STRUCTURAL CONTROLS OF THE OTWAY RANGES AND HAZARDS FOR ROAD USERS

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ABSTRACT

The Otway Ranges have long been established as a region with significant landslide hazards to both private property and public asset owners. Owing to the folded nature of the interbedded sedimentary Cretaceous Eumeralla Formation, dip-slope behaviour governs a large percentage of the slopes, and this is generally well documented by others. Along the southeast facing coastline of the ranges a significant proportion of the Great Ocean Road has been constructed sub-parallel to the strike of bedding and it is unsurprising that planar sliding on bedding is a common slope control that informs hazard assessments.

For inland routes and sections of roadway orientated outside of the kinematic window for dip-slope failure, structural controls on cut and buried slopes are often present. These are typically associated with shear and fault zones and in some cases the interaction with weaker siltstone and mudstone beds. The structural controls of two case studies are presented, each highlighting a unique set of hazards to road users. Each case study highlights the importance of establishing the structural trends, even when assessing slopes formed with fill and buried landforms. These trends then inform the engineering geological model and ultimately the assessment of hazards to road users.

1 INTRODUCTION

The Otway ranges in Victoria, Australia, are home to the Great Ocean Road (GOR), which adds significant value to the tourism industry. The State Government has active strategies in place to improve safety in the Otway Ranges (Great Ocean Road region strategy (planning.vic.gov.au) 2024) and was actively involved in the Wye River and Separation Creek rebuild following the Christmas 2015 bushfires. The Department of Transport and Planning (DTP) is tasked with management of roadside geotechnical hazards for the GOR and key inland routes.

The structural trends along the GOR have been well documented by Medwell (1968), Cooney (1982) and Edwards et al (1996). The works reported by the preceding authors are broadly focussed on major folds, faults and bedding trends with less detail on fault and shear systems, Figure 1. Furthermore, large planar failures on dip slopes are well established as a mode of failure, especially along the GOR where bedding is often undercut by wave driven erosion and the construction of the GOR itself (Williams & Muir, 1972). The extensive mapping of bedding trends is helpful as typical defect sets are consistent with literature in folded sedimentary rocks (Fookes, et al 2000). The present author's approach to hazard mapping in the Otway Ranges places a priority on locating intact rock in the study area and establishing bedding trends as a minimum to begin understanding structural controls at each site.

The two case studies presented are located within deposits of the Cretaceous Eumerella Formation (Edwards, 1996). The formation is composed mainly of fine to medium grained sandstone and siltstone interbedded with thinner and less frequent mudstone. The quartz content is relatively low and the deposits weather rapidly to sands and clays. The siltstones are notably of lower strength, slake prone and more readily erodible in comparison to the sandstone (Gill, 1979).

Edwards (1996) outlines the broad composition and physiography of the Otway Ranges as follows:

- The *"ranges are composed of uplifted and eroded Cretaceous Eumeralla Formation"*
- Miocene compression activity has produced northeast trending anticlinoria
- The southeastern limb of these folds often forms dip slopes in proximity to the coastline
- Numerous folds are offset by faults. Typically streams run sub-parallel to these fault systems.

The two cases studies aim to highlight the structural controls of slopes with aspects orthogonal to bedding. The first case study highlights that structure may control landslide geometry but not the mode of failure. It includes a translational failure in a fill batter built across a gully. The gully is controlled by a buried fault and the identification of the structure assisted with limiting the zone of remediation. The importance of historical publications that identified last interglacial sea levels and how this can affect slope remediation is discussed. The second case study was a thin wedge failure in weathered rocks in proximity to major regional folds and faults, where the structure directly controlled the landslide.

