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Engineering geology and stabilisation of the 2011 landslide which closed SH3 in the Manawatu Gorge, New Zealand

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ABSTRACT

The Manawatu Gorge contains a major road (State Highway 3) and rail link between the west and east coasts of the southern North Island. Excavations for the establishment and widening of SH3 on the south side of the gorge have cut back and oversteepened the toes of many slopes, resulting in rock falls and landslides that affected or closed the road in many places since it was completed in 1872. This paper relates to the ~150,000 m^3 landslide in the Manawatu Gorge in 2011 which closed SH3 for 13 months. The landslide resulted from a combination of adverse geological and geomorphic factors, together with poor road design and highway maintenance practice which undercut the toe of a large prehistoric landslide at the top of slope. Extensive earthworks were carried out to stabilise the slope by removing 370,000 m^3 of soil and rock from above and below the landslide and re-grading the slope to an overall angle of ~40°, which is similar to the long term stable angle for the slope. Other stabilisation and protection measures included slope drainage and the installation of steel mesh and catch fences to reduce the risk from small rock falls on the slip face, and grouted anchors to stabilise the colluvial slope to the west. These measures have effectively stabilised the slope and reduced the risk of further large-scale landsliding at the site to a very low level.

Keywords: Manawatu Gorge, landslide 2011, stabilisation earthworks, SH3
Steel mesh and a rock fall fence were installed to reduce the risk of rock falls on the slip face,

1 INTRODUCTION

The Manawatu Gorge is an antecedent gorge which has been cut by the Manawatu River eroding through the Tararua–Ruahine range over the last ~1.5 million years. Bedrock in the area comprises indurated greywacke sandstone, siltstone, and argillite of Triassic–Jurassic age (Lee and Begg 2002). The steep (~35–>60°) slopes of the gorge are overlain by surficial colluvium, old (prehistoric) landslide deposits, and remnants of alluvial deposits on the upper slopes. The Manawatu Gorge situated 12 km northeast of Palmerston North contains a major road (State Highway 3) and railway line (Figure 1).

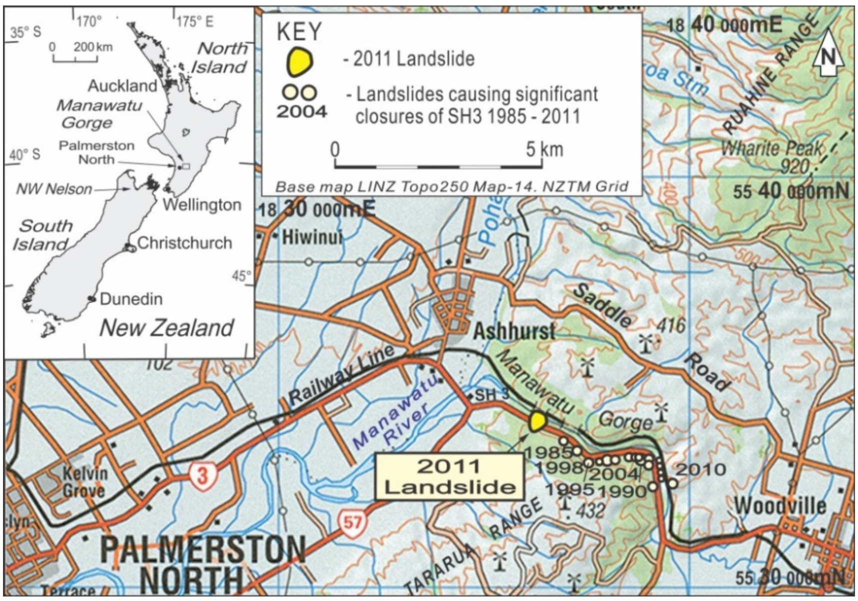

Figure 1. Location map for the Manawatu Gorge and the 2011 landslide.

