State Highway 5 Tumunui tomo - a case of road resilience to piping in the Rotorua-Taupo area

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ABSTRACT

On 23 June 2016, following a heavy rain event, a section of SH5 at the locality of Tumunui, about 18km south of Rotorua, was closed due to flooding. When the water recessed a little, significant damage to the road and adjacent properties was revealed. The New Zealand Transport Agency - Bay of Plenty East Network Outcomes Contract (BoPE NOC) is the road asset management contract covering the damaged section of SH5. Due to the immediate risk to road users arising from the event, the geotechnical incident response procedure of the BoPE NOC was triggered. Based on the geotechnical investigation undertaken it was concluded that the damage sustained by SH5 at Tumunui was due to reactivation of a naturally occurring internal erosion process that had been developing across the area since at least the 1970's. The process is intrinsically associated with the geomorphic context of the site and the underlying geology. Following the event, a risk assessment was undertaken and concluded that with management controls in place it was possible to keep the road partially open to traffic. Medium and long term remedial options were investigated to reopen the road to full traffic. A geogrid-reinforced soil raft was preferred due to its quick implementation even in wet weather, and relatively low cost. Three and a half months after the rain event, the road was fully reopened to traffic. Ongoing monitoring indicates that minimal settlement has occurred since completion of the works.

1 INTRODUCTION

State Highway 5 (SH5) is a regional strategic highway extending from SH1 at Tirau, in the Waikato, to SH2 just north of Napier. In the early hours of 23 June 2016, following a heavy rain event, a section of SH5 at Tumunui, about 18km south of Rotorua, was closed due to extensive flooding. A couple of hours later the rain eased and the water receded, revealing significant damage to the road and adjacent properties.

The New Zealand Transport Agency - Bay of Plenty East Network Outcomes Contract (BoPE NOC) is the road asset management contract covering the damaged section of SH5. Due to the imminent risk to road users arising from the event, the geotechnical incident response procedure of the BoPE NOC was triggered to better assess the risk and to develop mitigation strategies.

2 THEORETICAL BACKGROUND – PIPING AND TOMOS

Dispersion followed by internal erosion is the process causing the loss of soils due to entrainment by groundwater flow. Water seeping through the ground carries clay size particles followed by transport of the silt/sand particles leaving a cavity. Regressive erosion develops from downstream to upstream until it reaches the ground surface and a continuous pipe is formed. At this point, the flow rate, and hence the erosion potential, increases dramatically. As the pipe grows, the soil cover gets thinner. At a certain point the roof of the pipe becomes too thin to form a competent arch and collapses, forming a sinkhole. Tomo is the Maori word for sinkhole and is a very common feature in the central North Island due to the extensive occurrence of ash and pumice soils.

3 GEOTECHNICAL EMERGENCY RESPONSE

3.1 Site Walkover

A site walkover was carried out on the same day to assess the damage to the road and to develop an initial understanding of the geological process that caused the damage. It was observed that a 12m long section of the road, bound by cracks extending across the whole width of the pavement, had dropped about 30mm (Figure 1). Aligned with the dropped road section, tomos had developed in paddocks in the properties on both sides of the road. To the west, a 10m wide tomo had extended for more than 100m, terminating as a natural tunnel into a hill (Figure 2). Groundwater was observed at the base of the new tomos, flowing from east to west and then “disappearing” into the tunnel.

An inspection of the existing surface drainage system identified that the swales and culverts were too high to drain the water that ponds in the paddocks adjacent to the road (Figure 3).

3.2 Desk Study

A review of rainfall data confirmed a that heavy rain event occurred just before the new tomos appeared on the west side of the road. Between 6am on 22/06/2016 and 6am on 23/06/2016, the Okaro farm rain gauge (7km away from the site) recorded 110mm of rain with a peak intensity of 26mm/hr (Bay of Plenty Regional Council, 2016).

Lidar elevation data available for the region indicated that the Tumunui area is an enclosed depression, consisting of a catchment of about 270ha (Bay Explorer, 2016). Geologically, this depression corresponds to a volcanic vent of approximately 27ka, as indicated in the *Geology of the Okataina Volcanic Centre* (Nairn, 2002).

