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Development of Deep-Seated Gravitational Slope Deformation on a Dip Slope by Accelerated River Incision: Insights from Numerical Simulation

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As an integrated mass movement process, deep-seated gravitational slope deformation (DSGSD) is usually controlled by topography, geological structures, lithology and related mechanical properties, and geological history. This paper aims to acquire a comprehensive knowledge about the controlling factors, driving mechanisms and evolution process of DSGSD on a shale-dominated dip slop located in Kii-mountains, to clarify the origin of shear zones encountered in drill cores; and to reproduce the topographic features through numerical simulation.

Combining strength reduction technology, the numerical simulation was performed with continuum-based finite difference method FLAC, using Mohr Coulomb model with tension-cutoff and Ubiquitous Joint model. River incision process was simulated by eliminations of the corresponding elements to reproduce the physical change of modelling system.

Numerical simulation demonstrates that long-term strength degradation of rock mass due to physic-chemical weathering and stress-induced damage is an important controlling factor for DSDSD initiation and development. An elastic rebound displacement will occur if taking no account of strength degradation, which is resulted from unloading induced by river incision. Moreover, river incision constitutes an important triggering mechanism for evolution of DSGSD in the Kii-mountains. River incision deepens and steepens the slope, which in turn results in development or acceleration of stress concentration and readjustment at the slope toe. Correspondingly, two major different plastic shear zones are formed in different river incision stages and they connect with each other. It is deduced that new shear failure zone might occur accompanied by further river incision.

Numerical results considering the influence of bedding planes reveal bedding planes constitute a structural control for DSGSD due to its weaker strength. The evolution of DSGSD in a dip slope involves both local shear slip failure along the bedding planes and brittle fracture of intact rock across the bedding planes, which consequently results in shear failure propagation in a stepwise manner.

Numerical simulation reproduces weak zone distributions and brittle deformation structures recognized from drill cores very well, which illustrates these weak zones are formed due to DSGSD triggered by river incision while not tectonic activity. Moreover, the numerical simulation creates a link between gravitation-associated surface features of dimple-like depression and deformational structures within the slope. This indicates that topographic features are surface expression of deep-seated failure mode in the slope.

Different from traditionally geomorphological and macroscopic structural analysis for DSGSD, this study also illustrates that numerical simulation can provide a significant convenience for understanding the driving mechanisms, the kinematic and dynamic behavior of DSGSD. The study results may consequently provide a helpful reference for landslide hazard mitigation and management of potential landslide areas.