Excavations for the establishment and widening of State Highway 3 (SH3) on the south side of the gorge oversteepened the toes of slopes, causing rock falls and landslides that have affected the road since it was completed in 1872. By comparison the railway line on the north side of the gorge has been much less affected by landsliding, mainly because of the lower cuts and the use of tunnels to bypass steeper sections of the gorge (Hancox et al. 2012). After the gorge road was widened in the 1940s, 1960s, 1970s and 1980s it has frequently been closed by slips, especially during heavy rainfall. Most of these failures were related directly to the road-widening earthworks. The first significant landslide closures (of 2-8 days or more) of SH3 in the Manawatu Gorge occurred following large failures in 1990, 1995, and 1998. All of these failures were apparently related to the cutting back of the toe of the slope in the 1980s. Rock falls also occurred on many rock bluffs through the gorge and required extensive rock bolting, scaling, and 'meshing' of rock faces in places. The worst historical episode of multiple landslides in the gorge occurred during the February 2004 rainstorm, when prolonged rainfall spread over 2–3 days caused more than 40 landslides. The largest of the landslides was a ~100,000 m^3 rock and debris slide that closed SH3 for 70 days (Figure 1).

In September 2010 a small debris slide of about 2000 m^3 occurred at the toe of a colluvial slope which closed the west-bound lane of SH3 in the Manawatu Gorge 4 km southeast of Ashhurst (Figure 1). On 18 August 2011 a larger failure occurred 20 m east of the 2010 site, which completely closed SH3 in the gorge. This was the first of a series of rock and debris slides at this site which culminated in a major collapse on 18 October 2011 that closed SH3 until 19 September 2012. This paper describes the geotechnical characteristics and development of the 2011 landslide, the causal factors and methods used to stabilise the landslide in order to reopen the road through the gorge.

2 THE 2011 LANDSLIDE

The 2011 landslide is located about 1 km from the western end of the Manawatu Gorge between Bluffs 2 and 3 (Route Position (RP) 488/1.86–2.10). The collapse that occurred on 18 October 2011 is illustrated on an annotated aerial photo taken on 1 November (Figure 2) when the landslide and stabilisation options were being investigated. Figure 3 is a geomorphic map of the landslide and older slope failures in the area, including failures along SH3 from 1930-1980s and the relict scarps of large prehistoric landslides identified on aerial photos and LiDAR (Hancox et al. 2012). Most of these features were mapped by Perrin and Hancox (2000) in a scoping study of SH3 in the Manawatu Gorge (Beca 2001). A geological cross section through the 2011 landslide is presented in Figure 4.

Figure 2. Aerial photo of the 2011 landslide (a rock and debris slide) in the Manawatu Gorge on 1 November 2011 compared to the size of the failure on 29/9/11 (hs – headscarp; d – debris).

