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Dramatic weakening of shale and fault gouge as a mechanism for Tsaoling landslide induced by 1999 Chi-Chi earthquake

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Tsaoling landslide was the largest landslide triggered by 1999 Taiwan Chi-Chi earthquake. Sliding of the rock mass of 1.3 Km^3occurred along the boundary between Pliocene Cholan formation and Chinshui shale (Chigira et al., 2003). Despite it slid along a gentle slope (14°), the landslide mass probably reached several tens of m/s in speed and crossed over the river. For better understanding of mechanisms of such catastrophic landslides, we performed high velocity friction experiments on shale gouge and clayey bedding-parallel fault gouge collected from Tsaoling landslide area at slip rates from 0.01 to 1.3 m/s. XRD analysis show that both shale and clayey fault gouge contain quartz, plagioclase, illite, kaolinite, chlorite, and montmorillonite. Shale and gouge are not very different in mineral compositions. Experiments were done in both dry and wet condition at a normal stress of 3 MPa that roughly corresponds to the overburden pressure at the base of about 150-meter thick Tsaoling landslide mass. All results show dramatic slip-weakening towards steady-state frictional coefficient of 0.05 to 0.15 (friction angle of 3°to 8.5°). This is consistent with the prediction of 0.15 (8.5°) from analysis with discrete element method (Tang et al., 2009) and with 0.1 (6°) predicted from modeling using Saint Venant equations (Kuo et al., 2009). Peak frictional coefficient was around 0.2 (or 11°in angle of friction) for wet fault gouge, and hence it is unlikely that the sliding surface was covered completely with wet clayey fault gouge because it cannot sustain the slope even without earthquake. Whereas dry clayey fault gouge and wet shale gouge exhibit similar behaviors with the peak friction of about 0.6 (ca. 30°in angle of friction) followed by slip weakening with the weakening distance of a few meters. In other words, friction reduces from peak friction to 0.25 corresponding to the slope angle after 2 to 3 meters of sliding by slip weakening mechanisms in order to develop into catastrophic landslide. Experiments at different slip rates have revealed that the steady-state friction decreases dramatically with increasing slip rate. Low friction at high slip rates must have caused high-speed Tsaoling landslide. Thus our results provide fundamental information for analyzing triggering and sliding of the Tsaoling landslide.

References

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