Puhoi to Warkworth

Technical Memo

N1A Remediation Options - Technical Review Comments

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Interim Draft

04 April 2023

Waka Kotahi NZTA

Puhoi to Warkworth

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Executive Summary

Following previous slope failures and multiple stages of stabilisation designs, the N1A cut slope has experienced another landslide and the slope is moving towards the carriageway. Current slope monitoring and observations to date suggest that a pre-historical and deep-seated landslide has been reactivated (a reactivated slow-moving translational earth slide).

Ground displacement has recently occurred in the rock lined drainage swale that separates the shoulder from the toe of the slope. Ground models indicate multiple slip surfaces extending at depth beneath the carriageway. Cracks have been reported in concrete barriers in two separate places on the western side of the carriageway, aligning with projections of the lateral extents of the landslide on the cut slope, thus there is the potential that some landslide movement is occurring across the full width of the carriageway.

Surface monitoring data provided by NX2 (up until 6th March 2023) shows that following the 2023 Auckland Anniversary storm the slope above the road has experienced periodic episodes of comparatively rapid movement (~200mm/week to >300mm/week), separated by short periods of relatively little movement. Overall since early February 2023, displacement has occurred at an average rate of approximately 55-110mm/week. The periods of faster movement may be in response to rainfall events and likely increases in piezometric pressures.

Based on observations from similar cut slope failures during construction of the Puhoi-Warkworth motorway, catastrophic failure of the cut slope with significant debris rapidly failing onto the carriageway edge is unlikely during typical climatic settings.

The current risk to the **motorway width** (property only) is **'Moderate Risk'**. TAS recommends treatment to reduce the risk should be *implemented as soon as practicable*.

The current risk to the **N1A cut slope and the shoulder of the motorway** (property only) is considered **'High Risk'**. TAS recommends that the risk to this part of the asset is *unacceptable without treatment*.

A quantitative risk assessment of the risk to persons (loss of life) has not been carried out. Although, most human casualties are associated with high velocity landslides, slow moving landslides can cause high levels of financial loss, reputational damage and, in some cases, loss of life if not monitored closely and/or mitigation measures implemented promptly.

The CJV has provided three alternatives to stabilise the slope and arrest the movement:

1. Option 1 Earthworks - Layback plus Buttress
2. Option 2 Piling (single platform)
3. Option 3 Piling (two platforms)

The deepest shear surface is interpreted as being at a depth of about 6-8m below the base of the buttress. Therefore, the buttress of Option 1 is not expected to be 'keyed' into stable bedrock at depth. TAS considers there is a risk that the fill buttress (Option 1) could have both positive and negative effects. The piled solutions (Options 2 and 3) involve positively intercepting the slip surfaces and reinforcing the landslide mass. Consequently, of the options presented by NX2 to Waka Kotahi, it appears that the more durable options are likely to be stabilisation by piles. Option 3 appears to involve the least disruption to the southbound carriageway and is the preferred option of those presented by NX2.

Alternative stabilisation methods and additional measures that might be discussed with NX2 for consideration are presented in this technical memo. However, given that TAS is not privy to all information these alternatives may not be found to be viable or effective.

TAS considers that the N1A cut slope and associated geotechnical elements, in their present form, do not satisfy the design life requirements included in Works Completion Test 16.1 (Works Completion Test 16.1 included in Schedule 10). TAS recommends that Waka Kotahi should share this opinion with the IR.

It is recommended that Waka Kotahi request information from NX2 in relation to the N1A cut slope and associated landslide such as (1) all factual monitoring data and interpretations by the Designer; (2) interpretation of landslide mechanisms and landslide behaviour by the Designer; (3) the Designer's proposed additional investigations to ensure a robust ground model is developed for detailed remedial designs; (4) details of proof drilling proposed in advance of construction of remedial options; (5) assessments of temporary earthworks on the slope stability; (6) assessment of the effectiveness of the remedial options and demonstration that they mee the Works Requirements.

1. Introduction and Purpose of Memo

1.1 Introduction and Purpose

The TAS UJV (TAS) has continued to provide technical support and advice to Waka Kotahi NZ Transport Agency (Waka Kotahi) on landslides and the performance of cut slopes affecting the Puhoi to Warkworth project throughout the construction period.

The N1A cut slope has undergone previous movement and landsliding. Following previous failures the slope was flattened and had a series of counterfort drains installed in the lower portion of the slope. Current slope monitoring and visual observations indicates that the N1A slope has experienced another landslide and is moving towards the carriageway. The CJV has provided three alternatives to stabilise the slope and arrest the movement.

The purpose of this memo is to summarise:

1. TAS's opinion on the residual technical risk to opening the road before N1A stabilisation works are carried out (short term and long term risks).

2. TAS's technical evaluation of NX2's stabilisation options for the N1A slope including TAS's interim recommendation.

3. Additional information that may be provided by NX2 about the N1A slope and stabilisation options so that improved confidence can be achieved for all parties seeking a more durable outcome.