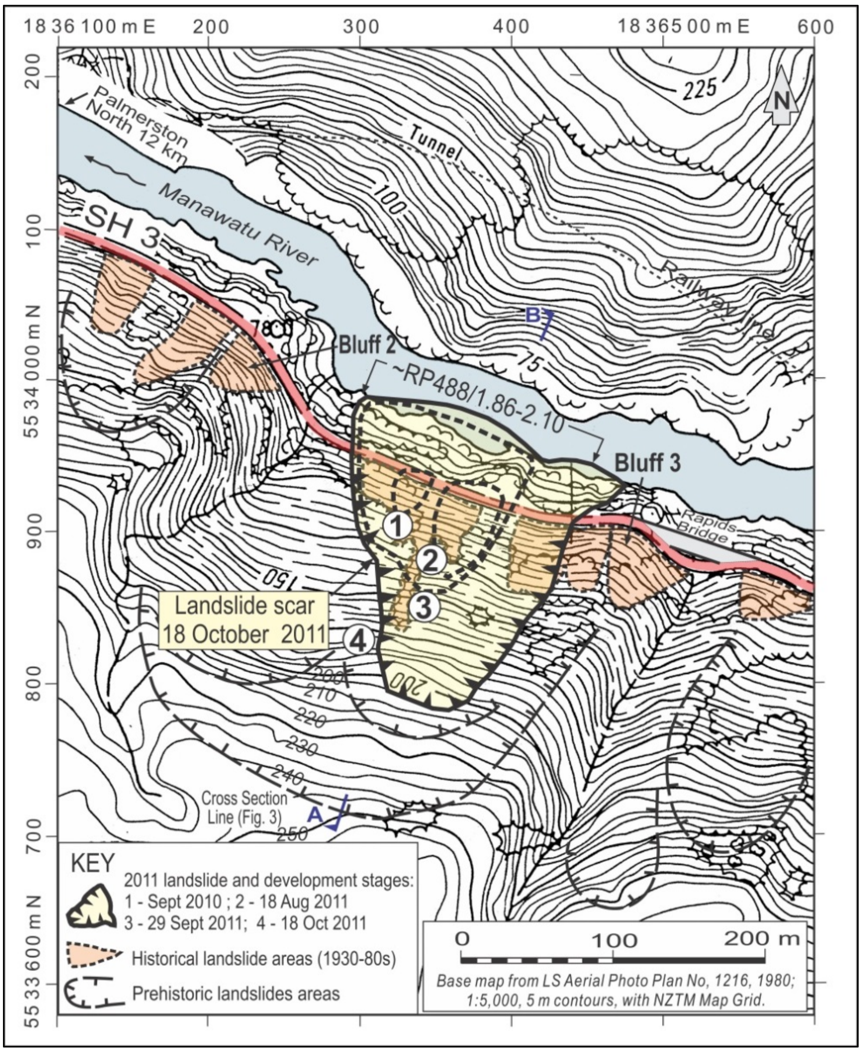

Figure 3. Geomorphic map of the 2011 landslide in the Manawatu Gorge.

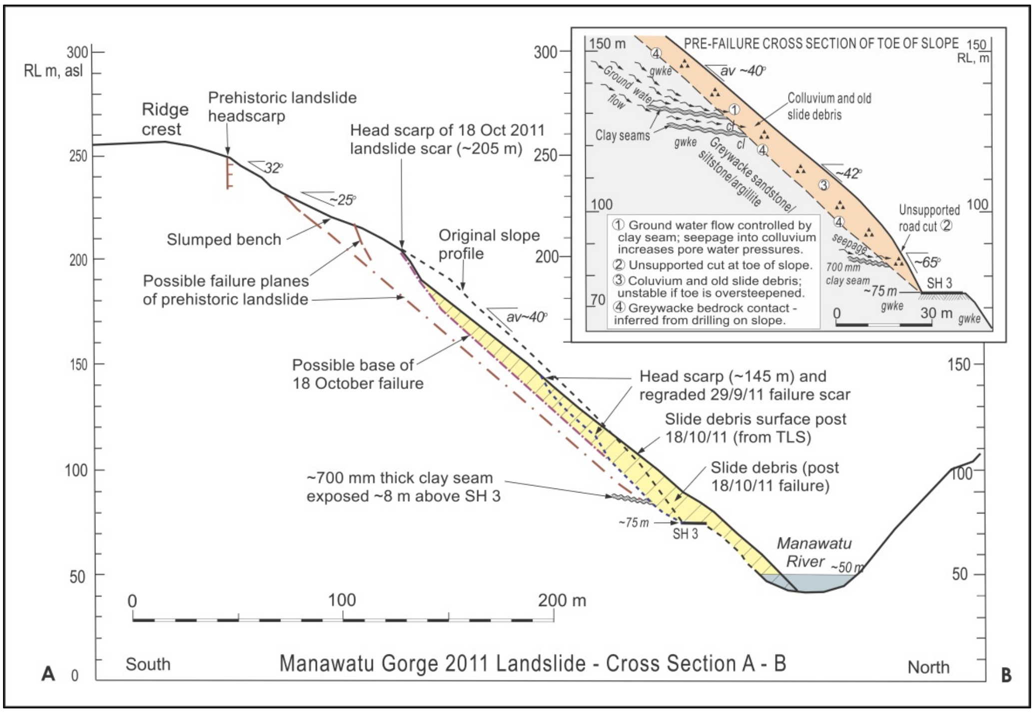

Figure 4. Geological cross section of the 2011 landslide and the slope above.

2.1 Description of the landslide

Following the failure in August 2011 which closed the gorge road, efforts were made by Higgins Contractors to clear debris from the highway, and a geotechnical assessment of the landslide was begun. The assessment included engineering geological mapping by MWH and GNS Science staff, data reviews, aerial photography, and LiDAR with 5 m contours (flown 29/9/2011). After the 18 October collapse a terrestrial laser scan (TLS) of the failure site was carried out by GNS Science on 1 November. The data obtained were used to create a geotechnical model of the landslide area and consider potential remedial measures to stabilise the slope.

The investigations showed that the 2011 landslide formed where excavations to widen SH3 had undercut a colluvial deposit below the toe of a much larger prehistoric. The presence of this feature was established from geomorphic evidence derived from aerial photos, LiDAR images, ground mapping, and cross section analysis (Figures 3 and 4). The main features of the 2011 landslide established from the post-failure studies are summarised as follows:

(a) Location: The landslide occurred between Bluffs 2 and 3 from RP488/1.86–2.10.

