Landslide Dams Caused by the November 14, 2016, M7.8 Kaikoura Earthquake, New Zealand

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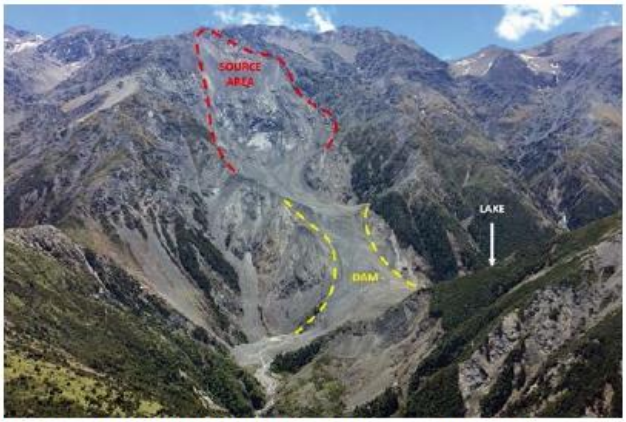
INTRODUCTION

At 12.03 am local time on 14th November 2016 (UTC: 11.03 am 13th November 2016) a shallow magnitude 7.8 earthquake, with an epicentre located near Waiau in North Canterbury, struck the North Canterbury and Marlborough regions of New Zealand. The earthquake produced one of the most complex fault ruptures observed in the historical period, with at least 23 on-land and submarine fault surface ruptures mapped. The most visible consequence of the strong ground shaking was widespread landslides. More than ten thousand landslides were triggered over a total area of about 10,000 km^2 with the majority concentrated in a smaller area of about 3,600 km^2.

LANDSLIDE DAMS

A feature of the landslides from this earthquake is the large number (196) of drainage blocking landslides it generated. This was partly due to the steep and confined slopes in the area and the widely distributed strong ground shaking. The largest landslide has an approximate volume of 23 (±2) M m^3 and the debris from this travelled about 2.7 km down slope where it formed a dam blocking the Hapuku River. Ten other valley blocking landslides with volumes ranging from 1 M to 10 M $m^3$are also known to have been triggered by the earthquake. The stability of the dams, and potential for sudden breaching and flash-flooding downstream, were a cause of major concern in the months following the earthquake.



Hapuku landslide dam: about 20 million cubic metres of rock travelled 2.7 km to the valley floor, blocking the Hapuku River.

Hapuku landslide dam, showing the deposit and lake forming upstream (photo: Environment Canterbury).

The majority of the landslide dams occurred in two geological and geotechnically distinct materials: weak sedimentary rocks (sandstones and siltstones) where first-time and reactivated rock-slides were the dominant landslide type, and; strong sedimentary rocks (greywacke and limestones) where first-time rock and debris avalanches dominated. This gave rise to two quite distinct end-member landslide dam types, large rock block slides comprised a few large blocks, and rock and debris avalanches comprised of coarse angular gravels.

Identifying the location and size of landslide dams was a priority in the post-earthquake response because of the potential public safety risks. Once dams had been located the hazard of catastrophic failure (likelihood) was assessed. Those with a higher likelihood of catastrophic failure had the consequences (risks) from failure identified. Those with a higher likelihood of failure and substantive risks were examined in more detail using field mapping and terrestrial laser scanning. These data were used to model the catastrophic failure scenarios to determine the scale of the hazard so that appropriate countermeasures could be put in place to alleviate the risks.

One year following the earthquake, most of the landside dams had failed. One of the landslide dams failed and overtopped within 24 hours of forming. Another failed within one month, and several dams failed as the result of rainfall associated with Cyclone Cook in April 2017. Most of the dams failed by a combination of overtopping, seepage and headward erosion during high intensity rainfall events. The evolution and failure modes of the landslide dams since the earthquake has varied with a wide range of factors including dam composition, dam height, upstream catchment area and subsequent triggering events (e.g. rainstorms) influencing dam longevity. 3D modelling of some of the landslide dams using repeat aerial LiDAR and ground-based laser scanning has enabled us to understand how the dams have changed with time, such as with the development of overflow channels, erosion and seepage points prior to failure.

Landslide dam on the Conway River (a) two days following the Kaikoura earthquake, and (b) one week following the earthquake. The landslide dam failed due to a combination of seepage and headward erosion through the landslide deposit.

Key words: Dam outburst flood, early warning system, Kaikoura Earthquake, landslide dam