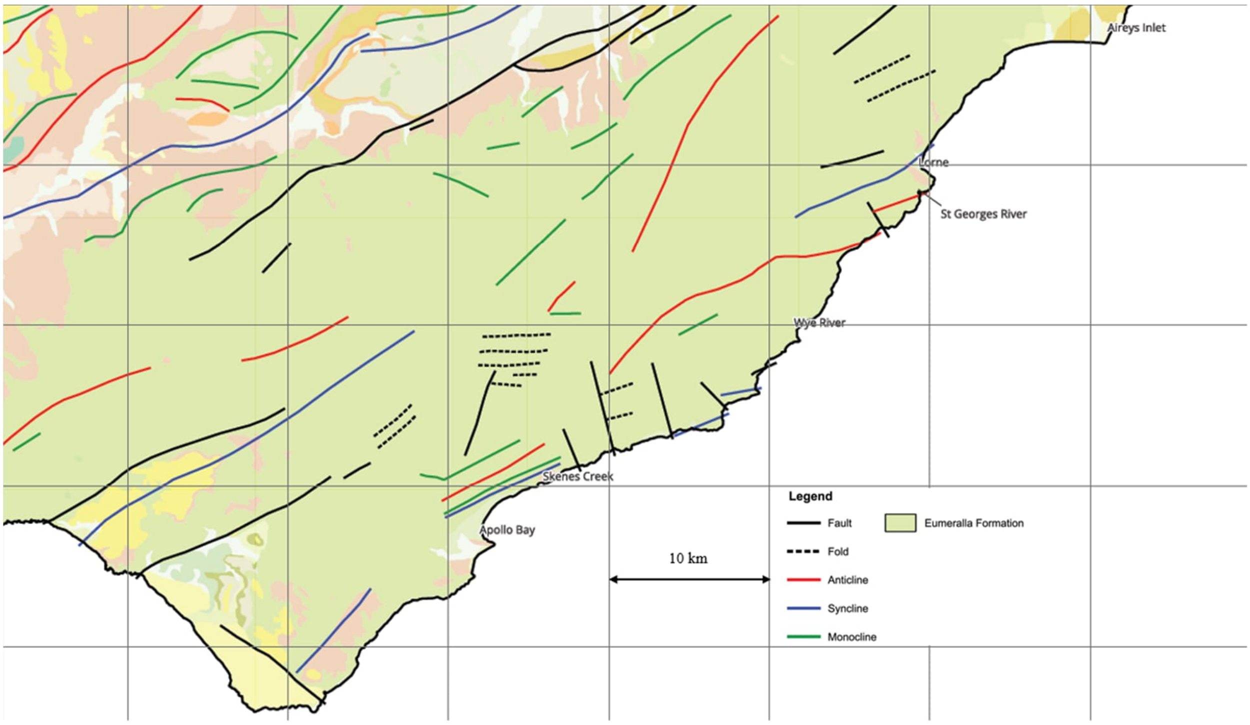


Figure 1: Otway Ranges with published major structure from Edwards (1996) and Medwell (1968). Surface Geology from Welch, et al (2011).

The hazard mapping was completed using the VicRoads Roadside Geotechnical Hazard Risk Management Guideline (VicRoads, 2018).

2 CASE STUDY 1: WYE RIVER

The GOR is a key route between Lorne and Apollo Bay and provides both community and industrial access with a significant portion of heavy rigid vehicles using the road. This section of the GOR is considered particularly important for emergency egress during bushfires and other emergency events.

The fill embankment at CH 62.54 km extends for approximately 50 m over a gully that has formed within a small amphitheatre along the coast. The site was inspected by DTP in June 2021 and pavement cracking and a slump in the fill was documented, Figure 2 (a). At that time, the DTP risk assessment identified hazards associated with vehicles impacting a stepped surface of at least 200 mm in the Apollo Bay-bound lane and single lane to road closure associated with the fill slope failure regressing into the Apollo Bay-bound lane. The assessed risk levels were in the range of "moderate to high". A geotechnical investigation scoped by DTP targeted the landslide in the fill and the relationship between the pavement cracking and the landslide.

Cut slopes on the western side of the road exposed weathered sandstones to the gully location, Figure 2 (b) and Figure 3. To the east of the embankment is a sub-horizontal coastal shore platform and gently inclined sand-covered beach, Figure 2 (b) and Figure 3. At low tides and with sand removed from the beach, an interbedded sequence of siltstone/sandstone extends to the north of the site.

2.1 SITE INVESTIGATION

During the 2021 DTP site walkover significant cracking of the pavement was identified (refer to the red cracking on Figure 2 (a) and Figure 3) as well as relatively narrow landslides at the crest of the fill batter, Figure 2 (b) and the yellow shaded areas on Figure 3. These landslides commenced immediately north of the inferred location of the fault, Figure 3. The back scarps of the landslides were steep (approximately 63°) and the translational slides mapped indicated evidence that movement had occurred in a "two wedge" mechanism, Figure 5.

DTP completed a preliminary site investigation of four boreholes to depths of up to 12.6m below the pavement level. The Author completed a walkover to conduct geomorphological mapping and improve the understanding of local structural trends. Importantly, in 2019, the Author had mapped the area for a Morley Avenue landslide assessment and at a time when there was very little sand on the beach.

During development of the conceptual geological model the abrupt transition in depth to bedrock was evident in the boreholes, Figures 4 and 5. This occurred broadly where the Wye River bound lane turns towards the north off the Point Sturt headland and immediately adjacent to a steep gully to the west of the roadway, Figure 3. The boreholes on either side of the blue fault zone (dip/dip direction of 70 to 80/020 to 030), Figure 3, indicated that the depth to bedrock changes from 2.0 m at BH96 to 6.7 m at BH97 over 12 m horizontally. On review of the LiDAR it was evident that a gully with moderate to steep convergent slopes was immediately adjacent to the fill slope. At this time, the depth to bedrock in areas of observed pavement steps/cracks, Figure 3, was not understood. A secondary targeted investigation was completed in this area and which identified that bedrock was very shallow in the Wye River- bound lane (0.5m below pavement) and up to 2 m deep in the Apollo Bay-bound lane, Figure 4.

