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The transition from toppling to sliding in deep rock slope instabilities

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This study is based on detailed monitoring data from a large DSGSD called Moosfluh instability, located at the current glacier tongue of the Great Aletsch Glacier (Switzerland). This about 100 Mm^3 large, and up to 170 m deep toppling mode instability started to accelerate around 1990, presumably caused by increased rates of glacier ice downwasting at the landslide toe. In 2013 and 2014, when average velocities reached about 500-700 mm/a, we installed a high accuracy displacement monitoring system, composed of 2 robotized total stations measuring displacements at about 15 reflectors positioned within the active landslide, 4 GNSS stations, and 2 Time-Lapse cameras. In the fall of 2016 a dramatic increase in acceleration occurred, leading to velocities of individual landslide compartments of up to 12 m in 6 weeks. Optical imagery and digital image correlation revealed that this acceleration was caused by the rapid development of three secondary rockslide scarps, and that movement initiated at the toe of the slope and evolved upslope. To investigate the depths of movements and the subsurface kinematic mechanism in detail, we developed a new analytical model, which considers the time series of three-dimensional displacements and plunge angles of discrete points within the landslide. The application of this model leads to the conclusion that a transition from primarily toppling to sliding mode displacements occurred during fall 2016. We can trace the detailed evolution of individual compartments, showing that toppling/sliding ratios varied in both space and time. The secondary rockslides forming during this period have a depth of about 30-40 meters and volumes ranging between 1 and 5 Mm^3. Planar sliding surfaces are expected to have developed at a major kink zone within the large toppling rock mass.

This kinematic evolution observed at Moosfluh significantly impacts the corresponding hazard and risk assessment, as flexural toppling tends to be a self-stabilizing mechanism, whereas planar rockslides can potentially transition into catastrophic failures. The estimated potential runout length probabilities show that the main hazard would be created by the formation and subsequent breach of a rock avalanche dam in the Massa gorge below the tongue of the Great Aletsch Glacier.