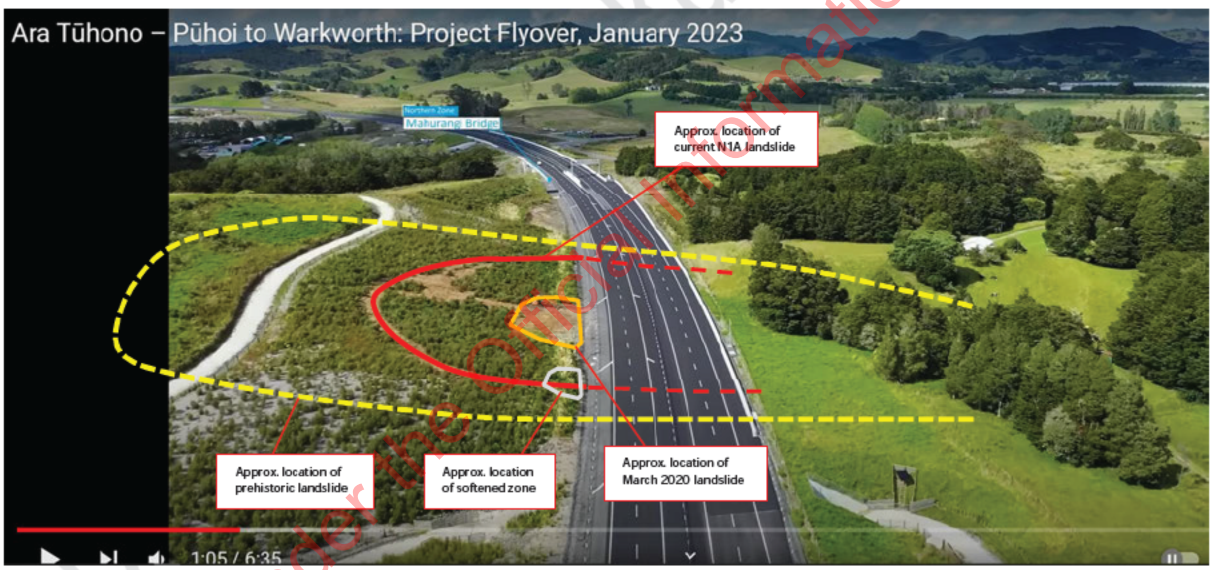

Figure 1 Screen capture of NX2's January 2023 drone flyover, with sketches of approximate locations of (a) March 2020 N1A landslide (b) current N1A landslide (c) prehistoric landslide. View towards the south-west.

2. Scope of Review

This Technical Memorandum summarises results from the following elements:

- NX2 Powerpoint slides of options considered ('*N1 Remedial works – analysis, 10 March 2023*'), provided to TAS by Waka Kotahi.
- Knowledge and observations from previous site visits by TAS technical specialists of the N1A cut slope and landslide area.
- Consideration from previous assessment of the cut slopes carried out by TAS, as well as those reported by PSM[1] and Gaia[2] as engaged by CJV and NX2 respectively.
- Extraction and collation of relevant CJV/DJV construction observations and design information from the project's Aconex database, where present.

  Documents typically gathered from Aconex include:

  - Design Engineer Instructions (DEIs),
  - Construction Observation Reports (CORs),
  - Contractor's Work Pack for Specific Lot Numbers,
  - N1A Landslip. Prehistoric Landslip and Softened Zone Remediation Factual Information Package,
  - N1A Cut Stability CH48730- CH48755 + Larger Pre-Historic Landslide Stability Design Calculations
  - DJV document entitled, "*Outline of Geological Model Development for Landslides*"
  - Specific Geotechnical Drawings with notes and mark-ups reflecting field construction,
  - Inspection and Test Plans (ITPs) for witness and hold points,
  - Non-Conformance Records (NCRs) for variances from design or known missed hold and witness points.

[1] PSM Report "Independent Geotechnical Review of Remediation Design for Cut Slope Failures" Report PSM4203-029R, latest revision 4 May 2022
PSM Report "Independent Geotechnical review of Cut Slopes: Susceptibility of Constructed Cuts, Report PSM4203-055R, latest revision 4 May 2022
[2] Gaia Report "Geotechnical Review of Cut Slopes and Landslide Risks", Report 2394-01 (Rev D), latest revision 28 April 2022

3. N1A Landslide Observations and Risk

3.1 Key Observations

- A pre-historical landslide feature has reactivated on the N1A cut slope east of the carriageway (a reactivated slow-moving translational earth slide). As displacement increases, there is an increased risk of water ingress into the slope from the dilation of tension cracks near the landslide headscarp.

- Surface monitoring data provided by NX2 (up until 6th March 2023) shows that since early February (following the intense and prolonged 2023 Auckland Anniversary atmospheric storm event) the slope above the road has experienced periodic episodes of comparatively rapid movement of approximately 200mm/week to >300mm/week, separated by periods of relatively little movement.

- Overall since early February 2023, displacement has occurred at an average rate of approximately 55-110mm/week. The periods of faster movement are inferred to be in response to rainfall events and likely increases in piezometric pressures.

- TAS has not seen monitoring data beyond the 6th March to confirm that this trend has continued over the last four weeks but a video recorded by the Waka Kotahi site monitoring team on 29 March[3] shows ground displacement had recently occurred in the rock lined drainage swale that separates the shoulder from the toe of the slope.

- Cracks have been reported in concrete barriers in two separate places on the western side of the carriageway, aligning with projections of the northern and southern lateral extents of the landslide on the cut slope. In addition, surface monitoring data from points on the western side of the carriageway show an increasing scatter in displacement rates recorded since mid-January 2023. Thus there is the potential that some minor ground movement is occurring on the western side of the carriageway, reflecting landslide movement across the full width of the motorway.

