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Structural control and preliminary numerical modelling of large bedrock slope failures in the Bhutan Himalaya

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Bhutan is linked from east to west by one continuous road, the East-West Highway, traversing mountainous terrain in the foothills of the Himalaya at altitudes between 700 and 4000 m a.s.l. The highway is severely affected by rainfall-triggered landslides, which often result in the closure of the road at multiple locations over prolonged periods. This has a major economic and social impact on the nation. The most common type of mass movement are debris flows that are triggered by intense and extensive monsoon rainfall. These either deposit material onto the road surface or remove material from beneath the road. Less common, both spatially and temporally are large bedrock slope failures, which in the study region of central and eastern Bhutan are characterised by jointed, folded and fault-damaged gneiss and schist. This research examines data collected at two large bedrock slope failures affecting the main highway. One landslide is presently considered inactive, whilst the other is highly active, closing the highway for several hours daily. The positions of the two failures are shown to be controlled by the daylighting of the rockmass discontinuities at the steep valley side, resulting in large wedge failures of highly fractured material that evolve into a source for debris flow and rockfall. Each of the failures had been surveyed using high precision Terrestrial Laser Scanning and a traditional joint survey to characterize the rock slope for numerical modelling purposes. Preliminary results are presented of modelling using both a commercially available continuum finite difference code and a hybrid finite element / discreet element discontinuum code better suited to a highly joined rock mass. Features under study include the initial failure surface generation and future evolution, the role of fluvial incision and the effect of slope cutting during road construction.