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Back-analysis of the 1756 Tjellefonna rockslide (western Norway)

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The 22nd of February 1756 the largest historically recorded rockslide in Norway took place at Tjelle in Lang Fjord (western Norway). Three displacement waves of up to 50 meters were created by the impact of the failed rock mass constituting the Tjellefonna rockslide. A total of 32 people were killed and several houses and boats around the fjord were destroyed.

This study presents a back-analysis of the Tjellefonna rockslide by (1) reconstructing the topography before the rockslide, (2) assessing the volumes of the initial rockslide mass, the onshore deposits and offshore deposits, (3) assessing the major discontinuities involved in the rockslide, and (4) by 2D numerical slope stability modelling for a detailed study of the parameters and trigger factors that affected the slope stability.

The topography before the rockslide is reconstructed using (1) the Sloping Local Base Level technique and (2) a manual ART reconstruction in the PolyWorks software. Both topographic reconstructions yield an initial rockslide volume between 9.2 and 10.4 million m3, which is lower than previous estimates (12-15 million m3). The onshore deposits are estimated to 7.6 million m3 and only 3.9 million m3 deposited in the fjord. Finally, the volume impacting the fjord (3.9 million m3) is important for the generation of rockslide-triggered displacement waves, which highlights the necessity of precise volume estimations prior to back-analyses of landslide-triggered displacement waves.

The granitic to granodioritic gneissic rock mass at Tjellefonna have high to very high mechanical strength. However, field mapping reveals that the intact rock strength is compromised by a combination of a variably developed foliation, extensive faulting and four persistent joint sets. The foliation is often folded into open folds with sub-horizontal axial planes. The foliation, faults and two joint sets are sub-parallel to Langfjorden and to regional structural lineaments. The back walls of the Tjellefonna crown are made up of a combination of these structures, while two joint sets that strike perpendicular to the fjord define the flanks of the scar.

The numerical slope stability model Phase2 analyses include shear strength reduction (SSR) investigations and parameter sensitive tests. These tests demonstrate that the failure of the Tjellefonna slope must have required strain softening in combination with triggering factors, where high groundwater level is an essential feature. An earthquake has previously been assumed as trigger, but sensitivity tests rule out seismic acceleration as a factor alone. Additionally, the analyses show that a sub-horizontal discontinuity set is critical in order to induce slope instability. The shallow fjord-dipping joint set and sub-horizontal fault might form this necessary discontinuity, although they were only mapped locally and their persistence was limited.

The sliding surface has been evaluated using the Phase2 model and the topographic reconstructions. It is concluded that the Tjellefonna rockslide was not composed of a uniform plane, but of a complex surface consisting of joints, faults, foliation surfaces and intact rock bridges. Finally, the failure was thus likely a consequence of progressive accumulation of rock weakening (strain softening), acting to degrade the equilibrium state of the slope. This could have generated a hillside creep explaining the opening tension cracks observed at the present head scarp prior to the rockslide.