- We note that NX2 have also shown an interpreted ground model section with two landslide slip surfaces at depth extending beneath the carriageway (Figure 2).

- TAS has previously requested the results from an inclinometer that has been installed in this area which may confirm subsurface movement on the western side of the carriageway. To date TAS understands that Waka Kotahi has not received any inclinometer data or reports for this inclinometer. The potential for movement along slip surfaces at depth beneath the carriageway is a significant concern for ongoing deformation of the road.

- A noticeable bulge has developed at the toe of the cut slope, with mobilised material squeezing and closing up the swale drain and a slight bulging of the edge of the shoulder[3]. The depth of engineered fill under the main carriageway is likely acting as a reinforced volume and encouraging some compression and upward movement of the landslide mass at this location.

3.2 Landslide Risk

- Based on observations from similar translational landslides in cut slopes and natural slopes elsewhere during the motorway construction, it is considered that catastrophic failure of the cut slope with significant debris rapidly failing onto the carriageway edge is unlikely in typical rainfall events.

- Unless stabilised, deformation of the eastern (southbound) carriageway edge is expected to continue and to increase in magnitude as the landslide movement continues. This is expected to require ongoing maintenance and rebuilding of drainage, structures (e.g. light poles, barriers), and the pavement surface. Ride quality has the potential to be impacted and this could conceivably result in the surface failing to maintain the NASSRA roughness requirement.

[3] Observed in Waka Kotahi video 'VIDEO-2023-03-29-10-39-10'

- Unless stabilised, deformation of the pavement on the lateral margins of the landslide, where the landslide underlies the main part of the carriageway, is anticipated to develop over time (leading to cracking and vertical depressions perpendicular to traffic lanes). This has the potential to impact the safe movement of traffic along the corridor if not addressed or limited to minor displacements.

- Unless stabilised, there remains uncertainty and a risk of the landslide movement accelerating or becoming more significant, especially if more extreme rainfall events are experienced, or if heavy rainfall occurs after periods of very hot and dry temperatures such that shrinkage and cracking of the soil mass occurs.

- Note that current rates of movement have already resulted in noticeable damage to the swale drain and shoulder edge in a short period of time (a matter of weeks). In TAS' opinion, stabilisation of the landslide is required in the short term to minimise the risk of accelerated movements and exposure to 'extreme' climatic/storm events/strong earthquakes.

- Adopting the AGS Landslide Risk Management guidelines for qualitative risk[4], **without any treatment** the landslide feature (as currently understood based on information provided by NX2 to Waka Kotahi) may have the following risk classification to the motorway width (property only, not safety or risk to persons):

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		Implied Indicative Landslide Recurrence Interval		Description	Descriptor	Level
Indicative Value	**Notional Boundary**					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}		100 years		The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-3}$	1000 years	200 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-4}$	10,000 years	2000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-5}$	100,000 years	20,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}	$5x10^{-6}$	1,000,000 years	200,000 years	The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

Note: (1) The table should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not *vice versa*.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		Description	Descriptor	Level
Indicative Value	**Notional Boundary**			
200%	100%	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	40%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%	10%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	1%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%		Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

Notes: (2) The Approximate Cost of Damage is expressed as a percentage of market value, being the cost of the improved value of the unaffected property which includes the land plus the unaffected structures.

(3) The Approximate Cost is to be an estimate of the direct cost of the damage, such as the cost of reinstatement of the damaged portion of the property (land plus structures), stabilisation works required to render the site to tolerable risk level for the landslide which has occurred and professional design fees, and consequential costs such as legal fees, temporary accommodation. It does not include additional stabilisation works to address other landslides which may affect the property.

(4) The table should be used from left to right; use Approximate Cost of Damage or Description to assign Descriptor, not vice versa

[4] AGS (2007a). Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management. Australian Geomechanics Society, Australian Geomechanics, Vol 42, No1.

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		**CONSEQUENCES TO PROPERTY** (With Indicative Approximate Cost of Damage)				
	Indicative Value of Approximate Annual Probability	**1: CATASTROPHIC 200%**	**2: MAJOR 60%**	**3: MEDIUM 20%**	**4: MINOR 5%**	**5: INSIGNIFICANT 0.5%**
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or L (5)
B - LIKELY	10^{-2}	VH	VH	H	M	L
C - POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D - UNLIKELY	10^{-4}	**H**	M	L	**L**	**VL**
E - RARE	10^{-5}	M	**L**	L	**VL**	**VL**
F - BARELY CREDIBLE	10^{-6}	**L**	**VL**	VL	**VL**	**VL**

Notes: (5) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.
(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

Risk Level		**Example Implications (7)**
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	May be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

- The resulting risk to the motorway width is interpreted as 'Moderate Risk'. The implication is particularly important as the risk assessment framework suggests that treatment to reduce the risk should be implemented *as soon as practicable*.

- If only considering the N1A cut slope and the shoulder of the motorway, TAS interprets the likelihood to be classed as 'almost certain', and the resulting risk to the motorway shoulder alone would therefore be considered 'High Risk', suggesting that the risk is *unacceptable without treatment*.

- A quantitative risk assessment of the risk to persons (loss of life) has not been carried out by TAS but may have been undertaken by NX2 and its suppliers. Doing so would involve assessing traffic flows, types of vehicles, and the temporal probability of vehicles and occupants being subject to effects of landslide movement. Most human casualties are associated with high velocity landslides, however, slow moving landslides such as we interpret the N1A landslide to be (based on the available monitoring data made available to TAS) can cause high levels of financial loss, reputational damage and, in some cases, loss of life if not monitored closely and/or mitigation measures implemented promptly.