The lowest point of the Tumunui depression is located on the east side of SH5, which means that the only possible exit for all surface water in the catchment to the west of the highway is via groundwater flow, including a natural underground pipe/tunnel network, as the road embankment creates a damming effect and the surface drainage system is ineffective (refer Section 2.1).

A review of historical aerial photos revealed that a gully has existed on the east side of the site since the mid 1970’s at least (older photos were not reviewed). Small circular sinkholes started to appear on the west side after 2006. The fact that these sinkholes align well with the currently developed tomos, could suggest that some sub-vertical geological structure is influencing the development of the piping process.

Although a number of active faults are present in the wider Rotorua region associated with the Taupo Rift Zone, in the Tumunui area in particular, no active faults are known to exist, as indicated in Figure 4 (New Zealand Active Faults Database, 2016). In addition, whilst the vast majority of the active faults in the region are NE-SW oriented, in Tumunui the orientation of the gully on the east side of the road and the recently developed tomos is closer to E-W. Therefore it is considered unlikely that the piping process affecting SH5 is associated with active faults.

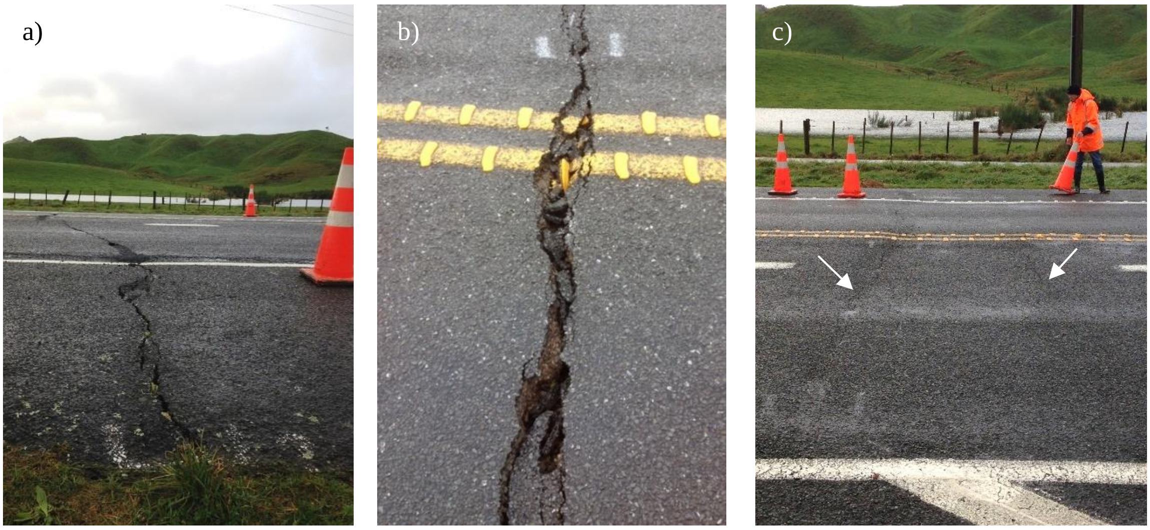

Figure 1: Observed damage to the road. a) North crack; b) Detail of the north crack; c) South cracks, as indicated by the arrows.