(b) History: Shallow failures at or near the site from 1930 to ~1950 and 1968-1969 (Figure 3).

(c) Dimensions: Height: 130 m; area: 15,000 m^2; average thickness: ~10 m; volume: ~150,000 m^3; average slope angle: 45–60°(headscarp), 45–35° (above scarp, see Figure 4).

(d) Geology: The bedrock is greywacke sandstone/siltstone and minor red argillite, overlain by 1-10 m of older slide debris, colluvium, and at the top of the slope ancient alluvium capped by surficial loess and top soil.

(e) Failure type: Based on the Varnes Landslide Classification (Hungr et al. 2014) the landslide is classed as a typical rock and debris slide (see Figure 2).

The 2011 landslide is the largest slope failure in the Manawatu Gorge in the last 100 years and is possibly the biggest landslide to affect a highway in New Zealand. It mainly involved surficial soils, colluvium, and weathered bedrock, and is most likely to have been initiated by the cutting back and subsequent poor support of the toe of the steep slope above SH3. Continuation of similar methods during efforts to reopen the road after the initial collapse in August 2011 led to the oversteepening and enlargement of the slip face, culminating in the major collapse on 18 October 2011 (Figure 2). The effects of this process on the development of the landslide are discussed below.

2.2 Stages in landslide development

The main stages in the development of the landslide are shown on the geomorphic map (Figure 3) and the sequence is illustrated by a graphic in Figure 5 and a series of photos in Figure 6.

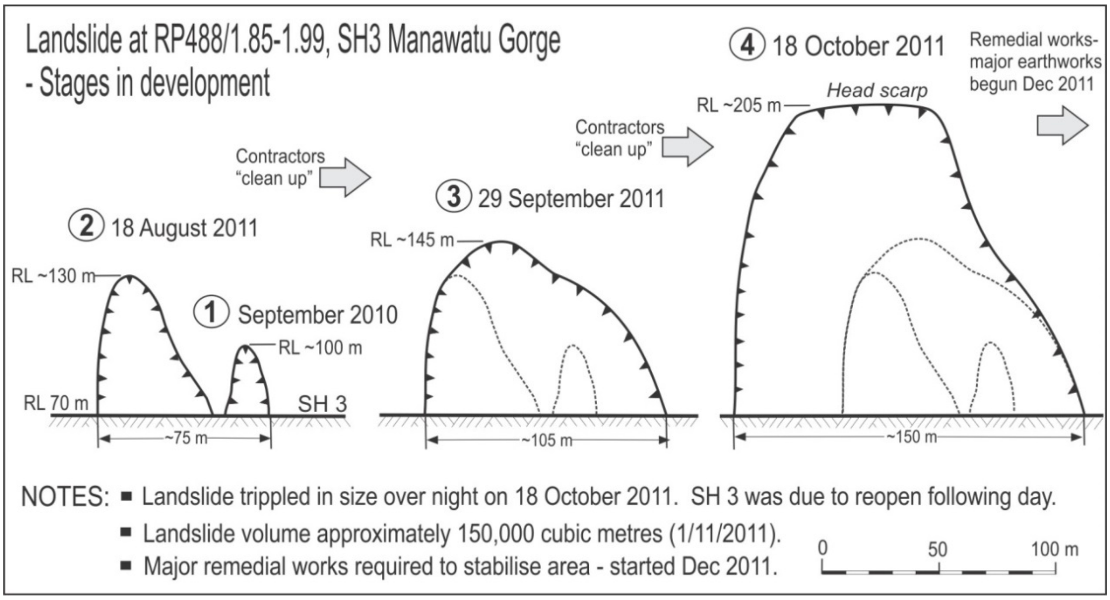

Figure 5. Graphic illustration of stages in the development of the 2011 landslide.

Figure 6. Photos sequence showing the main stages in the development of the 2011 landslide.

As shown in Figure 5 and 6 the initial failure at the landslide site between Bluffs 2 and 3 was a small rock and debris fall that closed the west-bound lane of SH3 in September 2010 (Stage 1). Debris from this failure was quickly cleared away and the road was reopened. Following a period of higher than usual rainfall on 18 August 2011 a debris fall of ~1000 m^3 occurred about 20 m east of the 2010 collapse (Stage 2). This second failure extended upslope to ~60 m above road level and increased in size to about 5000 m^3, at which point it completely blocked both lanes of SH3 (Figure 6).

