Tairāwhiti Roads Storm Damage: Determining factors for the best remediation solution to a mass number of slope failures

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ABSTRACT

In 2017 and 2018 the Tairāwhiti Region was subject to multiple extreme rainfall events resulting in widespread damage to the regions roading network. Geotechnical assessment of the storm damage has found most failures were underslips resulting in loss of road width to the outside lane or road shoulder. The appropriate remedial solution for a site was determined by the following three fundamental engineering geology factors: geometry, geology, and water. Other varying factors included traffic volume/road importance level, expected level of resilience post repair, client budget, and construction material availability. Three geotechnical solutions were typically applied: bench and fill or mass stabilised earth walls (MSE), cantilever retaining wall (with or without anchors), and minor upslope road cut or full road retreats. Applying such fundamental engineering geological factors in a simple assessment template assisted the remediation of multiple sites in a rapid timeframe. This process highlighted the important role of an engineering geologist undertaking good geological observations, mapping, photography, record keeping, and understanding the wider context of the site. Including understanding the likely failure triggers such as leaking and blocked culverts, aging stormwater infrastructure, and forest harvesting.

Keywords: Engineering geology, slope stability, storm damage assessment.

1 INTRODUCTION

In 2017 and 2018, the Tairāwhiti region experienced three significant rainfall events and two cyclones. The extensive rainfall led to widespread damage to the Gisborne District Council's roading network, with 5,200 roading faults recorded. High levels of rainfall caused many road culverts to be overwhelmed resulting in downslope scour and saturation of the surficial soils and fills triggering slope failure. The failures caused loss of road carriageway or road shoulder. Rapid assessment was undertaken to assist in the resolution of the road damage across the network. This paper summarises the fundamental factors that resulted in the final remedial design solution for each site and the role of the engineering geologist. Having a strong understanding of such factors allowed for an effective repair solution to a significant number of storm damage sites across the Tairāwhiti local roading network.

1.1 2017/2018 rainfall intensity and deforestation

It is not unusual that the Tairāwhiti Region is exposed to frequent large rainfall events. The most notable event was Cyclone Bola in 1988. After this event much of the damaged steep land was planted into exotic forestry with a harvesting lifecycle of approximately 25-30 years. Consequently, many of these plantations are now mature and are being harvested. This is a notable factor in the widespread land damage within the region from recent storm events. The increase in deforestation in some areas and associated traffic results in increased pressure on Gisborne District Council roading infrastructure. After the June 2018 rainfall event, landslip damage was proven to be highest in areas that had been logged within the last 3 years, with 46% resulting from forestry infrastructure such as logging roads, haul sites and landings (Rosser et al. 2019). The specific details of the 2017 and 2018 rainfall events are outlined in Table 1.

Table 1: 2017-2018 Damaging rainfall events

Event	Rainfall	Time period
5 April 2017 (Cyclone Debbie)	85 mm	16 hours
12 April 2017 (Cyclone Cook)	80 mm	3 hours
13-16 & 20-24 July 2017	50-80 mm	Peak
3-4 June 2018 (Queens Birthday Storm)	266 mm	24 hours
4-9 September 2018	100 mm	Peak

Information sourced from (Fellows and Barker, 2021).