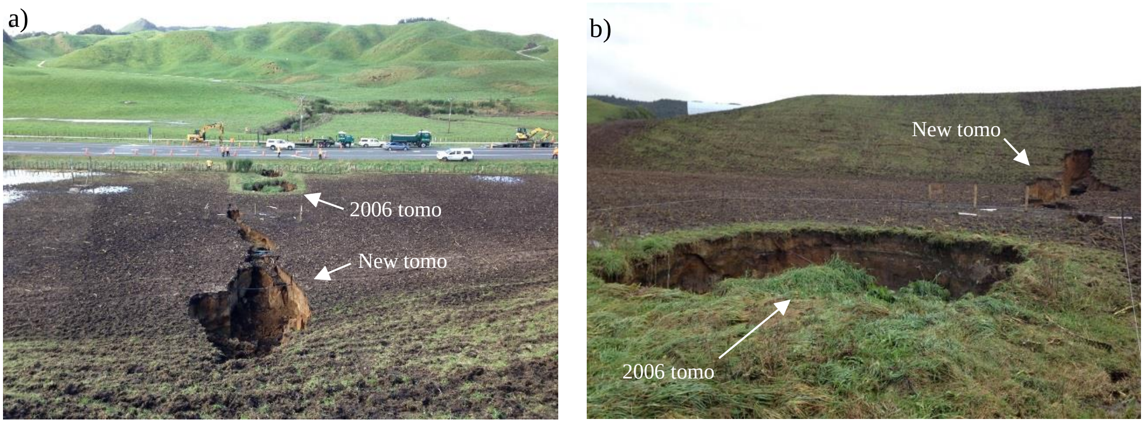

Figure 2: Sinkholes/tomos developed in the adjacent properties. a) Looking east from the hill towards the road. b) Looking west from the road towards the hill.

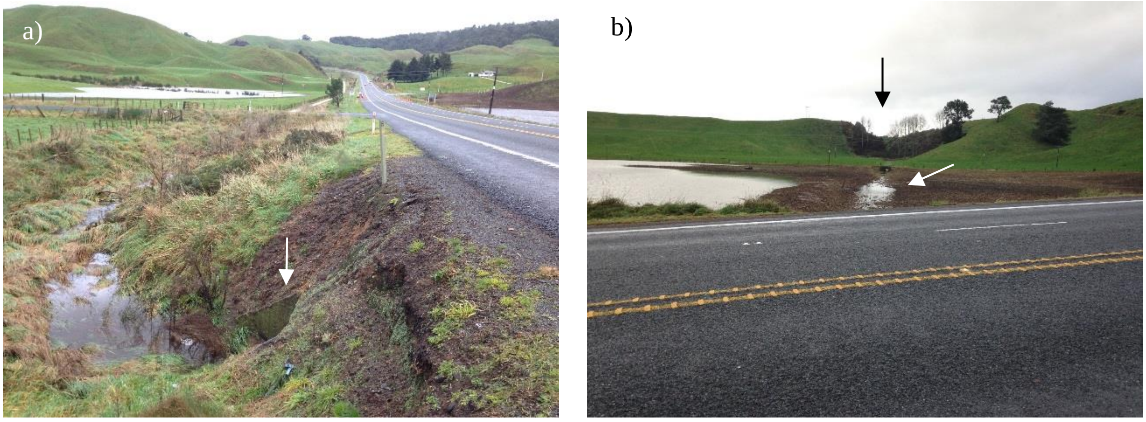

Figure 3: The existing surface drainage is too high to drain water ponding in the area. a) Culvert (as indicated by arrow) supposed to drain water from ditch on the east side of the road to swale on west side. b) Swale (white arrow) supposed to drain water to gully downstream (black arrow).

Figure 4: Active faults in the Tumunui area (New Zealand Active Faults Database, 2016). White ellipse indicates section of road affected by tomos.

3.3 Ground Investigation

Based on the information gathered from the desk study and the observations from the site walkover, a conceptual ground model was developed. To confirm some key aspects of the model and inform the development of remedial options, limited geotechnical investigations were carried out at the site. These investigations consisted of:

- One trial trench, about 15m long, 1m wide and 4.5m deep.
- Three large diameter machine auger holes (450mm diameter), to up to 12m depth.

The position of these investigations at the site is indicated in Figure 5.

In addition to the investigations mentioned above, about a year before the piping event affected the road, 14 Cone Penetration Tests (CPTs) to up to 10m depth were carried out by Pattle Delamore Partners Ltd (PDP) for First Gas Ltd (First Gas) on the adjacent property to the west of the site. The location of these CPTs, as well as some representative results are indicated in Figure 6.

3.4 Ground Model and Understanding of the Piping Process

Based on the information obtained from the site walkover, the desk study and the ground investigation, a ground model for the site was developed. A cross-section illustrating the ground model is shown in Figure 7. The key findings from the investigation are discussed below.

