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Characterization of a large landslide complex in weak rock at Cape Turnagain, North Island, New Zealand.

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Cape Turnagain is located on the east coast of the southern North Island, New Zealand. The physiography of the area is characterized by rolling hills and near vertical coastal cliffs up to 250m in height. The bedrock geology underlying the site consists of a weak Miocene blue-grey calcareous mudstone overlain by a resistant Pliocene beige fossiliferous limestone cap. The region has a dominant northeast-southwest tectonic fabric that is a result of past and on-going oblique subduction of the Pacific Plate under Australian plate. Also due to the plate boundary, the study area is seismically active with 253 earthquakes (within an approximately 50km radius of Cape Turnagain) of magnitude of 4.0 or greater since 1892 listed in the New Zealand national earthquake database (GEONET). These include five earthquakes with a magnitude greater than 6.0.

The Cape Turnagain landslide complex exhibits a wide range of mass movement types that are active at various scales. The main component of which is a slumped block 700m long, 300m wide and approximately 150m thick for a volume on the order of $30Mm^3$. An old debris avalanche initiated at the front of the slumped block where resistant limestone boulders from its deposit can be observed 500m from the bottom of the cliff. This colluvial material now acts as rip-rap protecting the southwestern end of the slumped block from current coastal erosion. Active soil and bedrock erosion is evidenced by gullying in the main mass wasting complex and areas surrounding it. Tension cracks and disturbed vegetation in the headwall and sidewall of these gullies suggest ongoing slope instabilities. Finally, terracettes indicate ubiquitous soil creep processes in surrounding slopes with gradients greater $\sim 20^o$ that are used as pasture.

The rock mass quality observed at Cape Turnagain was quantified using the Geological Strength Index (GSI). According to this classification the rock mass structure was very block to disturbed/blocky/seamy and the surface conditions were dominantly fair. This corresponds to an average range of GSI values of 35-45. The field strength estimates of the mudstone suggested that it was weak (could be peeled with pocket knife with difficulty and indented by firm blow of geological hammer, 5-20MPa) while the limestone was moderately strong to strong (requires one or more blow of geological hammer to break 20-100MPa). The intact rock strength of the weak mudstone was further characterised using a NCB cone indenter. The results of 60 tests on two samples estimate the unconfined compressive strength between 5-6MPa. The GSI and intact rock strength estimates were entered in the freeware RocLab to derive equivalent rock mass strength values. These equivalent rock mass strength parameters were used as input for limit equilibrium and finite difference slope stability analyses. Preliminary models using both techniques suggest that the factors of safety for the overall slope conditions are in the 1.1-1.2 range for a dry slope scenario.

Discontinuity measurements (N=65) were collected in the mudstone unit of the headscarp area. The discontinuity surfaces were dominantly planar and smooth (with some rough surfaces). The bedding was observed to dip gently ($\sim 10^o$) into the slope. A preliminary kinematic analysis using the discontinuities orientation measured and assuming a friction angle of 30^o suggests that planar sliding is feasible on some surfaces, while wedge sliding would need a lower friction angle to be feasible and toppling is not feasible.