(a) (b)

Figure 2: (a) Pavement cracking in proximity to fill failure looking towards Morley Avenue (b) Looking south towards the Wye River headland with undercut fill slope highlighted

2.2 GEOLOGICAL MODELS

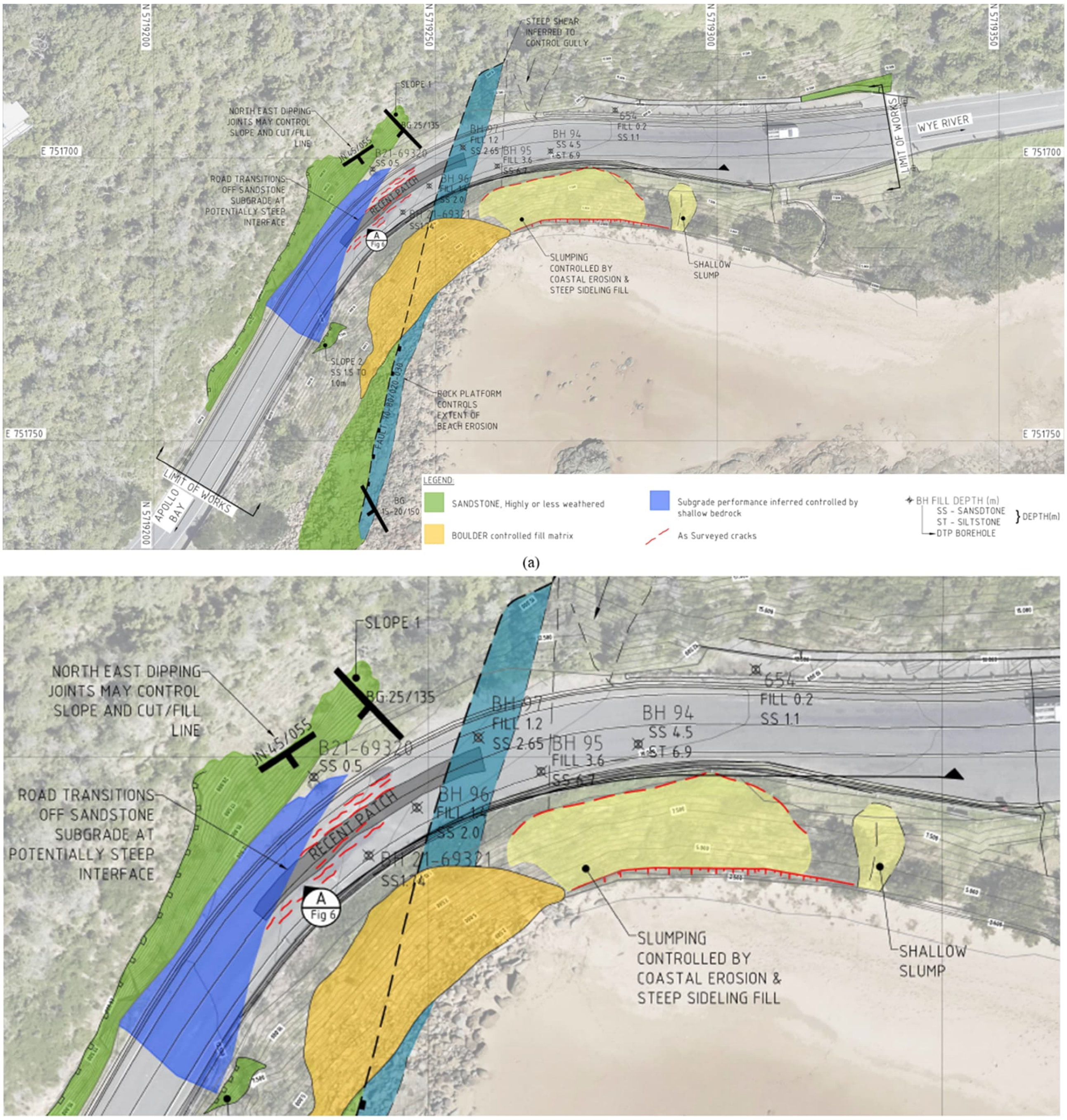
A site-wide engineering geological model combining interpretation of LiDAR survey, field mapping and the results of the intrusive investigation allowed for a thorough assessment of potential mechanisms to be undertaken. The geotechnical units identified in cut slopes and boreholes in the assessment area included:

- Fill associated with the GOR construction. The Fill was observed to be boulder dominant clast supported in zones where cuts had been made in Sandstone and matrix supported and clay dominant soils where a gully was inferred to have been backfilled, Figure 3
- Residual/Colluvial: predominantly a Sandy Clay of low to medium plasticity
- Sandstone: fine to medium, orange, brown and grey, low to medium strength, highly to moderately weathered. Blocky rock mass with conchoidal “onion skin” weathering product about the surface exposures
- Siltstone: Logged as a hard clay of low plasticity (extremely weathered) in boreholes. Where visible on the rock platform the beds had low strength and were moderately weathered.

Two cross sections that summarise the model at conceptual remediation stage are included in Figures 4 and 5.

The thickness of soil cover notably increased immediately adjacent to a steep gully and where there was an abrupt change in both the headland and sideling fill slope aspects, Figure 3. A long section at the inferred location of the buried gully and used in design is presented in Figure 6. Note that the “Design” surface was developed using Maptek GeologyCore and is a triangulation of observation points in boreholes and the shore platform.

DTP selected a pre-emptive treatment of a rock socketed cantilevered bored pile retaining wall and capping beam and with upgrades in surface and sub-surface drainage. The “post construction” surface, Figure 6, represents the profile developed from borehole, pile and shore platform records following the retaining wall remediation. Although the transition was expected in design, pile records indicated the depth to bedrock changed on a much steeper gradient most likely associated with the dip/dip direction of the fault zone.