Previous tomos occurred at the site in the past, as indicated by the existence of naturally infilled voids with an upright conical shape, extending from the surface to about 7m depth.

A layer of loose, clean, fine to coarse pumiceous sands was found typically between 4m and 7m depth. When the trial trench was being excavated, even though the groundwater level was nearly at the ground surface because of flooding, the excavation was progressing relatively dry through the topmost layer of fine soils. Once the excavation entered the loose pumiceous sands, water immediately started gushing into the trench. This indicated that the loose pumiceous sands are permeable and can conduct significant amounts of groundwater.

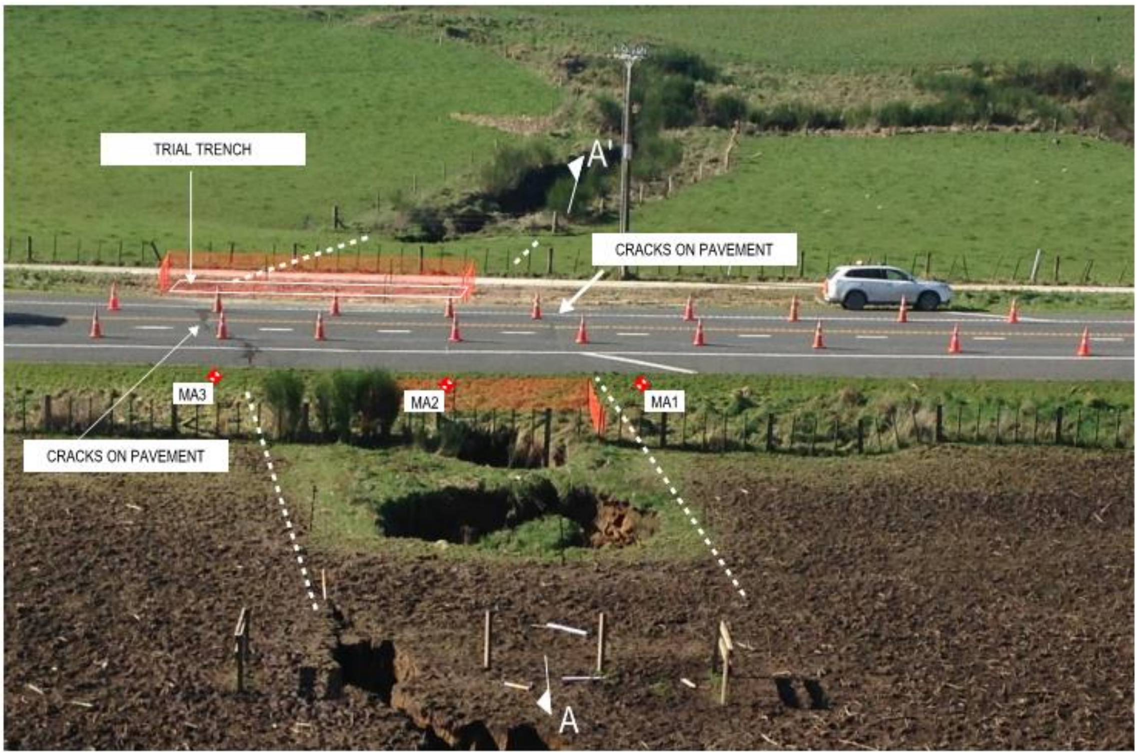

Figure 5: Location of ground investigations. Dashed lines indicate position of cracks observed. Section line A-A' is also indicated.