From 18 to 28 August 2011 the two landslide scarps formed in Stages 1 and 2 regressed upslope and enlarged with a series of small collapses from the headscarps, which eventually merged the two areas. Over this time continued efforts were made by roading contractors to clear slide debris from the road and the base of the slip. From the initial failures an estimated 20,000 m^3 of weathered greywacke and colluvium ended up on SH3 or in the Manawatu River (Avery and Bourke 2013). Our observations suggest however, that the overall result of this work was to undercut and oversteepen the slip face, resulting in further falls of soil and rock from the head scarps, often in response to rainfall. By the 29th of September the two initial failure areas had merged into a single landslide feature about 105 m wide and extending upslope to about RL145 m (Stage 3, Figure 6). After reaching the enlarged stage of development at the end of September, in the first two weeks of October the rate of failures from the headscarp declined. The roading contractors continued to clear debris from SH3 and cut back the base of the slope to form a 'debris fall area' beside the road (Stage 3a, Figure 6). Geological mapping by engineering geologists and geotechnical engineers from MWH NZ, GNS Science, and Geovert NZ, raised concerns about the stability of the upper slope as small to moderate falls of loose rock, colluvium, and soil from the headscarp continued. Compared to the 'original ground profile' (Figure 4) the clean-up process oversteepened the headscarp and made the slope vulnerable to a large regressive failure.

The gorge highway road was due to be reopened to traffic when a major collapse occurred early on 18 October 2011, engulfing SH3 over a width of 150 m and sending about 150,000 m^3 of rock and soil tumbling down the slope into the river (Stage 4, Figure 6). The area of the landslide tripled overnight and the headscarp regressed to about 130 m above road level (RL205 m). Fortunately nobody was harmed as the road was closed. A hill-shaded aerial and terrestrial (TLS) LiDAR image shows the extent of the failure and other geomorphic features on the slope on 1 November 2011(Figure 7).

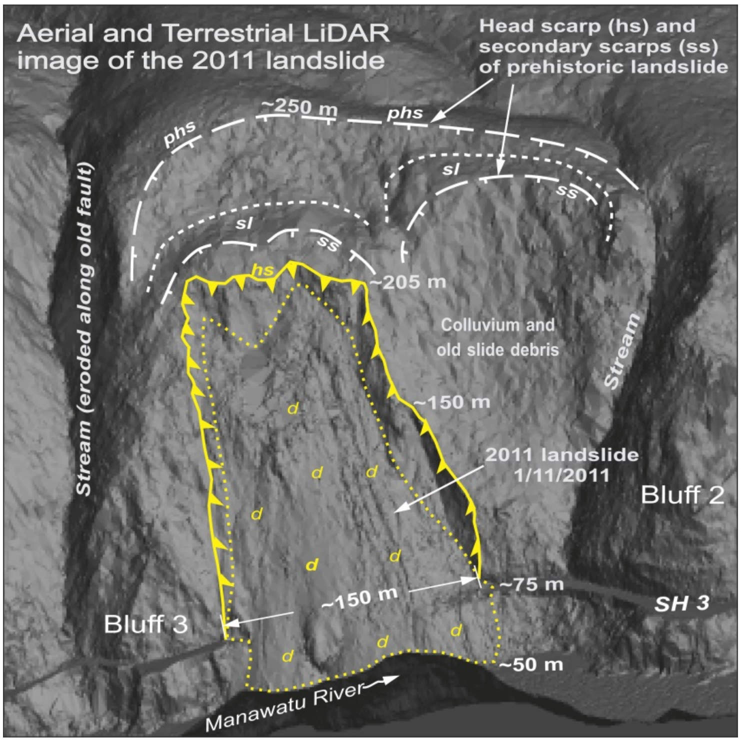

Figure 7. LiDAR and TLS image of the 2011 landslide and prehistoric landslide scarps (hs, ss), and potentially unstable slumped areas (sl), colluvium and old slide debris at the top of the slope.