(a)

(b)

Figure 3: (a) Site plan with pavement cracking in red and translational slides in yellow (b) Detail

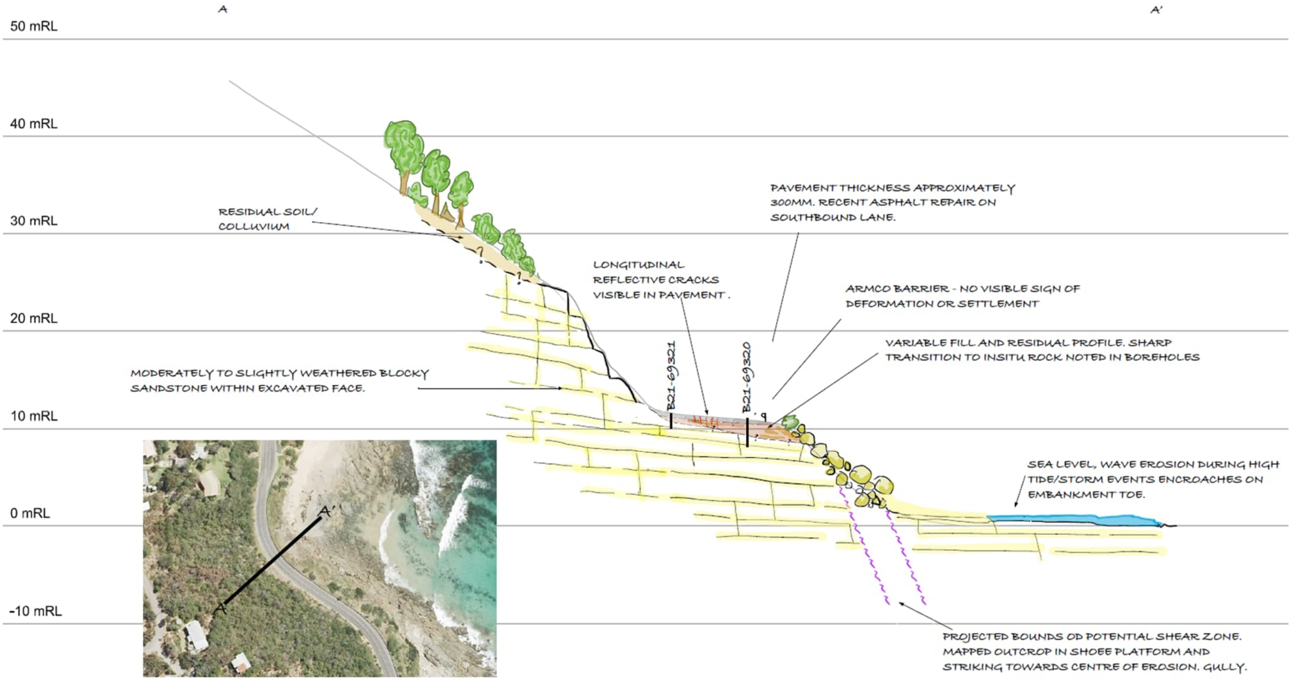


Figure 4 Cross section A-A’

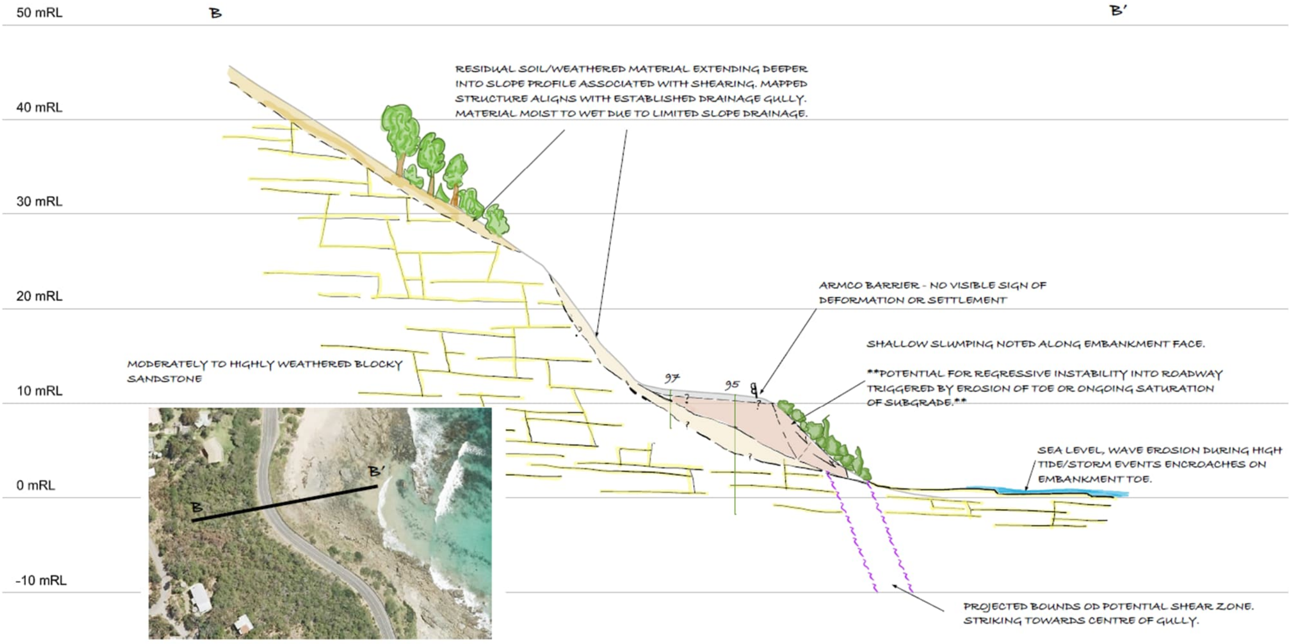


Figure 5: Cross section B-B’