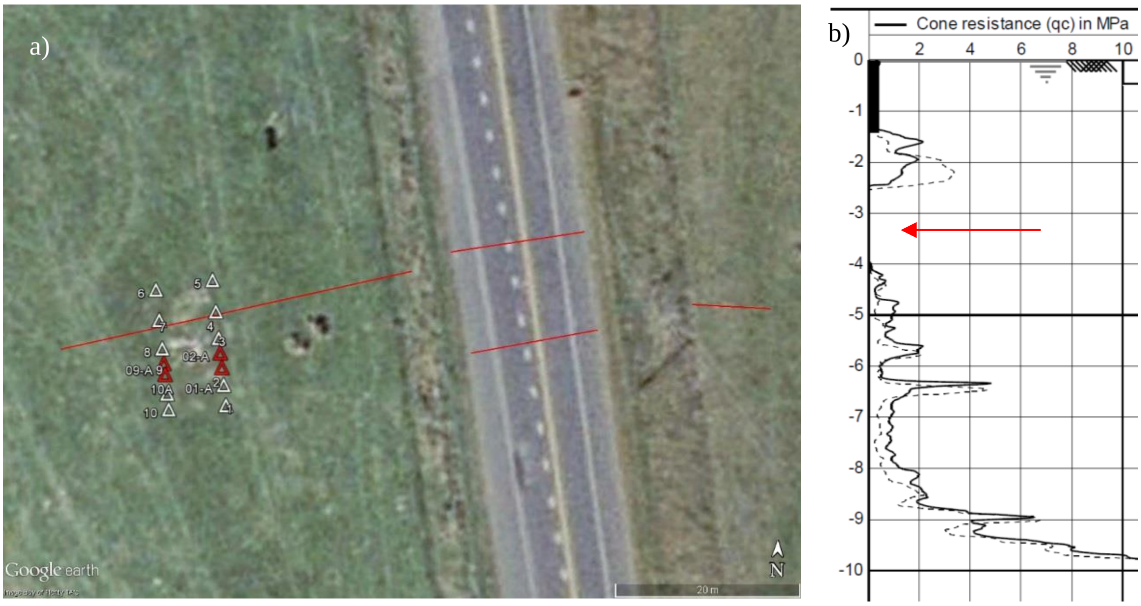

Figure 6: CPTs on adjacent property to the west. a) Test locations: red triangles indicate location of potential voids. Red lines indicate position of cracks observed. b) CPTs where potential voids were intercepted, as indicated by red arrow.