2.3 Geotechnical assessment and remediation options

Although the 18 October landslide was not unexpected, the size and speed of the failure was at the upper end of the range considered possible by engineers and geotechnical specialists. Following the enlargement of the landslide in October a geotechnical workshop involving MWH, GNS Science and Geovert engineers and geologists was held on 15 November to assess the landslide and consider stabilisation options. Analysis of geological data (Figures 3 and 4) indicated there was potential for enlargement of the landslide upslope. It was concluded that a further 25,000 m^2 or about 200,000 m^3 of prehistoric slide debris and colluvium above the headscarp was capable of generating further large and potentially rapid failures (Figure 7). Because the head of the landslide was continuing to collapse it was thought to be too dangerous to approach from below. The basic design concept determined at the workshop involved accessing the top of the landslide from above, and using earthworks equipment to remove the unstable material and cut (bench) the slope back to a more stable angle, similar to the long term stable angle for the slope (40-45°). This was ultimately shown to be the most cost effective and technically suitable option, and was approved by NZTA, earthworks contractors, and land owners, including the Department of Conservation, over the following few weeks.

2.4 Cause of the landslide

Based on the data available we believe that the 2011 landslide between Bluff 2 and Bluff 3 in the Manawatu Gorge can be attributed to a combination of factors, including:

(a) Relatively weak sandstone and argillite bedrock between spurs (bluffs) of strong sandstone.

(b) The presence of old (prehistoric) landslides and thick colluvial deposits on slopes of the Manawatu Gorge, which were cut back and oversteepened during the construction of SH3. The same pattern of landslide development has occurred at several other locations in the gorge in the last 20 years (Hancox et al. 2012), particularly in 1995, 1998, and 2004 (Figure 1).

(c) Rainfall and adverse slope drainage further decreased the stability of unsupported cuts in colluvium and weathered bedrock along SH3, resulting in shallow rock and debris falls through the 1930-40s, 1968-69, 2004, and August to October in 2011. The first 2 stages of the 2011 landslide occurred after higher than average rainfall before the first 2011 failure on 18 August.

(d) During the earthworks on the slip face ground water seepages were noted from joints and above clay seams in greywacke bedrock. A significant ground water seepage flow of ~12.5 litres/min was found to coincide with the head of Stage 2 landslide at RL ~135 m. This suggests that ground water seepage was a significant causal factor in the two initial landslide events.

(e) The methods used by roading contractors to clear slide debris from SH3 involved cutting back the toe of the failure site to form a debris 'catch area' alongside the highway. As shown in Figure 6 this process undercut and is likely to have further destabilised the head of the landslide and the slope above, making it more vulnerable to collapse. Since the slope was already close to the point of failure this is believed to be the main cause of the large collapse on 18 October. As similar 'clean-up' measures were used to clear debris from the road after the failures in August and September 2011, this is also believed to be a reason for the considerable enlargement of the landslide between Stages 2 and 3.

3 STABILISATION MEASURES

The remediation earthworks began in December 2011 and were completed down to road level in May 2012. Approximately 370,000 m^3 of material was removed from the landslide area. The extent and shape of the earthworks was determined using a digital terrain model based on aerial and terrestrial LiDAR images. The earthworks excavation began near the ridge crest above the landslide and progressed down the slope to road level. All of the excavated soil and rock was pushed over the edge of the benches and removed from the base of the slope. Figure 8 shows the landslide area on 24 August 2012 after the main earthworks and benching had been completed, while the overall shape of the earthworks benches and material removed from the slope is shown in Figure 9.