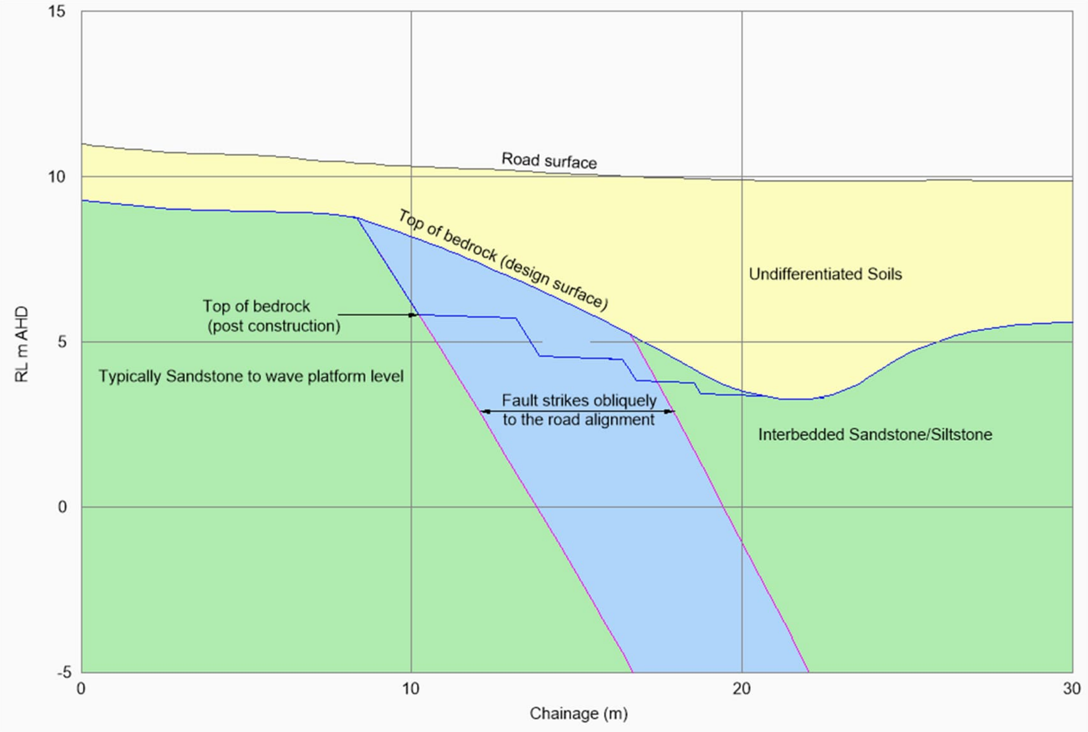
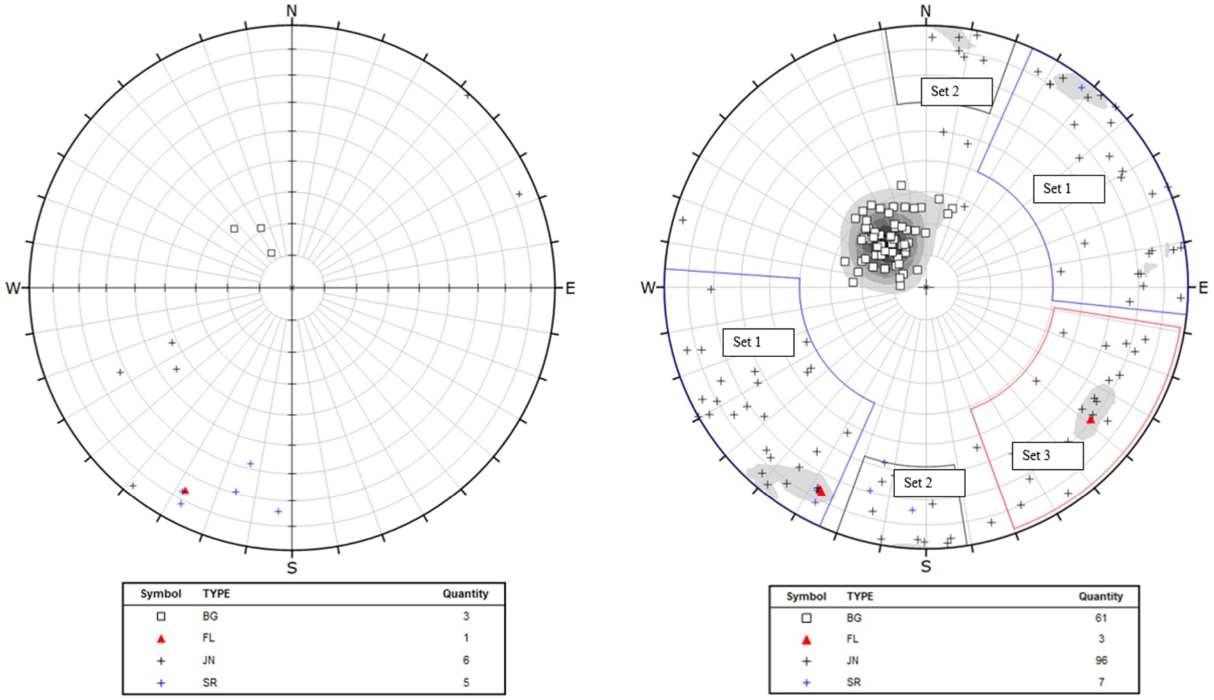