4. N1 Remedial Options Under Consideration

4.1 NX2 Remedial Options

NX2 has recently presented several options to Waka Kotahi. TAS were not present during the meeting but subsequently received a copy of the slide deck. NX2 outlined a summary of the following options:

4. Option 1 Earthworks - Layback plus Buttress
5. Option 2 Piling (single platform)
6. Option 3 Piling (two platforms)

4.2 NX2 Option 1: Layback plus Buttress

NX2's Option 1 is an earthwork solution, comprising reprofiling of the N1A cut slope (to a slightly steeper gradient), and constructing a fill buttress at the toe of the N1A cut slope. Earthworks appear to be limited to the eastern side of the carriageway. Option 1 is indicated by NX2 to necessitate closure of both southbound lanes.

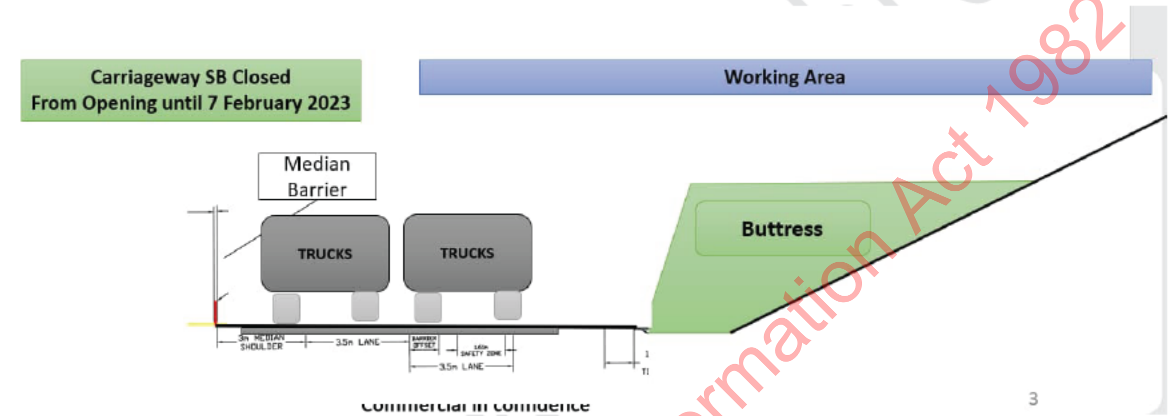

Figure 2 NX2 Option 1 section.

