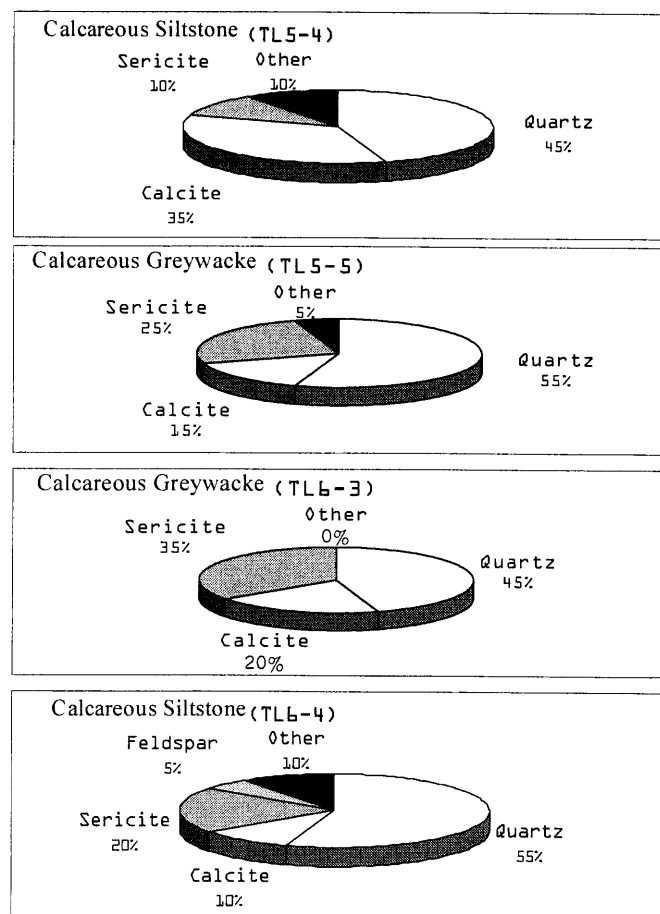


Figure 2. Relative abundance of mineral composition of rocks at Ta-Tou landslide (volume %).

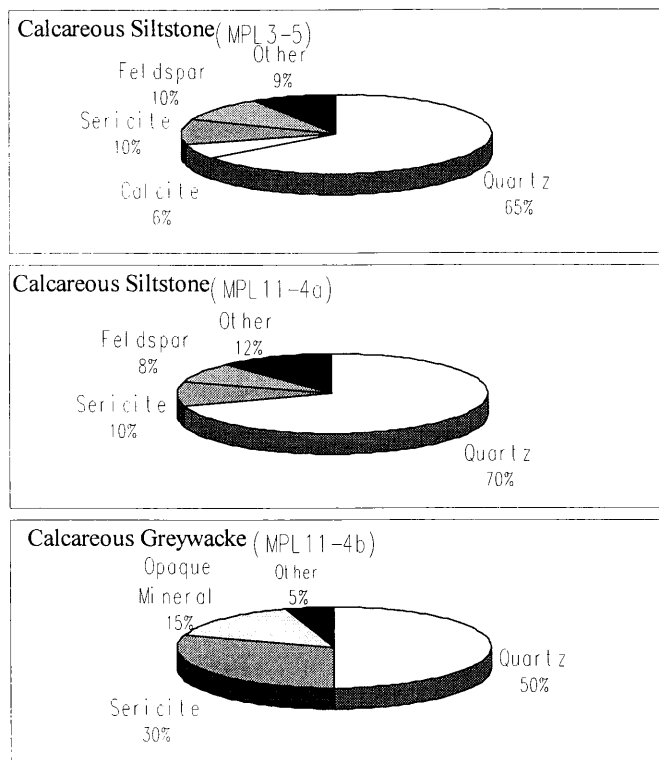


Figure 3. Relative abundance of mineral composition of rocks at Mao-Pu-Tes landslide (volume %).