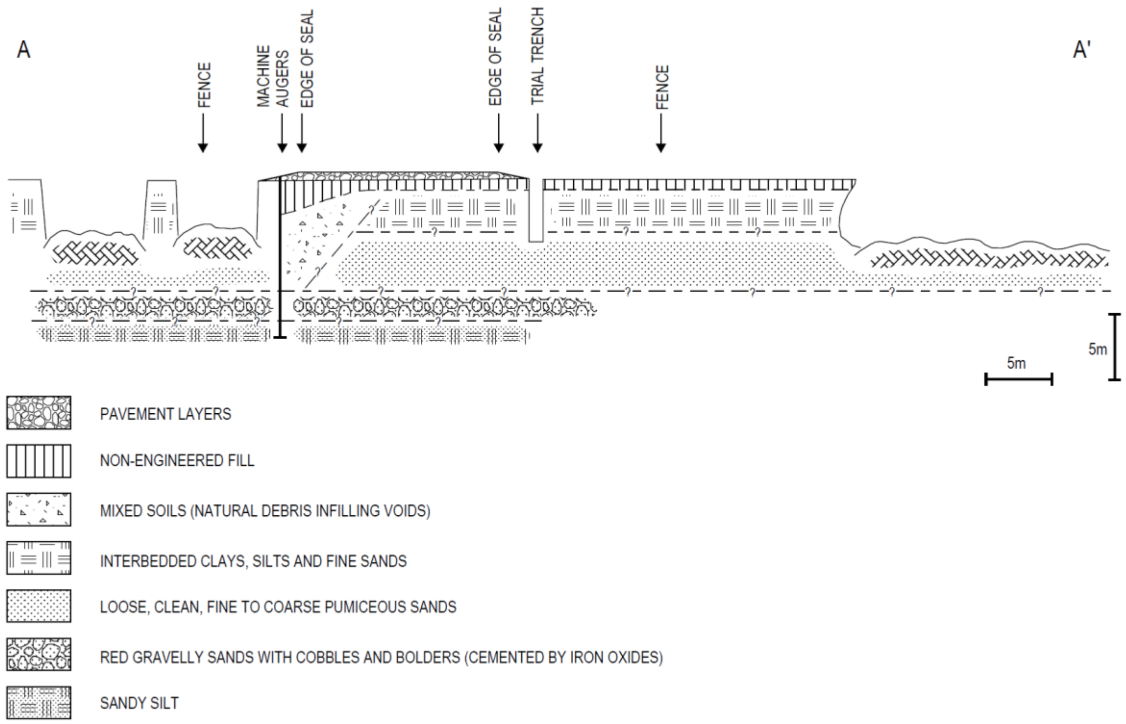

Figure 7: Section A-A' illustrating the ground model for the site.

Another point noted was that the depth of the loose pumice sands matched with the base of the gully to the east of the road. Also, the position of these sands coincided with the depths of the potential voids detected by the CPTs.

Below the loose pumiceous sands, a 1m thick layer of dark red gravelly sands with some cobbles and small boulders, partially cemented by iron oxides was encountered.

Based on the key points described above, it was concluded that the layer of loose pumiceous sands was the main zone were the piping (silt/sand transport) process was developing, and that the top of the layer marked the roof of the piping system. It was considered that the underlying cemented gravelly sands with cobbles and boulders would likely mark the base of the system.

The width of the piping zone was interpreted to be likely around 12m, as marked by the cracks on the pavement. It was also concluded that the piping was well developed under the road and downstream (i.e. to the west).

Lastly, it was concluded that the cover above the tomo was up to 4m thick and the shallow soils were unable to naturally bridge a tomo of the intepreted size.

4 RISK MANAGEMENT STRATEGY

Based on the understanding of the internal erosion piping process described above, it was concluded that the section of road between the two cracks (about 12m long) subsided and needed to be replaced by a suitable solution. As a result, immediate measures were put in place to manage the risk to road users and options for the long term repair of the road were investigated.

4.1 Short term

Following discussions between all parties involved with the BoPE NOC, it was decided to put the following measures in place to manage the risk to road users:

- 24/7 Temporary traffic management consisting of single lane stop-go operation to enforce a 30km/h temporary speed limit and close the road if conditions deteriorated.
- Overweight vehicles diverted from the site.
- Three times daily monitoring of pavement cracks (width and drop).
- Monitoring of weather conditions: road to be closed when there was heavy rain.
- Flood-lighting to improve visibility for night traffic.

4.2 Medium and Long Term

Temporary and long term remedial options were discussed with the BoPE NOC team, with the main philosophy being to interfere as little as possible with the existing underground water flow system. Any blockages to the natural drainage path would cause groundwater to find an alternate path, which could lead to the development of new tomos, introducing new unknown risks.

The preferred option was a medium-term solution consisting of a geogrid-reinforced soil raft, able of spanning the voids whilst providing enough robustness to avoid sudden collapse should the cavities enlarge as the erosion progresses.

The final design of the geogrid-reinforced soil raft was carried out based on BS 8006-1:2010. A long section of the raft is illustrated in Figure 8.

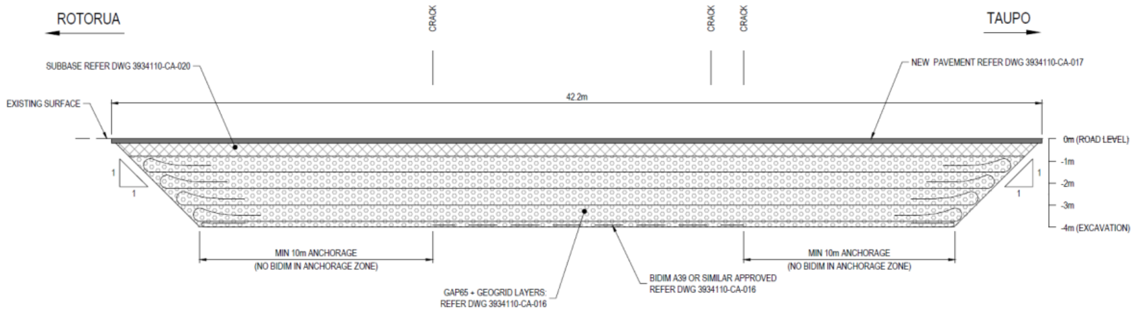

Figure 8: Long section of the geogrid-reinforced soil raft.