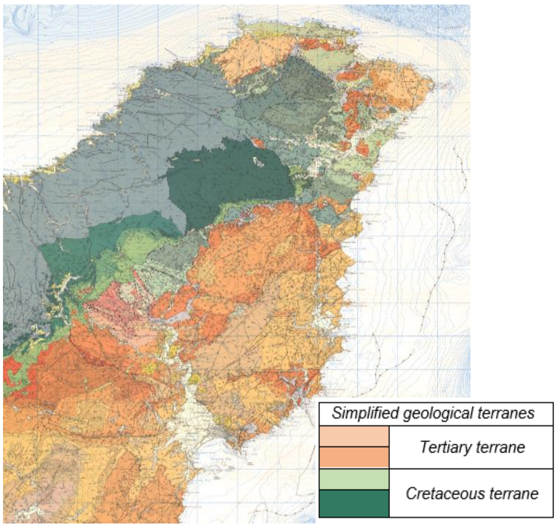
2 REGIONAL GEOLOGY AND GEOMORPHOLOGY

The geology of the Tairāwhiti Region has been broadly simplified into two geological terranes as illustrated in Figure 1. Much of the region comprises of the Tertiary terrane of less deformed massive to bedded sandstones and mudstones of early to middle Miocene age (Ministry for Primary Industries, 2018). The second is the Cretaceous terrane with variably indurated, extensively sheared, alternating siliceous mudstone; and sandstone of late Cretaceous to Palaeocene age comprising part of the East Coast Allochthon (Mazengarb & Speden 2000). Rhyolitic ash deposits are also present across the region up to 10 m thick. The upper weathered rock profile and volcanic ash material is prone to sliding on the underlying bedrock when steep or saturated.

The difference in the two geological terranes result in different geomorphology. The Cretaceous terrane is subdued slopes (15-25°) and prone to gullying, deep-seated earthflow, and slumping, while the Tertiary terrane is steep and prone to storm-initiated shallow land sliding and gullying (Ministry for Primary Industries, 2018). The steepness of this topography is a significant factor in defining the most appropriate remedial solution to the storm damage sites. This is an ongoing maintenance challenge for Gisborne District Council roading assets with 26% of the Tairāwhiti Regions land being prone to significant erosion compared to the national average of 8% (Ministry for Primary Industries, 2018).

3 DETERMINING FACTORS TO REMEDIATION OF ROADING INFRUSTRCUTRE

Of the 5,200 roading faults reported, 381 sites were classified as needing engineering assessment on the local roading network (Fellows and Barker, 2021). Figure 2 illustrates the significant number of design sites spread across the region. Numerous factors summarised below had to be considered in defining the best remediation solution for each site.



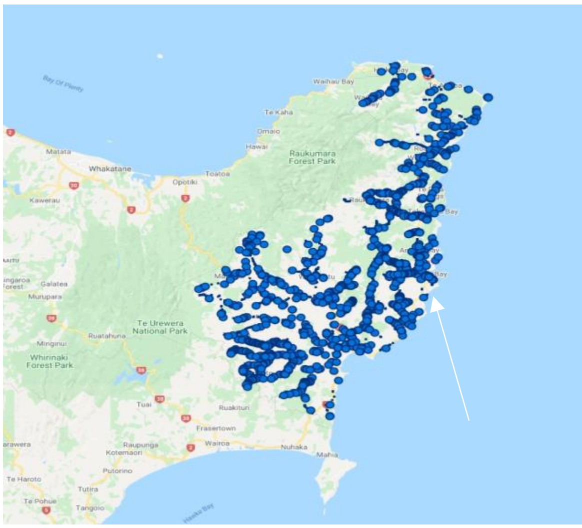


Figure 1 (Left): Geological map of the East Cape (Source Mazengarb and Speden, 2000)
Figure 2 (Right): Geographical spread of storm damage across Gisborne District Council roading network

3.1 CLIENT FACTORS

Understanding the client's appetite for a repair solution for each site was the first step. Due to the large number of damaged sites and limited budget the client and consultant worked together to agree low-cost repair approaches that allowed the road to remain functional short term. This approach had limited engineering design and often did not meet typical New Zealand design standards. The approach considered returning the road to an operational level by the following decision factors summarised in Table 2**.**

Table 2: Client agreed design factors

Design feature	Client requirements
Downslope shoulder	Reinstatement of the downslope road shoulder to a minimum of 1.0 m width.
Functioning drainage	Repair the site with adequate drainage. Minimal to no storm water design or catchment analysis was to be undertaken by engineers.
Resilience post repair	Limited design life. This included a reduced seismic design life of 15 years.
Large scale global failure	Large scale global failure was not addressed.
Construction supervision	Limited to no construction supervision during construction.

As discussed in section 2, the highly erodible geology means natural construction materials such as hard crushed aggregate or gabion rock is scarce in the region and often needs to be sourced from large distances at an increased cost. This was a major factor in defining the types of repair solutions. The ease of construction in a short timeframe was also a client priority. The design solutions needed to be cost-effective and to be undertaken by local contractors from easily available materials. The three remedial options typically applied are summarised in Table 3.