Figure 6: Long Section. Refer to Figure 3 (b) for Section location

2.3 STRUCTURE

Sandstone exposures within the cut face on the southern end of the site, Figure 2 (b) presented as a blocky rock mass which is consistent with mapping completed across the township. Mapping from available exposures and across the coastal exposures of Wye River and Separation Creek, and within similar domains, are presented in Figure 7 and Table 1.



(a) (b)

Figure 7 (a): Stereonet of features at the site mapped in 2021 (b) 2021 data supplemented with data from 2019 mapping at the site and the coastal exposures of Wye River and Separation Creek

2.3.1 Joints

Discontinuities are inferred to have formed during deposition (bedding) and post-depositional folding (joint sets). In folded sedimentary rocks, Fookes (2000) indicates that longitudinal, transverse joints and cross cutting joints are common. Two joint sets were mapped within the sandstone cut face on site and typically three sets are documented in the Wye River coastal exposures, Figure 7 (b) and Table 1.

2.3.2 Shears

Intact major shears and faults are seldom observed along the coast within the Otway Ranges due to wave and gully erosion removing the infill materials within the structure. Subsequently major geomorphological features (embayment, gully etc) form at the location of these structures.

A persistent fault was logged in 2019 as part of a separate investigation, Figures 7 (a) and 8. The author notes that the infill may include partially recemented boulders associated with Quaternary variations in sea level and erosion/deposition (Gill, 1979). The fault zone is inferred to have had a series of tightly spaced joints that were evacuated by erosion. This fault zone is inferred to control the abrupt change in depth to bedrock, Figures 3 to 6 and the location of the gully west of and above the road, Figure 3. Broadly the intersection of the fault with bedding (and bedding parallel shears) is inferred to control the location and axis of the gully.

On reconciling post construction records, the Point Sturt abandoned terrace 250 m southeast of the site was considered. This location was identified as of special geological significance (Rosengren, 1984) and has features including *"*cavitation weathering, abandoned channels and a level surface" approximately 7.5 m higher than current sea levels. On review of post construction records, Figure 6, in the authors view, a similar platform was likely present on the southern side of the gully. This is of significance to remediation of fill slopes along the GOR with slope aspects perpendicular to bedding dip direction as the subvertical nature of the edges of the platforms require special attention in investigation and design to make reasonable efforts to mitigate design variations during construction.

Table 1: Typical discontinuity sets – Wye River coastal exposures

Bedding Set	Joint Set 1 – Transverse	Joint Set 2 – Shear	Joint Set 3 - Longitudinal
Bedding	Joint strike orthogonal to bedding strike	Cross cutting bedding	Joint strike parallel to bedding strike
ORIENTATION (TRUE NORTH) DIP/DIP DIRECTION			
5 to 30/95 to 200 (20/145)	40 to 90/030 to 090 (70/050) 45 to 90/205 to 275 (75/245)	70 to 90/180 to 195 (80/190) 55 to 90/000 to 015 (75/005)	45 to 85/285 to 335 (70/300)
EFFECTIVE LENGTH (m)			
Dip slope and regional folds indicate 100's of metres	Horizontal 10 to 20m observed on rock platform Vertical generally less than 5m (limited by height of cuts and beds)		
EFFECTIVE SPACING (m)			
<0.25 to 0.75	Typically, 0.25 to 1 up to 5 m. Terminate at beds	Typically, 0.25 to 1 m, up to 5 m	
CONDITION			
Planar. Slightly rough to rough. Iron stained with clay veneers and seams common in highly weathered bedrock. Bedding parallel shears are less common (5%)	Highly weathered - typically Planar, slightly rough, iron stained with some clay seams and smooth surfaces. Moderately weathered or better - typically Planar, Rough, iron stained.		