5 CONSTRUCTION

During construction, the anticipated ground model was generally confirmed and no significant voids or cavities were encountered in the excavation to 4m depth. Some small cavities up to 200mm long and 20mm wide were observed along a set of widely spaced subvertical fractures oriented at around N75E, as illustrated in Figure 9.

These subvertical fractures were only observed within the 12m wide zone delimited by the north and south cracks in the pavement. The north and south cracks themselves were found to be surface traces of the subvertical fractures, and could be traced along the full height of the east and west walls of the excavation. No displacements were observed across any fractures at the site.

6 POST-CONSTRUCTION MONITORING

On completion of the remedial works, a settlement monitoring program was put in place. The purpose of the monitoring was to track the performance of the reinforced soil raft and to identify early signs of potential larger ground movements due to progressive development of the underground tomo system. The program is still ongoing and, after more than 250 days, the maximum measured settlement is 7mm, which can be considered negligible for the soil raft.

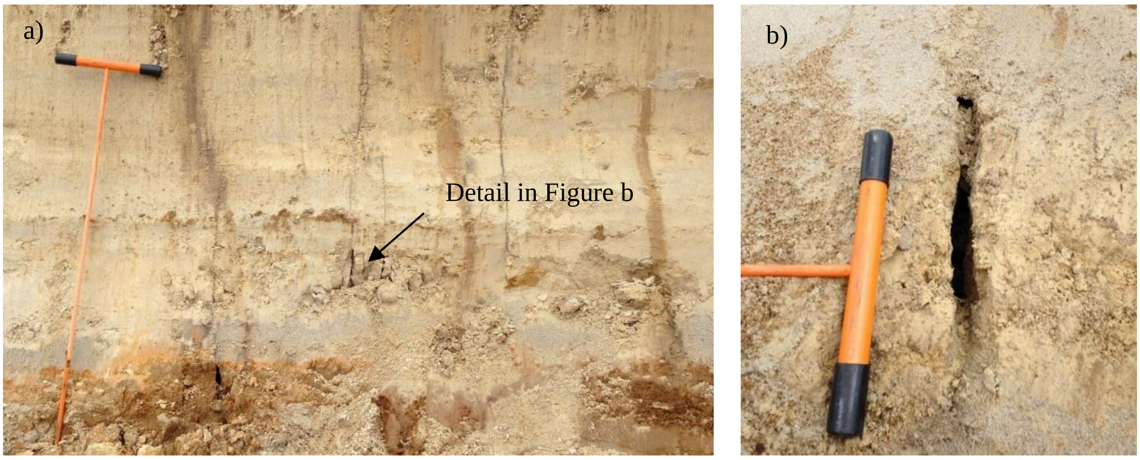

Figure 9: Small-scale piping along subvertical fractures on the west wall of the excavation.

7 CONCLUSIONS

The damage sustained by SH5 at Tumunui after the heavy rain event that occurred on 23 June was due to reactivation of a naturally occurring internal erosion process that had been developing across the area since for a long time. The process is intrinsically associated with the geomorphic context of the site and the underlying geology.

Following the event, a risk assessment was undertaken and concluded that with controls in place it was possible to keep the road partially open to traffic. Medium and long term remedial options were investigated to fully reopen the road. A geogrid-reinforced soil raft solution was preferred due to its quick implementation even in wet weather, and relatively low cost.

Three and a half months after the rain event, the road was fully reopened to traffic. Ongoing monitoring indicates that minimal settlement has occurred since completion of the works.

The key highlights of the project were: (i) The remediation measures were delivered in a good timeframe, considering the extent and seriousness of the natural hazard involved; (ii) A large earthworks solution was delivered over the wet season; (iii) There was relatively little disruption to road users, with the road partially open all the time.

8 ACKNOWLEDGEMENTS

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