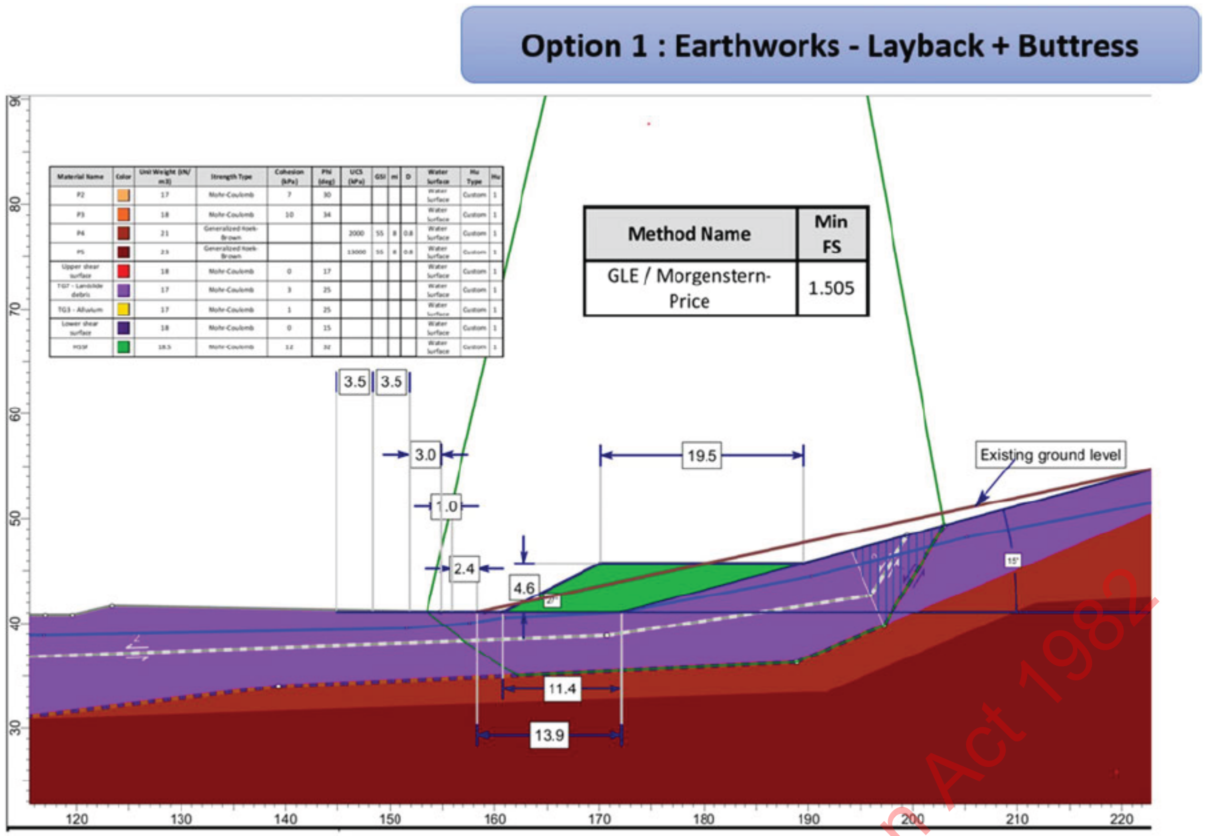

Figure 3 NX2's stability section for Option 1

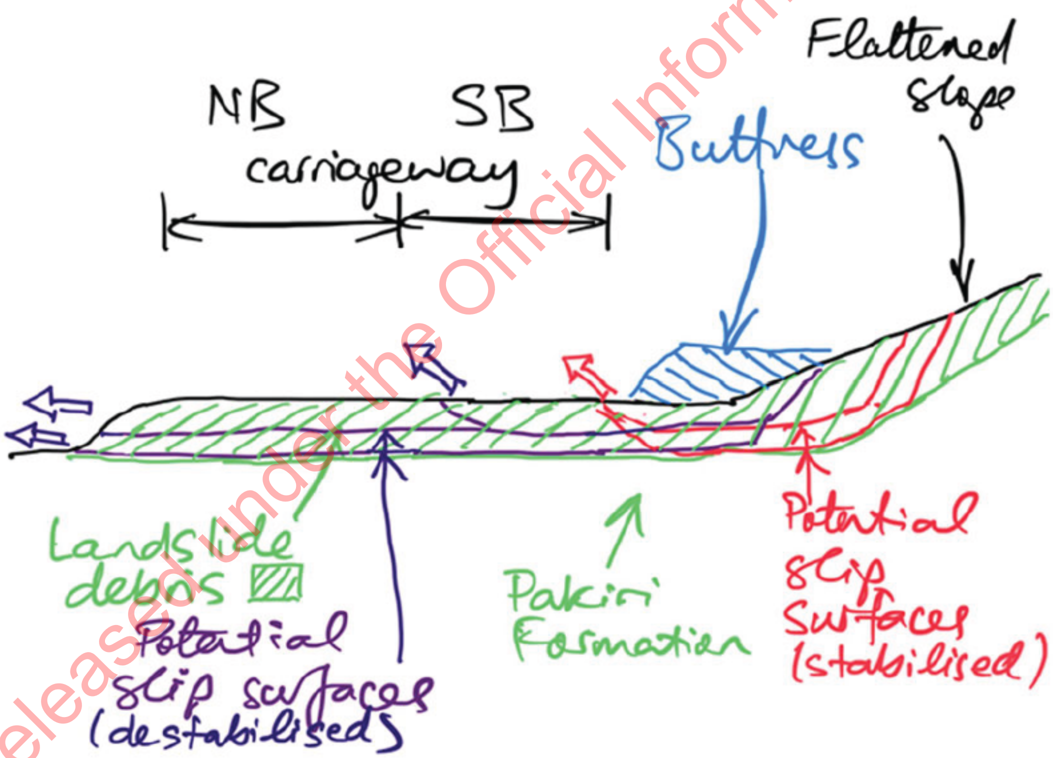

Figure 4 TAS's interpretation of stability for Option 1

TAS have the following comments on this option:

- Option 1 involves placement of a fill buttress at the base of the cut slope.
- In their presentation NX2 have shown an interpreted ground model section with two landslide slip surfaces at depth extending beneath the carriageway (Figure 2). The deepest shear surface is interpreted to be at a depth of about 6-8m below the base of the buttress. Therefore, if option 1 was implemented as shown by NX2 the buttress will not be 'keyed' into stable bedrock at depth.
- The performance of the buttress to stabilise the landslide when not keyed into stable bedrock requires a very robust knowledge of the ground model, slip surfaces and the landslide behaviour, with as many uncertainties as possible eliminated.
- While reprofiling the cut slope removes some of the material in the upper part of the cut, and the buttress acts as a toe buttress to further stabilise landslides involving the slope (red slip surfaces in Figure 3), there is the risk that the buttress destabilises potential slip surfaces existing beneath the carriageway (purple slip surfaces in Figure 3).
- Thus there is a risk that a fill buttress could have both positive and negative effects.

4.3 NX2 Option 2: Piling (single platform) and Option 3: Piling (two platforms)

NX2's Options 2 and 3 involve a structural solution, comprising installing a row of inground reinforced concrete piles in the slope on the eastern side of the carriageway. The piles penetrate the two identified slip surfaces and the toes of the piles are shown as being embedded into underlying rock. The piles would act in shear and provide a restraining force to the upslope portion of the landslide.

The difference between options 2 and 3 is purely in construction method; i.e. whether the piles are installed using a single construction platform or two platforms. A single platform is indicated to necessitate closure of both southbound lanes whereas the two platforms option requires more earthworks but only one southbound lane to be closed.