Conclusion

The mechanisms, causes, and rock properties at three landslide sites in the Tsengwen Reservoir watershed in southern Taiwan were studied. A prediction model for the rupture timing of creep landslides was also developed. Critical results are summarized as follows:

- The Da-pang landslide is an arc-shape creep failure type. Landslide failure was due to the steep topography, a road cut, and saturated hillslope material from heavy summer rainstorms. The rock stratigraphic unit of the site is in the Neogene Middle Miocene Da-Pang Formation composed mainly of argillaceous shale and calcareous siltstone. The mineral components of argillaceous shale include sericite, quartz and calcite; calcareous siltstone includes quartz, calcite, sericite and feldspar.
- The Ta-Tou landslide, another arc-shape type creep landslide, was caused by road excavation, concentrated runoff, poor drainage, increased pore-water pressure due to rain-storms, and gully head

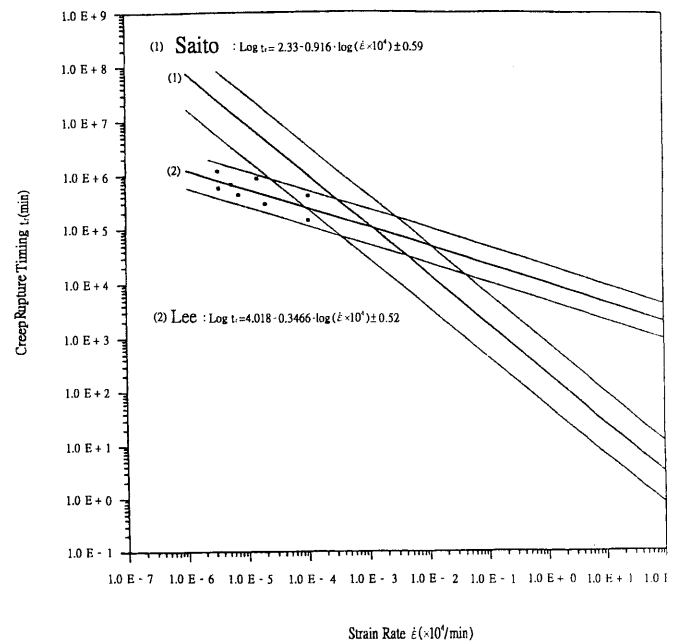


Figure 4. Comparison of rupture timing between Saito and Lee models.

erosion on a steep slope. The site is located in the Neogene Late Miocene Nanchuang Formation with calcareous sandstone and calcareous shale containing quartz, calcite, sericite and feldspar, and quartz, sericite and calcite, respectively.

- The Mao-Pu-Tse landslide is also an arc-shape type failure. This landslide was caused by the fluctuating water levels of the reservoir and the flow of the hillside after extended submersion in water undercutting of the hillslope. The Neogene Late Miocene to Early Pleistocene Kueichulin Formation at the site contains siltstone and fine greywacke with quartz, sericite and feldspar.
- Chemical analyses of the rock indicate a higher Na content than K at all three landslide sites. Iron normally occurs as Fe^{3+} .
- For different pressure heads at the same depth, the relationship between permeability velocity (V) and hydraulic gradient (I) are:

Da-Pang landslide site $V=0.0100 \sim 0.0138I$

Ta-Tou landslide site $V=0.0146 \sim 0.0211I$

Mao-Pu-Tse landslide site $V=0.0099 \sim 0.0207I$

- For different rock depths at the same pressure heads, the relationship between permeability velocity (V) and hydraulic gradient (I) are:

Da-Pang landslide site $V=0.0121I$

Ta-Tou landslide site $V=0.0211I$

Mao-Pu-Tse landslide site $V=0.0144I$

- The prediction model for the creep failure timing developed from surface extensometer measurements at six landslide sites is:

$$\log t_r = 4.018 - 0.3466 \log (\epsilon \cdot 10^4) \pm 0.52$$

where:

t_r is the creep failure timing (T)

ϵ is the strain rate (t^{-1})

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