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# Toppling deformation process of an anti-dip rock slope under excavation: a physical model investigation

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The toppling deformation is a typical failure mode of the destabilization of the anti-dip rock slope. Its deformation and failure is the process of accumulating deformation strain energy. The study of toppling deformation should pay attention to its time-dependent deformation and cracking process. The slope of the Zhala hydropower station dam site in Tibet is an anti-dip slope made up of thin layer of slate. It is controlled by the continuous effect of the terrain of steep and narrow river valleys and the river valleys geo-stress field of steep slope, showing the strong toppling deformation. For studying on toppling deformation evolution process, a physical model is established based on this slope geological knowledge and similarity theory, and method of staged excavation is adopted to simulate the incised action of a valley. The evolution of the toppling deformation of the slope is studied through the deformation and rupture of the model slope during excavation and the analysis of the real-time displacement monitoring data. The development process after excavation shows that: The toppling deformation modes of anti-dip slope has experienced three stage, initial unloading rebound deformation, long-term gravity bending (fracture) deformation and creep deformation in the later stage. Firstly, the unloading and airfield conditions are the starting factors of slope toppling, which play a leading role in the initial stage of toppling deformation. With the internal stress adjustment of slope body, the toppling deformation first appears from the foot of slope and gradually declines to the interior of slope body. Secondly, the development of toppling deformation is mainly caused by the slow bending deformation of rock slab and the birth of rupture zone under the action of slope weight. When the internal rupture zone passes through gradually and forms a uniform bending zone with the tension crack in the trailing edge, the toppling deformation begins to transform to creep deformation. Finally, slope rock occurred the whole slip damage along the bend rupture zone. Through the analysis of the law of displacement, deformation rate and deformation acceleration: The toppling deformation process of anti-dip slope can be divided into 3 evolution stages(the stage of toppling initiation, the stage of steady deformation and the stage of rapid destabilization) according to the deformation acceleration a($a<a1\leq 0$,$a1\leq a<a2$,$a\geq a2$, a1 and a2 are the upper and lower limits of the acceleration fluctuation in the stage of steady deformation respectively, and are constants close to 0). Each stage corresponds to the deformation characteristics of attenuation creep, steady creep and accelerated creep respectively. On this basis, the deformation acceleration a is used as the criterion of slope stability, and try to use a2(upper limit of steady-state creep) as a slope instability prediction criterion. That is, if a reaches or exceeds the a2,the acceleration fluctuation upper limit value in the steady creep stage,it is considered that the toppling body begins to destabilize.