Seismic Stability Analysis of Tsukidate Landslide Triggered by the 26 May 2003 Sanriku – Minami Earthquake

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ABSTRACT

Earthquake–induced high–speed landslides are among the most destructive phenomena related to failure of slopes during earthquakes. Several landslides triggered by past earthquakes in Japan fall within this category (e.g., the January 1995 Nikawa landslide, Hyogo Prefecture; the January 1995 Takarazuka landslide, Hyogo Prefecture; the May 2003 Tsukidate landslide, Miyagi Prefecture). These landslides occurred on gentle slopes (i.e., ≤ 20°) along shear surfaces in saturated cohesionless materials, and were responsible of great lives losses and/or significant damage to the local environment due to the high mobility of the sliding earth mass.

The concept of "sliding surface liquefaction" was introduced by Sassa in 1996 to explain the phenomenon of gradual loss in undrained strength after failure with progress of shear displacement, exhibited during undrained cyclic shearing by the soil on the shear surface of the earthquake–induced Nikawa landslide. The major consequence associated with sliding surface liquefaction is that the process of shear strength reduction may result in ultimate steady state strengths smaller than static (gravitational) driving shear stress. In these circumstances, the potential sliding mass is expected to develop an accelerated motion under static conditions if the shear strength loss due to some transient disturbance (e.g., earthquake) is large enough to bring definitively the shear resistance on the sliding surface below the gravitational driving shear stress.

This study addresses an easy–to–use performance–based method of predicting the onset of a catastrophic landslide in liquefiable soils under seismic conditions. The equation of motion of an infinite slope for undrained conditions on the shear surface is derived based on the Newmark analogy between the potential landslide and a rigid block sliding on an inclined plane. The computational procedure employs the shear resistance–displacement data from undrained monotonic ring shear tests to obtain the undrained yield resistance on the sliding surface at a certain shear displacement during earthquake. An experimental study based on undrained monotonic and cyclic ring shear tests with initial shear stress carried out on saturated sandy soils comes to support the accuracy of this approximation.

The proposed sliding block formulation was utilized to investigate for various groundwater levels above the sliding surface, the seismic performance of Tsukidate landslide triggered by the 26 May 2003 Sanriku–Minami earthquake in Tsukidate town, Miyagi Prefecture. The shear resistance–displacement curves used in undrained dynamic calculations were provided by undrained monotonic ring shear tests on soil specimens from Tsukidate landslide site. According to the numerical results, a ground water level at a height above the sliding surface equal to almost half of the average thickness of the slide mass appears to be sufficient for the onset of a catastrophic landslide during the 26 May 2003 Sanriku–Minami earthquake. It was also found that the softening of the material on the sliding surface has a crucial role upon the accelerated motion of the slide mass after the initiation of a catastrophic failure.

The analysis presented in this study strongly emphasizes the effectiveness of a performance–based methodology in making reliable assessments of earthquake–induced catastrophic landslide risk, provided its capability to encompass the sensitivity of computed displacements to variations in yield acceleration; when comparing with a traditional limit equilibrium approach, where the seismic loads are treated in a pseudo-static fashion.