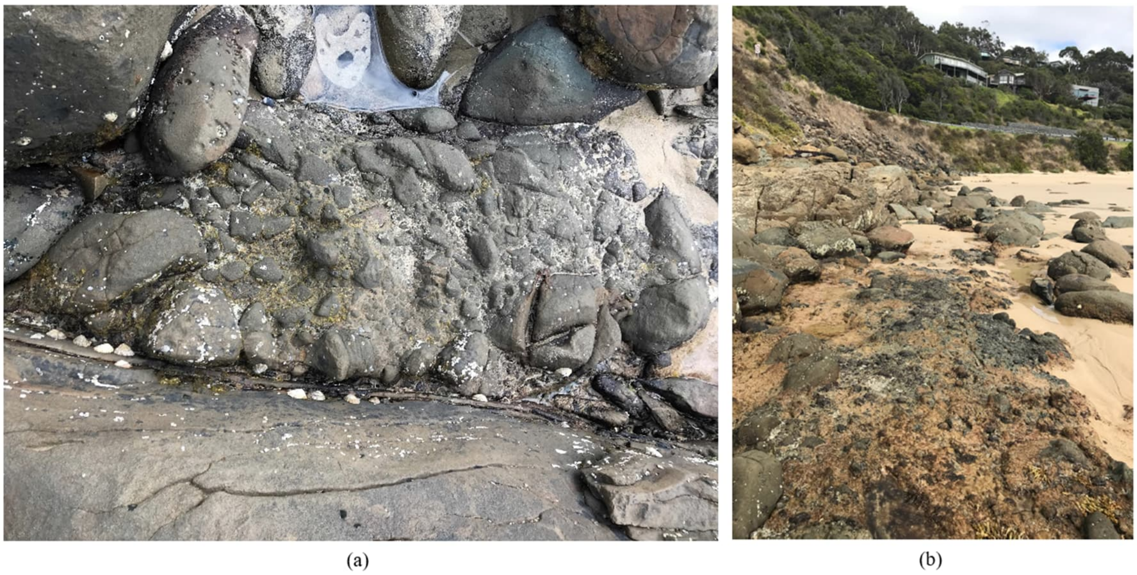

(a) (b)

Figure 8 (a): Fault with re-cemented boulders/cobble infill which strikes sub-parallel to the gully. Location is highlighted in blue in Figure 3. (b) Looking along strike of the fault towards the GOR and Morley Avenue properties

2.4 MECHANISMS OF FAILURE

Two potential mechanisms of failure were identified: pavement settlement and translational sliding of the sideling fill slope.

The pavement settlement was considered likely to be controlled by one, or a combination of the following:

- Progressive collapse settlement of fill at the abrupt change in subgrade (shallow rock versus deep fill)
- Strain incompatibility between the two subgrade types (highly weathered rock versus saturated fill) including likely influence from the identified fault
- Saturated subgrade and insufficient depth of cover to the subgrade given the increase in heavy rigid vehicles post 2015 bushfires and re-building (i.e., pavement design related).

Regarding the translational slide mechanism, the buried contacts between the fill and residual soils and bedrock were gently dipping towards the east. As such, failure by translational sliding was governed by undercutting at the toe of the sideling fill slope and the overall slope of the fill (approximately at repose). Furthermore, due to the superelevation of the corner of the road, surface water was directed to the two landslide areas.

Kinematic failures in the rock mass were assessed to be barely credible. The intersecting planes from moderate dip joints of Set 1 intersecting and sub-vertical joints of Set 2 could cause small wedge failures however less than 1% of defect combinations supported this mechanism. Planar sliding on defects within the rock mass was not kinematically possible.

2.5 ROADSIDE HAZARDS

Two roadside hazards were assessed, and these include pavement settlement (Hazard 1) and translational sliding of the fill embankment (Hazard 2)

Hazard 1 was primarily associated with a vehicle impacting a stepped surface greater than 200 mm in depth. Note that creep along low angle defects dipping out of the slope was identified as a potential mechanism however it is unlikely to be the primary cause of pavement failure. This was supported by the Armco barrier that did not appear to be misaligned which otherwise would indicate the occurrence of mass movement.

Hazard 2 was a translational slide in the fill embankment. Regression of the landslide could result in a headscarp developing in the adjacent lane and vehicles may strike the resulting step in the pavement.

Mitigation of the hazards incorporated a combination of a cantilevered bored pile retaining wall with capping beam, inclusion of sub-surface cut off drains to the west of the roadway and improvements to kerb and channel with discharge of surface and sub-surface water further north where natural dune slopes were present along with a wide shoulder.

Although the hazards are not directly linked to structure in the rock mass, the bounds of the hazards were certainly controlled by structure. Post construction records indicated remnants of a buried shore platform from the last interglacial stage may have been present on the southern extent of the site where the buried geometry of bedrock was very steep to sub-vertical, Figure 6. The author later encountered a very similar issue at St Georges River, Lorne, Figure 1, and notes that geometry of the buried platform must be considered in scoping both geotechnical investigation and design.

3 CASE STUDY 2 – SKENES CREEK

At CH 1.2 km along Skenes Creek Road a thin wedge failure in sandstone bedrock occurred following heavy rainfall on 18 August 2018. The runout initially extended across both lanes and with most of the failure volume (volume in the order of 50 m^3) in the lane immediately adjacent to the slope, Figure 9. The landslide was cleaned up, but parasitic rock falls continued and between 10 to 11 August 2019 rockfall was documented by DTP to have reached the kerb of the opposing lane. Debris impact cracked the kerb. The site required a landslide risk assessment to DTP guidelines followed by conceptual to detailed design advice.

During the Author's initial visit in 2020, most of the cutting had thick vegetation, Figure 10. The slope at the 2018 wedge failure was comprised of weathered, blocky Sandstone. Two intersecting joint surfaces with relatively minor variation on southwest dip created a thin wedge, Figure 10. A limited zone was mapped between approximate project chainage Ch. 60 and Ch.150; however, it was clear that the joints controlling the failure were prevalent in all exposures. Evidence of several similar failures was observed in the cuttings, Figure 11. Due to the size of potential landslides and the limited space between the cutting and road, engineering controls would almost certainly be required to reduce the risks to target DTP levels, however vegetation clearance was required to map the exposures in detail. The extent of 2021 vegetation clearance was in the order of 180 m and the extent of works is highlighted in Figure 12.