Table 3: Client agreed remediation solutions

Remedial Option 1	Bench and fill or mass stabilised earth walls (MSE).
Remedial Option 2	Timber or steel pole cantilever retaining wall (with or without anchors).
Remedial Option 3	Minor upslope road cut or full road retreats.

3.2 ENGINEERING GEOLOGY FACTORS

As standard with the engineering geology discipline, the site geology, geometry, and the impact of water were the three fundamental factors needing to be understood for each site. Site assessment to understand the failure type (e.g., translational, circular or flow) and the movement triggers are crucial to defining the most appropriate solution. Undertaking geological mapping of these site factors with detailed sketches and observations in a simple site template enabled the design engineers and client to have a comprehensive understanding of the site. A breakdown of what fundamental site factors were recorded are summarised in Table 4.

Table 4: Key site factors recorded during site assessment

Geology	Geometry	Water
Depth, weathering, composition, and strength of • Road fill • Underlying soil • Upslope/downslope rock	• Existing carriageway width • Upslope/downslope angles • Failure height • Extent/length of failure • Inside/outside shoulder width • Road width suitable for lane closure to support construction	• Control of surface water, such as upslope table drain and cut off drains • Nearest culvert and condition including inlet/outlet culvert condition • Depth of ground water • Proximity to a stream or river

This process highlighted the importance of thorough use of the observational approach, good note taking, measurements, geological mapping, sketches, site photography and ground model development. Robust walkover of both above and below the failed section of road and thorough inspection of all stormwater infrastructure at the failure was essential. Having this information on hand during the remedial options review enabled the designers and client to make knowledgeable decisions, option adjustments or redesign without having to go back to site.

3.2.1 Geology and Geometry

Although the triggers and failure mechanisms are similar for many sites, the geology and geometry were always different. Every remedial option had to be tailored to fit the site. Experience from assessing many sites enabled the field team to understand the key geologic and geometric factors which influence the remedial options. Figure 3 shows a general schematic of what geometric and geological factors helped form the best fit remedial option. Option 1 relies on the underlying material to provide a suitable bench for an MSE/bench foundation. The depth to solid founding soil or rock coupled with slope angle on the downslope side strongly influences the choices for Options 2 and 3. A steeper downslope often arises in longer poles and/or multiple anchors, resulting in Option 2 becoming uneconomical. Remedial Option 3 was often the preferred solution by the client due to the short-term economic benefit.