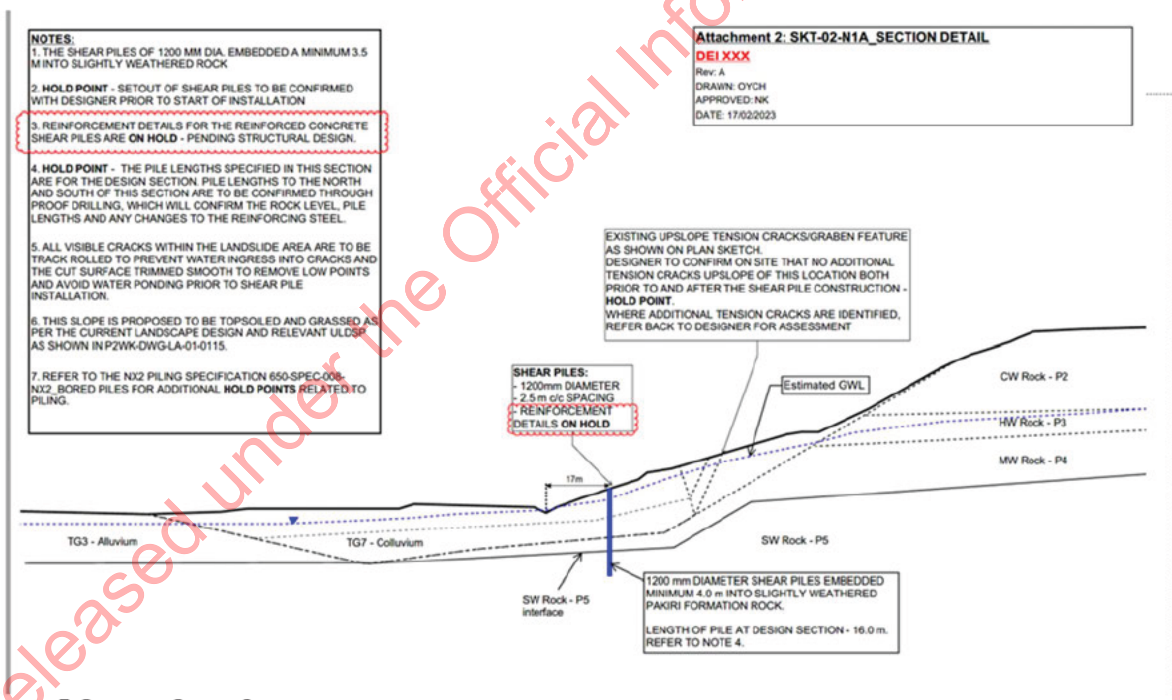

Figure 5 Options 2 and 3 section

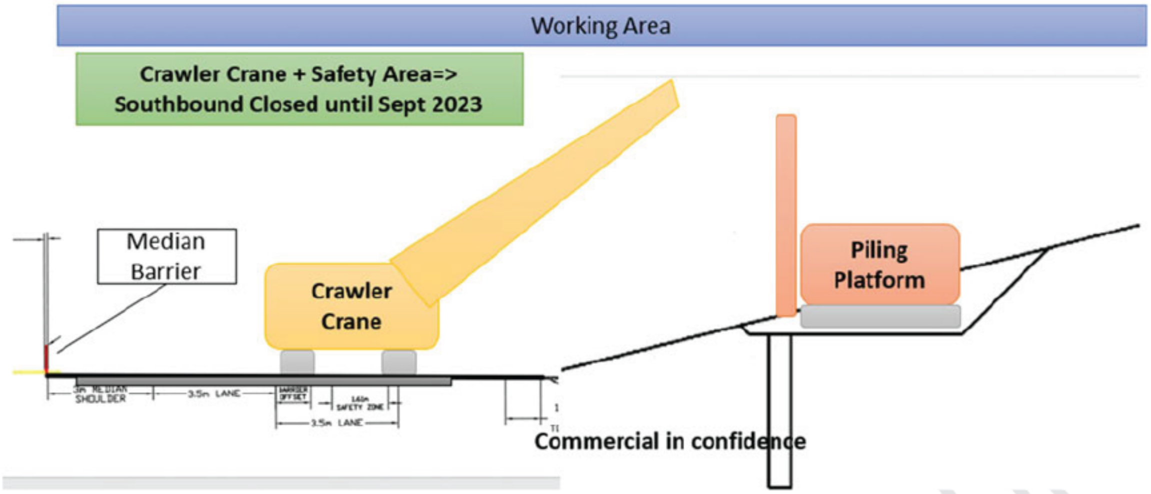

Figure 6 Option 2 (single platform)

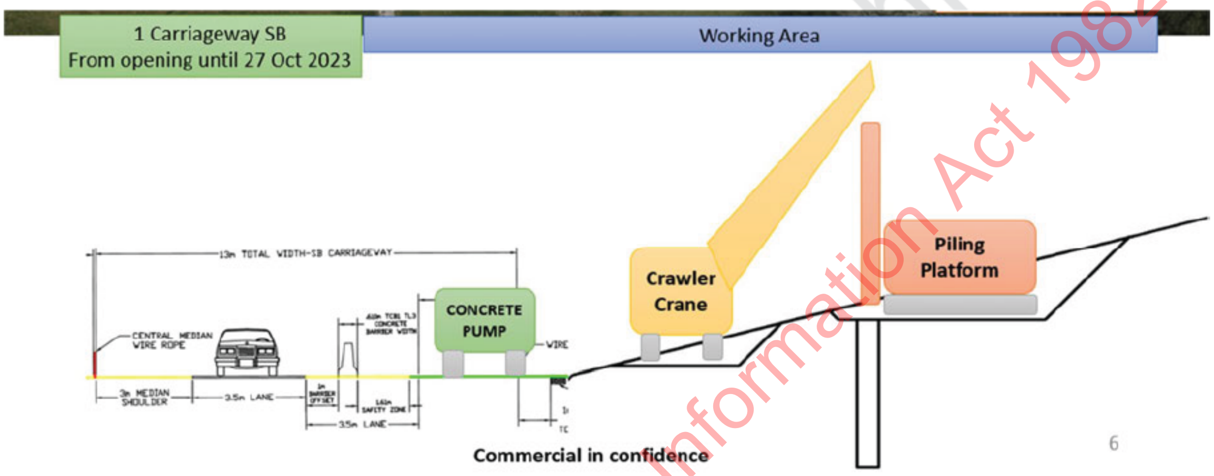

Figure 7 Option 3 (two platforms)

