3.0 Existing Landslides

3.1 Overview

Multiple landslides including at temporary works slopes have occurred during the construction since late 2019. Based on the provided CJV weekly progress reports, 19 landslides are being tracked for their progress with regards to their respective status on design, peer review and remedial works completion.

The locations of the landslides are shown in Figure 1 below.

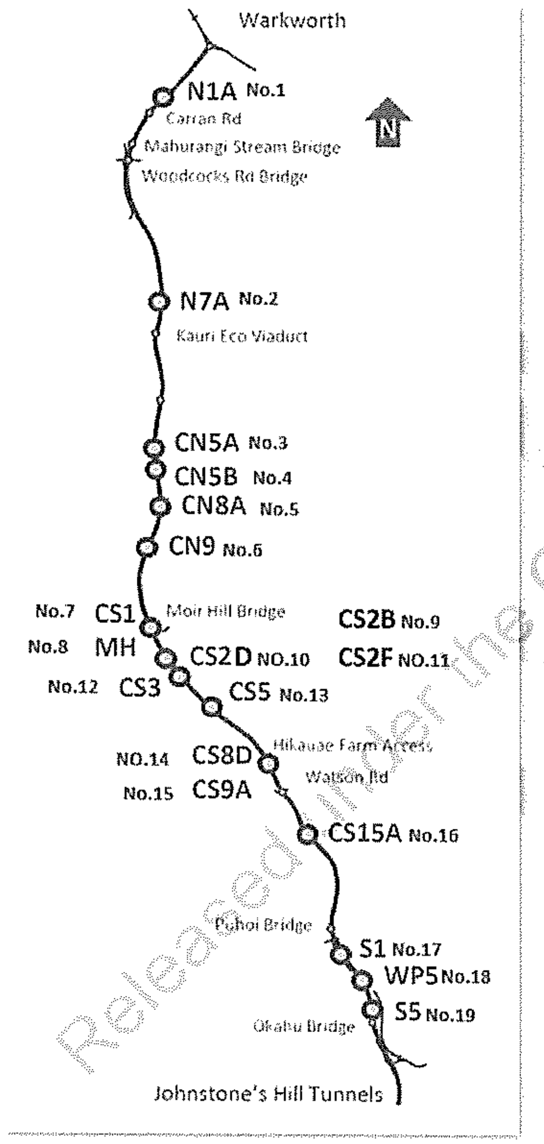


Figure 1: Landslide Locations along the P2Wk Alignment

The followings risk items have been identified:

- Soil slope failures, predominantly failing along the soil rock transition zone,

- Topsoil slumps and surficial erosion,
- Softening of ground (soil, weathered rock, fill) caused by groundwater seepage or surface water run-off,
- Surficial failure rock slopes and rockfall behind mesh draping,
- Wedge failures at rock slopes between rock bolts or at location without rock bolts,
- Scour/erosion and debris flow from soil slopes or soil-rock interface above rock slopes.

After occurrence, the existing landslides were assessed by DJV and CJV geotechnical engineers and remedial works design solutions developed. We understand that the design solutions were developed based on geological site observations and review of geotechnical investigations and detailed designs.

New geotechnical design and analysis models were developed.

3.2 Landslide Risk Factors

The geotechnical risks and their respective mitigation measures for the landslides are stated in Table 9 below.

Table 9: Summary of Slope Stability Key Factors

Feature (Design Input)	Description	Risk & Assessment
Soil (and Rock) Slope Height	The alignment sections and plans indicate that some of the soil cut slopes are more than 40m high.	The height of a soil slope has a direct effect on the factor of safety against slope failure. If all other features (design inputs) listed in this table are identical, the factor of safety against slope failure decreases with increase in the slope height. Long slopes are also prone to surface erosion.
Soil Slope Batter	Generally, the designed soil slope batters are 2H:1V throughout the project, irrespective of whether slope material, height or site-specific geological settings.	As above. High 2H:1V slopes are also prone to surface erosion.
Strength of Soil	The adopted soil strength is a key design parameter with respect to the slope stability design, under drained and undrained conditions.	Where slope stability analyses utilise homogenous soil models, consideration of bedding planes shall be reviewed to ensure that the geotechnical model reflects the ground conditions on site.
Inclination and direction of rock level	The two-dimensional (2D) alignment cross sections present inferred rock levels, which have been derived from a 3D surface based on a 3D geological model. The 2D alignment cross sections only provide a 2D interpretation of the inclination and direction of the 3D rock level surface. Rock levels may also be inclined in alignment direction (perpendicular to cut slope faces) which may explain that some landslides occurred in oblique direction.	Slopes where the rock surface dips towards the cut slope face are considered higher risk than that with gentle bedding angle. However, from the remedial works design reports (DEIs), it appears that the landslides occurred generally at horizontal to sub-horizontal rock surfaces. The risk of steeply inclined rock surface shall be considered in the design. We would consider dip angles larger than 20 degrees as high risk.