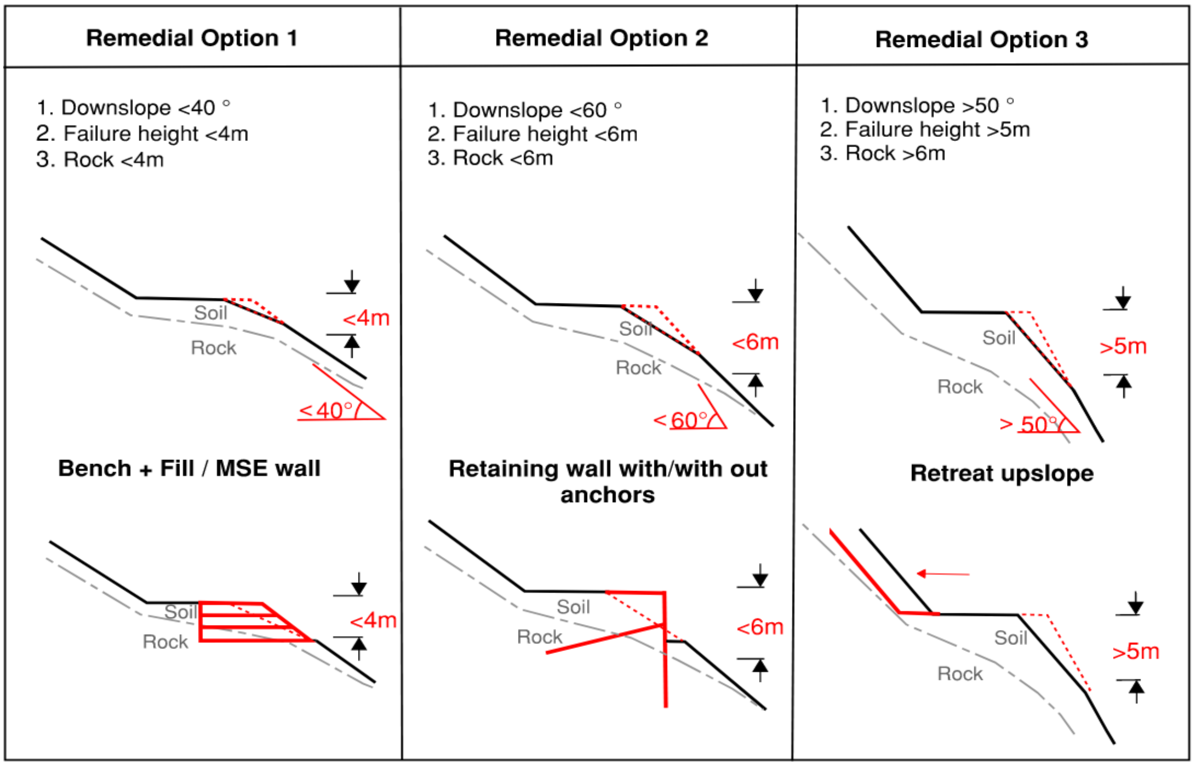


Figure 3: Generic schematic of the geometric and geological factors that helped determined the remedial option.

3.2.2 Water

As stated previously water is a fundamental driver of failure. Uncontrolled storm water or a high ground water table resulted in translational failure of saturated soils on the underlying bedrock and scour of the downslope sidling fill. Understanding the condition on site of the table drain or nearest culvert and how to better control storm water was essential for long term stability of the slope. Figure 4 shows a typical scour failure resulting from undersized and ailing storm water infrastructure.

Figure 4: Anaura Road RP6.18 – Example site of scour from uncontrolled stormwater.

4 SELECTION PROCESS OF SOLUTION

The three typical remedial options were provided to the client together with the associated risk profile and estimated rough order cost. The three solutions were defined into the following categories for the client.

- High risk – Low-cost option
- Medium risk – Medium-cost option
- Low risk - High-cost option

Each solution was assessed on a case-by-case basis with several outside factors impacting the final solution. These factors included consenting, iwi, property boundaries, land purchase, client preference, utility locations and construction factors e.g., construction time and road closure needs. The site geology and geometric conditions usually resulted in the initial remediation selection, other factors gave rise to option changes or adjustments to best suit the above requirements. Figure 5 shows an example of each remedial solution before and after construction.

Figure 5: Examples showing the initial storm damage and final constructed design for each remedial option.

5 FUTURE STORM ASSESSMENT

Many learnings from the early 2017-2018 storm damage works have been adopted by both the client and consultant and applied to more recent storm events. A consistent design philosophy has been adopted by Gisborne District Council in 2020 for any ongoing storm damage. This philosophy has enabled a tiered approach to the importance level of the road and the required engineering design for remediation. Field assessment templates have since been digitised, with site assessment now being undertaken directly onto tablets enabling the data to be more readily accessible by the consultant and client. Initial reporting is now more stream lined and rough order cost estimate can become more automated.

6 CONCLUSION

Significant rainfall events over 18 months between 2017 and 2018 caused widespread damage to the Tairāwhiti Region and the Gisborne District Councils local road assets. Engineering geological assessment found most failures to be caused by uncontrolled stormwater resulting in slope instability and scour of the outside live lane or road shoulder. Several factors influenced the outcome of the final design solution. Understanding these factors were fundamental in selecting the preferred design solution to each location. These factors included.

- Geology and geomorphology of the Tairāwhiti Region
- The geometry and geology at the failure locations
- Ground and surface water including aged stormwater assets such as culverts or table drains
- Client factors such as limited budget, risk appetite and agreed design remediation factors
- Other varying factors such as traffic volume, consenting and construction material availability

Understanding these factors allowed the application of three typical remedial options based on risk and rough order cost. Key to the successful outcome of the process has been good engineering geological field practice and observations. The importance of the fundamentals such as the observational approach, geomorphic mapping, robust walkover, good note taking, accurate measurements, sketches, site photography and ground model development cannot be underestimated as key tool in the remedial option decision process. In addition, engineering geological assessment must be undertaken jointly with observation of the roading and stormwater infrastructure state.

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