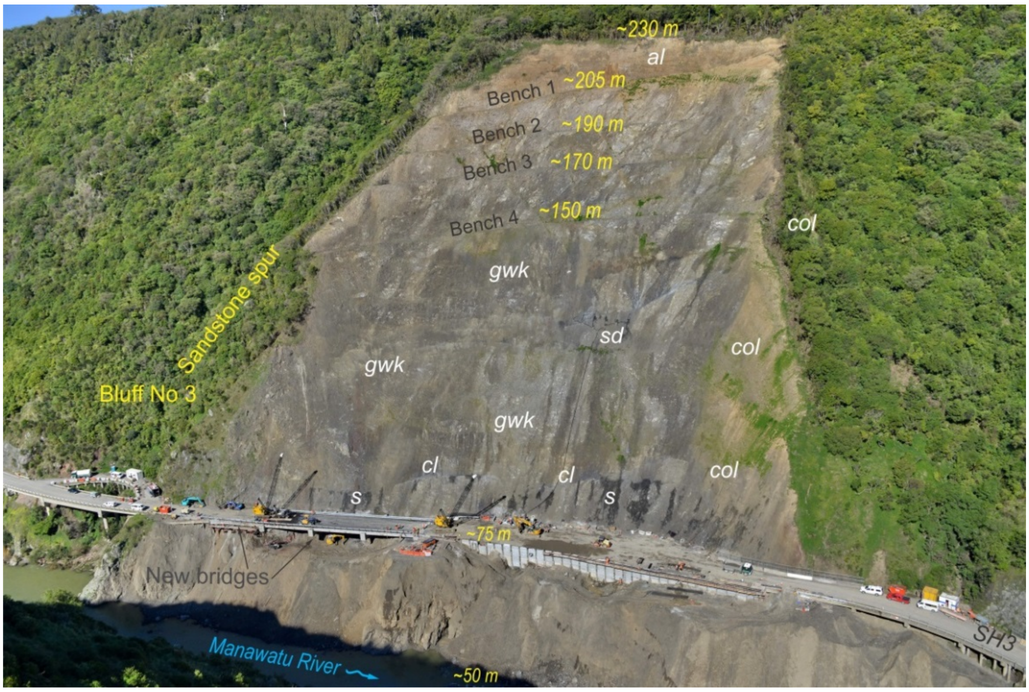

Figure 8. Completed earthworks and benching (1-4) of the 2011 landslide on 24 August 2012 (gwk – greywacke, col – colluvium, cl – clay seam, s – seepage, sd – seepage drainage, al – alluvium).

Once the earthworks and four benches were completed (Figure 9) the highway bridges damaged by the landslide were rebuilt, ground water seepages controlled, and rock fall control measures were installed on the slip face. Geovert were commissioned directly by NZTA for the installation of slope drainage holes, Geobrugg Deltax mesh drape over the eastern part of the slip face, a 500kJ Geobrugg rock fall attenuator fence, and grouted rock anchors with steel waling beams to stabilise the western colluvial slope. These measures are described in detail elsewhere by Avery and Bourke (2012).

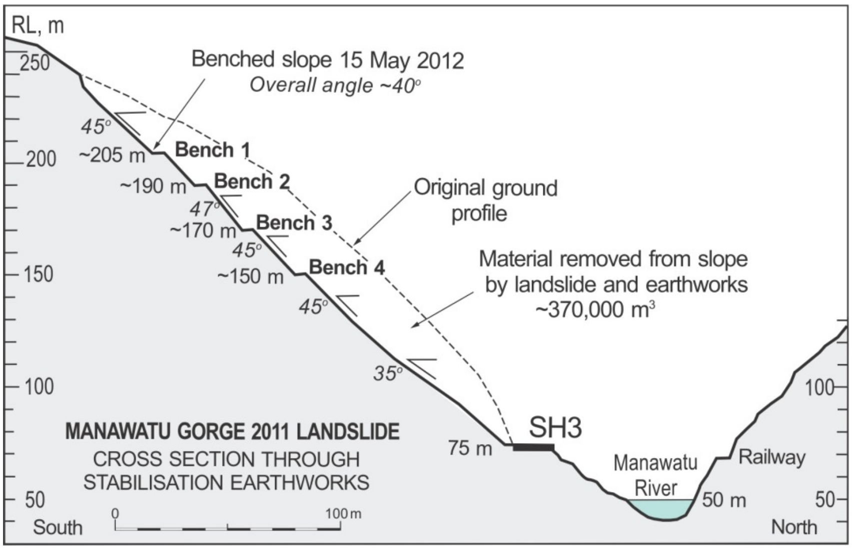

Figure 8. Section showing the shape of the completed earthworks in May 2012.

4 CONCLUSIONS

The 150,000 m^3 landslide that closed State Highway 3 in the Manawatu Gorge from 18 August 2011 to 19 September 2012 was the largest landslide to occur in the gorge for over 100 years. Our assessment has shown that the landslide resulted from a combination of adverse geological and geomorphic conditions, coupled with poor road design and highway maintenance practice which undercut and removed support from the toe of a large prehistoric landslide at the top of slope. Extensive earthworks carried out to stabilise the landslide involved the removal of about 370,000 m^3 of soil and rock from the head of the landslide, and cutting the slope back to an overall angle of ~40°, which is similar to the long term stable angle for the slope. Steel mesh and a rock fall fence were installed to reduce the risk of rock falls on the slip face, and grouted anchors were used to stabilise the colluvial slope to the west. These measures have effectively stabilised the slope affected by the 2011 landslide and reduced the risk of further large-scale landsliding at the site to a very low level.

5 ACKNOWLEDGEMENTS

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