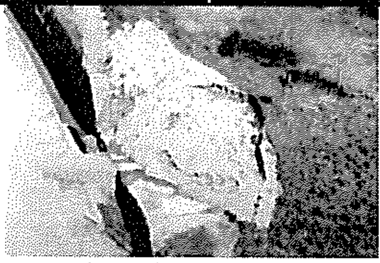
Feature (Design Input)	Description	Risk & Assessment
	The cross sections show that the 2D rock levels are inclined towards and away from the cut slopes. Some rock interfaces are inclined up to 20 to 25 degrees (Note that a 26.5-degree inclined plane is 2H:1V steep).	
Strength of weathered rock at transition zone	A softened transition zone at the weathered rock surface could be present.	The strength of the transition zone and groundwater conditions need to be considered in the geotechnical models, particularly where the rock interface is dipping towards the cut slope face.
Groundwater conditions and recharge of groundwater	Groundwater levels and seepage are a key factor for slope stability and cause of potential failures. The soil rock interface is typically a permeability boundary. The upper soils are more permeable than the underlying Pakiri Formation. Subsequently, groundwater is likely ponding (perched groundwater) on the soil rock interfaces, which can reduce the shear strength at the interface.	Ongoing groundwater seepage with or without direct correlation to rainfall are considered a risk item.
Slopes adjacent to existing landslides	Slopes with similar topographical features and ground conditions would be similarly prone to slope failures unless there are site specific conditions which explain the slope failure.	Soil slopes adjacent to landslides may have similar underlying site-specific geological conditions and potentially similar risk of failure.
Construction Sequence and speed of excavation (temporary conditions)	The excavation a soil or rock slope causes a change of stress state. A rapid change of the stress state (especially slope cutting in winter seasons when the groundwater level is still high) may result in a slope failure under temporary conditions.	If the construction sequence and speed of excavation was a contributing factor of the slope failures, it is considered unlikely that the future stability of adjacent soil slope would be adversely affected. However, it shall be verified that the excavation did not cause any cracking at the slope which may allow ingress of surface water into the slope and subsequent softening.

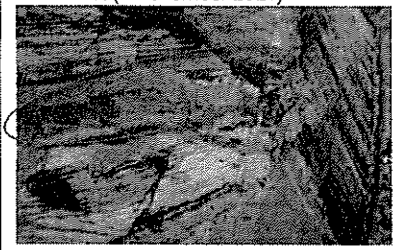
Any of the above geotechnical features listed in Table 9 may trigger a slope failure if their respective influence is significant. Likewise, any combination of the items may cause a slope failure depending on the weighting of the triggering geotechnical feature.

3.3 Typical Slope Failures Modes and Risks

This section provides a summary of the typical slope failure modes and potential future risks encountered at the project site.

Table 10: Typical Slip and Landslide Features

Risk Item	Example	Potential Causes	Locations
1. Soil slope failures, predominantly failing along/above the soil rock transition zone	 CN1 North-west (September 2021, now repaired)	• Cut slope too steep for geological conditions, i.e. conditions and inclination of soil-rock transition zone, • High groundwater levels or groundwater seepage, • Surface water runoff infiltration into slope,	• Transition into cut slopes from embankment fills, • Soil slope above rock cuts, • CN1 North-west,
2. Slope failures within transitional rock or highly weathered rock at previous landslides	 CN5B East (12 November 2021)	• Surface water runoff infiltration into exposed fractured and highly weathered rock mass or zone of transitional rock, • Groundwater seepage,	• Exposed highly weathered and fractured transitional rock near cut slope surface, particularly where not protected by topsoil, • CN5B East,
3. Softening of ground (soil, weathered rock, fill) caused by groundwater seepage or surface water run-off	 N7A West (12 November 2021)	• Large groundwater seepage, • Inappropriate or not functioning subsoil drainage system	• Groundwater seepage visitable at soil slope faces, • N7A West,
4. Wedge failures at rock slopes between rock bolts or at location without rock bolts Wedge failure may result in large scale failures.	 CN5B East	• Intersection defect sets, • Heavily faulted rock mass, • Too steep cut slopes for encountered geology, • Insufficient rock support (rock bolts), • As-built cuts are steeper than design,	• Refer to Table 11 for locations of 85°/64 ° steep rock cuts, • CN5B East & West,
5. Scour/erosion and debris flow from soil slopes or soil-rock interface above rock slopes	 CS2F East (2 November 2021, now replaced by rock lined swale drain)	• Insufficient cut off drains at top of slope, • Long and steep slope faces without sufficient slope face erosion protection, • Highly erodible soils/rock exposed at slope face,	• CS2F East, • CS3 East,

Risk Item	Example	Potential Causes	Locations
6. Rockfall from debris above rock cuts, potentially rolling or dropping on the SH1. Refer to revised rockfall risk assessments in Section 4.2.	 CS2F East (2 November 2021)  CN5B East (buttress fill)	• Exposed weathered and highly fractured rock, • Steep slopes above rock cuts without sufficient rockfall catch area or protection, • Rock lining fill from swale drains or buttress fill,	• Refer to Table 11 for locations of 85° steep rock cuts, • CN5B (buttress), • CN5B East & West, • CS2F East, • CS3 East,
7. Topsoil slumps and surficial erosion	 CS16D	• Soil slopes with smooth surfaces or topsoil placed on rock cuts, • Too loosely placed or think topsoil, • Topsoil placed prior to winter (rainfall) season,	• Soils slopes, particularly at transition into cut slopes from embankment fills, where batters could be steeper than 2H:1V, • CS16D,
8. Surficial rock dropouts and rockfall behind mesh draping without affecting rock cut integrity.	 CN5B	• Defect sets of rock mass, • Ongoing weathering of exposed rock surface, • Groundwater seepage,	All location of steep rock cuts. Refer to Table 11.