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Movement of a long-runout landslide in deep snow: A case of the Kokugawa landslide in the Joetsu area, Niigata, Japan

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On 7 March 2012, a snowmelt-induced landslide (hereafter, the Kokugawa landslide) occurred on a gentle slope (10-20 degree) of Higashi-Kubiki Hill, adjacent to the Takada floodplain in the Joetsu area. The displaced mass of the Kokugawa landslide travelled 750 m from the scarp, destroying 11 houses in the process. The landslide occurred in the early snowmelt period, and the site was covered by a 2-m-thick snow layer when the landslide initiated. A major reason for the long runout may have been reduced friction at the snow interface at the base of the displaced mass. To examine this hypothesis, we describe the detailed movements and topographies of the landslide, based on field observations and aerial photography and LiDAR observations. We then discuss how the snow affected the behaviour of the landslide movements.

The site consists of Neogene marine mudstone and Early Pleistocene conglomerate, with the slope surface covered by loose materials (7-8 m thick) composed of old colluvial deposits and spoil materials from gravel extraction in the 1980s. The collapsed slope was 500 m long and 150 m wide, and the volume of the displaced mass was estimated to be 750,000 m3. The apparent friction angle was 9 degree (H/L = 0.15), as low as that of debris flows or extremely large landslides. Thus, the Kokugawa landslide had a significantly longer runout than landslides with an equivalent volume.

Although the outer part of the displaced mass spread out and deposited at the foot of hill, 350-500 m downward of the scarp, the main body of the mass continued to move rapidly (approximately 15 m/h) without spreading out after reaching a flat paddy field (1-3 degree). Snow on the paddy field was pushed by the mass and swelled up several meters above the snow surface level. The swelled snow formed a moraine-like snowpack of 5-20 m width around the mass. The mass including the snowpack reached houses 250 m from the foot of the hill on the morning of 10 March and stopped after destroying them. Repeated measurement of fixed points on the snowpack and the mass revealed that the mass, including the snowpack on the paddy field, gradually spread out over nine days after reaching the houses.

A lateral ridge developed for 180 m along the right side of the mass on the paddy field. At the boundary between the ridge and the snowpack, slickenlines were observed on the flank of the ridge. Neither snow nor mixed sediment/snow layers were found at the base of the ridge, and the ground surface beneath the ridge appeared undisturbed. In contrast, profiles from boring cores and a transverse trench at the centre of the mass showed that a clay layer about 1 m thick in the paddy field was eroded by the mass. Thus, the formation of the lateral ridge could be attributed to the following two mechanisms: lateral confinement by the compacted moraine-like snowpack that developed around the mass, and depression of the centre of the mass caused by the ground surface erosion.

We could not find any distinct evidence to support the hypothesis that reduced friction at the snow interface at the base of the displaced mass was the major reason for the long runout of the Kokugawa landslide. Rather, our results suggest that the long runout was a result of lateral confinement by the compacted moraine-like snowpack. The behaviour of the Kokugawa landslide indicates that snowpack confinement has a major effect on landslide movement. This effect should be taken into account for accurate prediction of landslide runout and related hazard mitigations in heavy snowfall regions.

Keywords: landslide, long-runout, deep snow condition, lateral ridge