TAS have the following comments on the applicability of these options:

Stabilisation

- The piled solutions involve providing a restraining force to the upslope portion of the landslide, and effectively reduces the driving force on the lower portion of the landslide. The slip surfaces are positively intercepted and reinforced.

- The potential instability on gently inclined slip surfaces to the west of the piles and beneath the carriageway is likely decreased. Although the landslide body and slip surfaces here would remain unrestrained, and therefore the remaining instability of the downslope landslide mass should be investigated and confirmed during detailed design.

- It is essential that the piles are embedded into underlying stable rock well below the lower slip surface. This would require a knowledge of the geometry of the lowermost slip surface in the direction along the row of piles. We note that the NX2 presentation shows a proposed hold point to confirm the pile lengths through proof drilling. TAS agrees with this approach and would recommend that adequate proof drilling is carried out in advance of the construction in order to adjust or confirm the design based on the drilling results.

Some Comments on Constructability

- The lifting radius of a crane operating from the motorway for Option 2 will likely require a large crane. The surface of the motorway would need to be protected if the motorway is used as a crane platform. Any requirements to stop adjacent (live) traffic during lifting operations will also need to be factored in.

- The minimum width for the piling platform is anticipated to be around 6-8m to allow for safe operations. Temporary cuts for the platform will need to be excavated such that they do not exacerbate the existing slope instability.

- In addition to the piling activities itself, the following is typically required for this type of activity:

  - A suitable working area for rigging / de-rigging the piling rig
  - Space for the large crane to be assembled / disassembled (often another crane may be required).
  - Storage areas for reinforcement cages.
  - Access for spoil removal trucks and concrete pump / trucks.

- Production rates of approximately 1.0-1.2 piles per shift appear achievable and reasonable in such constrained conditions. Consequently, the piling programme as presented by NX2 appears a reasonable estimate based on the information provided.

4.4 Comparison of NX2 Options

Of the options presented by NX2 to Waka Kotahi, it appears that the most durable option is likely to be stabilisation by piles (Options 2 and 3). However, these are anticipated to require a portion or the entire southbound carriageway to be closed. This introduces a safety risk as construction might need to be carried out adjacent to a live traffic lanes unless such work was undertaken prior to road opening.

Table 1 TAS' relative assessment of NX2 remedial options

	Option 1 Buttress	Option 2 Shear Piles (1 platform)	Option 3 Shear Piles (2 platforms)
Stability improvement	Least robust	Robust	Robust
Programme	Short	Long	Long
Relative Indicative Cost	$2M	$7M	$7M
Lane Closures	Both Southbound	Both Southbound	Single Southbound

5. Alternative Options for Consideration

TAS is not the designer for this project. We have outlined possible alternative solutions that Waka Kotahi may wish to discuss with NX2 and its suppliers. If any of these solutions are deemed to be attractive to NX2 then Waka Kotahi should make it clear that the purpose of sharing such options for discussion is purely to understand the extent of alternatives that NX2 might have considered. Alternative stabilisation methods that might be discussed are presented below.

Without the full information that NX2's designers have, TAS is unable to assess if these may be any more robust in their ability to stabilise the slope compared to Options 1 to 3. However, they may not necessarily require extended carriageway closure and might be able to be performed along the slope outside the carriageway.

5.1 Option 4: Rock anchors

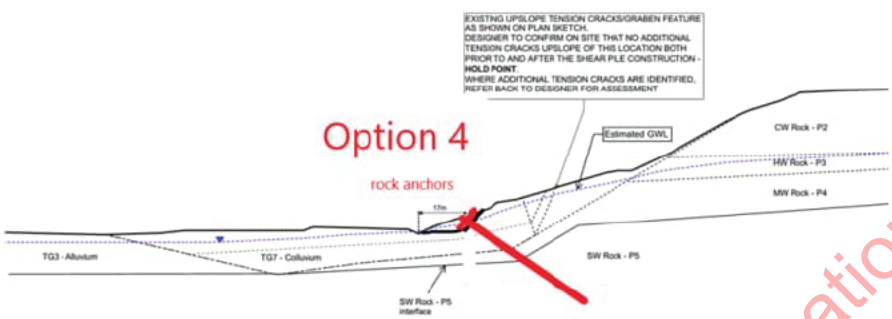

Figure 8 Modified NX2 sketch to show potential rock anchor option for consideration

As an alternative deep rock anchors could be investigated as a possible solution requiring works to be performed along either one or two platforms on the slope face similar to Options 2 and 3. A second platform may be required if two rows of rock anchors are needed rather than a single row of rock anchors. The anchors would need large concrete pads to transfer anchor loads into the landslide mass. We expect that road closures for this option would be similar to that required for Option 3. Installation of rock anchors is likely to require smaller plant than that for Options 2 & 3.

