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Triggering and catastrophic sliding of the 1999 Jiufengershan landslide in view of high-velocity friction experiments

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Jiufengershan landslide was one of the two large-scale catastrophic landslides triggered by the Chi-Chi earthquake of 21 September 1999 (e.g., Wang et al., 2003). Jiufengershan landslide is located about 12 km to the north-northeast of the epicenter. The huge rock mass slid along bedding planes of Tertiary sedimentary rocks for distances over 1 km. The slope angle was 20 at the top and 36? at the base of landslide.

We have conducted high velocity friction experiments on shale gouge and clayey fault gouge collected from Jiufengershan landslide area at slip rates from 0.43 to 1.3 m/s, in order to understand the mechanism of the catastrophic landslide. A rotary shear low- to high-velocity friction apparatus at Hiroshima University (the second high-velocity machine) was used for the experiments. Experiments were done at a normal stress of 0.8 MPa that roughly corresponds to the maximum overburden pressure at the base of Jiufengershan landslide mass of 30-50 m in thickness. Clayey fault gouge was collected from small fault zones near the monocline reported by Wang et al. (2003). This paper reports bedding-parallel faults due to flexural slip folding. We were not sure if landslide occurred all along bedding-parallel faults or not, so that we used crushed shale using shale samples collected from a northern part of the landslide area. XRD analyses show that clayey gouge contains quartz, plagioclase, kaolinite, illite, smectite and chlorite and that shale is composed of similar minerals, but showed slightly stronger peaks of illite and chlorite.

High-velocity friction of clayey fault gouge and shale gouge is characterized by peak friction, subsequent dramatic slip weakening specified by the slip weakening distance, and low level of steady-state friction. Wet shale and clayey fault gouge at slip rates over 1 m/s exhibit ultra-low friction with steady-state friction of 0.1 or even less, whereas steady-state friction is 0.2 to 0.3 for dry clayey gouge. Such a low friction at high slip rates must have caused catastrophic Jiufengershan landslide triggered by Chi-Chi earthquake. Slip-weakening distance was around 10 m for all cases. Peak friction is 0.7-0.8 for dry clayey gouge, around 0.2-0.3 for wet clayey gouge, and about 0.15 or even less for wet shale gouge. In addition, the mineral composition did not change before and after experiment.

It was surprising to see a very low friction of shale gouge. Its peak frictional coefficient is nearly half of that for clayey fault gouge which corresponds to an angle of friction of about 11 o. This is far smaller than the slope of area (20-36 o). Wang et al. (2003) recognized peculiar structures such as monocline and buckling in the landslide area even before the Jiufengershan landslide, and they attributed those structures to unstable slope. They also proposed that the slope is supported by thick sandstone layers whose collapse can trigger landslide. Shale sample we used is just ordinary shale in the formation and is everywhere in the slope and our experimental results support do their observations and view.

Reference

Wang, W. N., Chigira, M. and Furuya, T. (2003). Geological and geomorphological precursors of the Chiu-fen-erh-shan landslide triggered by the Chi-chi earthquake in central Taiwan, Eng. Geol., 69, 1-13.

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