A risk with Option 4 is that a better understanding of anchor founding conditions through further ground investigations would be required so that when installation of the anchors begin the risk of longer anchors being required is minimal. Trial anchors would need to be drilled and load tested to confirm anchor design prior to construction.

5.2 Additional measures that could be used in conjunction with Options 1, 2, 3 & 4

Reprofile slope below farm access track and install inclined drains

Additional measures to improve stability of the slope and in particular the upper portion of the slope, include:

- reprofiling the slope below the farm access track to reduce the driving force on the upper portion of the slope. Originally fill was placed in this area prior to the 2020 landslides. See drone photo below.

Figure 9 Screenshot of N1A cut (view southwards) from the February 2020 Drone Flyover

This measure may not be considered viable since the access road stability would have to be reviewed.

- A series of inclined bored drains could be installed along the slope to intercept water that may be entering the fill and slope material from the steep rock face shown in the ground model Stability Section (Figure2). Drains can be installed at mid slope as well as closer to the toe of N1A to help reduce the potential for development of high pore pressures in the fill (which is considered a risk in the DEIs and could be causal in the landslide and episodic movement observed in the most recent monitoring data for N1A).

6. Additional Commentary

TAS considers that it would be unreasonable for NX2 and the Independent Reviewer to state that the N1A cut slope and associated geotechnical elements have satisfied the design life requirements included in Works Completion Test 16.1 (Works Completion Test 16.1 included in Schedule 10).

TAS recommends that the applicable sections of Part 3, clauses 16.2(a) to 16.2(h) of Section 11 of the Project agreement that all Geotechnical Elements have a design working life of not less than 100 years be adhered to.

The ground model does not appear to be well defined given the level of proposed stabilisation works proposed. TAS is not privy to the full quantum of monitoring or investigation being undertaken by NX2. In the absence of such an understanding we would recommend that prior to finalising the proposed stabilisation scheme that NX2 and its suppliers (CJV/DJV) consider obtaining additional information that would help constrain the uncertainty in the ground model which includes the deeper shear surface depth, location and effective friction angle, the ground water level and the slope pore pressures. Inclinometers should be installed and read to determine the amount of slope displacement is occurring and at what depths so that the stabilisation can be designed to be congruent with the subsurface conditions.

It appears from a cursory review of the available site monitoring movements that the slope appears to be moving in episodes followed by periods of low to no movement. It was beyond the scope of this review to associate these episodic movements with coincident periods of high rainfall and increases in ground water level (increases in pore pressure) but these should be evaluated by the Designer as it is important to note as the rate of changes in pore pressure on the slope could be triggering syncopated landslide movements in a complex relationship.

7. Information to be requested from NX2

It is recommended that Waka Kotahi request the following information from NX2 in relation to the N1A cut slope and associated landslide:

1. All up to date factual monitoring data (including piezometers, inclinometers, surface monitoring) and a report detailing the methodology, results and interpretation of the monitoring data. This is expected to include the Designer's assessment of measured ground movements, groundwater levels and interpretation of slope stability. It is the view of TAS that following Good Industry Practice the Designer will have looked to inform their assessment based on appropriate investigation.
2. The Designer's interpretation of landslide mechanisms and landslide behaviour.
3. The Designer's proposed method(s) of investigation, and any relevant results, to develop a robust ground model for detailed design of the stabilisation options.
4. Details of investigations or proof drilling to be carried out in advance of the construction for any option adopted, will such investigations be completed in advance to enable adjustment or confirmation of the design based on the drilling results?
5. What assessments have been made for temporary platform cuts (Options 2 and 3) such that they do not exacerbate the existing slope instability?
6. NX2's assessment of the effectiveness of the remedial options and demonstration that they meet the Works Requirements.

8. Limitations

The sole purpose of this memo and the associated services performed by TAS (GHD and Jacobs) is to provide observations and commentary on elements of the N1A slope stabilisation construction methodologies proposed by NX2's supplier (CJV) and to provide additional recommendations or information to request from NX2 and its supplier CJV regarding the N1A slope stabilisation for the Puhoi to Warkworth project in accordance with the scope of services set out in the contract between GHD, Jacobs and Waka Kotahi NZ Transport Agency (Waka Kotahi).

In preparing this N1A slope stabilisation memo, GHD and Jacobs have relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by Waka Kotahi and/or from other sources. Except as otherwise stated in the memo, GHD and Jacobs have not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this memo may change.

GHD and Jacobs have derived the data in this memo from information sourced from Waka Kotahi (if any) and/or available in the public domain at the time or times outlined in this memo. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this memo. GHD and Jacobs have prepared this memo in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this memo. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this memo, to the extent permitted by law.

This memo should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by GHD or Jacobs for use of any part of this memo in any other context.

This memo has been prepared on behalf of, and for the exclusive use of Waka Kotahi. GHD and Jacobs accept no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this memo by any third party.

Prior to taking any action that is implied, inferred, or recommended in this technical memo it would be both reasonable and appropriate for Waka Kotahi to seek a legal opinion of those implied, inferred, or recommended actions so that it understands how they might be interpreted under the Project Agreement and whether they should be taken. The TAS UJV is not best placed to provide such legal advice. TAS is acutely aware that there are commercial and legal implications associated with actions that Waka Kotahi might take and the need for Waka Kotahi to not compromise its commercial or legal obligations.