Immediately prior to mobilisation for remediation of the cuttings, a further small landslide occurred, Figure 13. At this location up to 2m of colluvium was overlying a laminated sequence of slake affected siltstone and sandstone of very low strength and with significant shears parallel to dominant joint sets and bedding in this area. The lower portion of the failure was controlled by a wedge formed from the intersection of south dipping shears (55/180) with a shear zone dipping orthogonal to bedding (65/330), Figure 13. In a zone approximately 120 m long, no less than six similar landslides were inferred to have occurred between the widening of the road in the 1960s and 2022. For a frequency of landslide events of approximately 1 every 10 years, the assessed risk level exceeded typical target DTP levels of "low to moderate" risk or "no further action" required.

(a) (b)

Figure 9: Excerpt from DTP failure records from 18 August 2018 (a) Looking north (b) Looking east

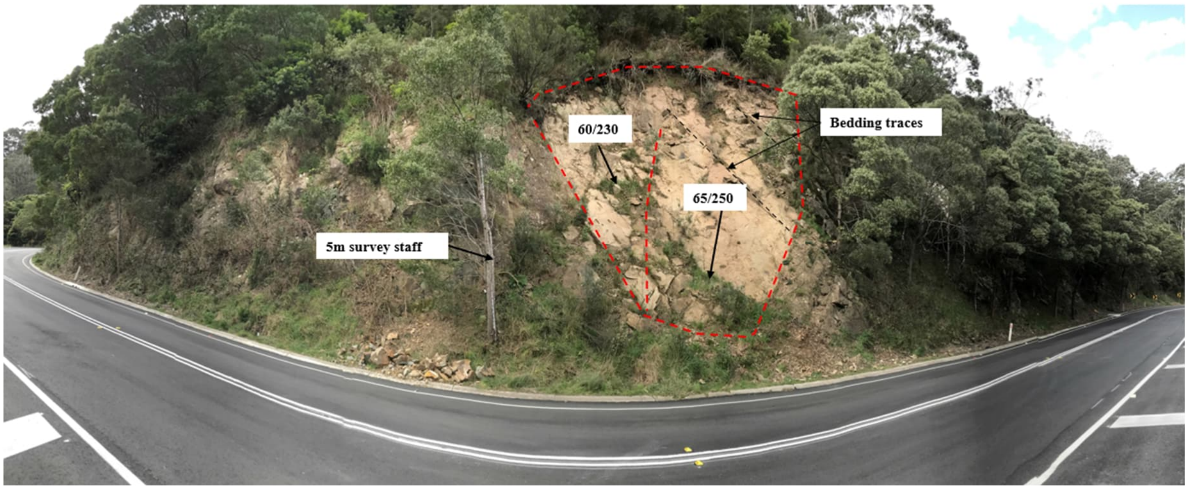


Figure 10: Wedge details in September 2020 looking east

(a) (b)

Figure 11: Planar slide at Ch. 115 of Figure 12. (a) Test bolting location and extent of failure (b) Sandy CLAY seam identified as the infill on the sliding plane

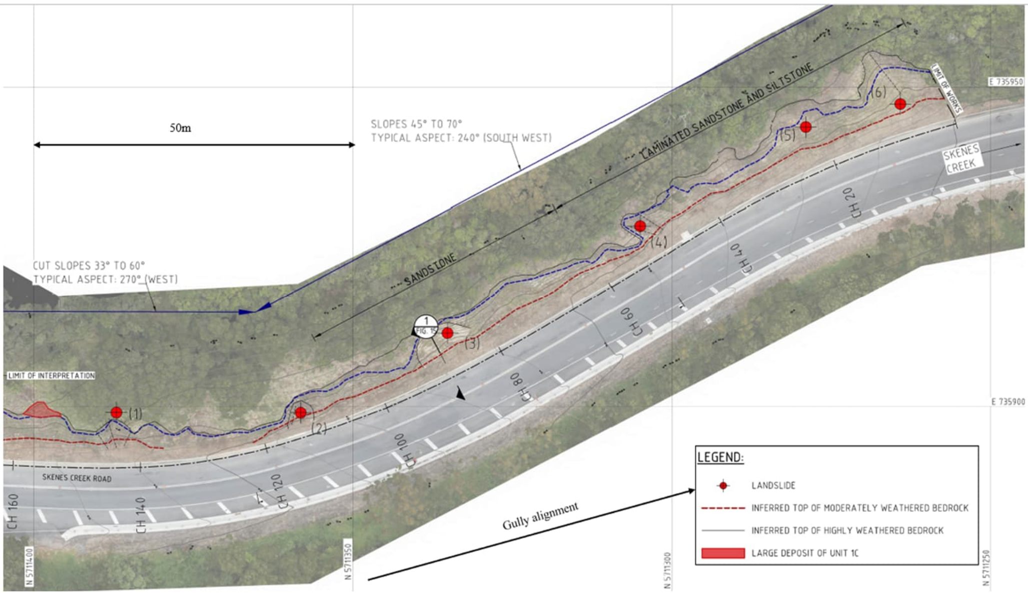


Figure 12: Extent of Skenes Creek site with project chainages highlighted

Figure 13: Extent of landslide at location (5) of Figure 12 (a) left hand side in November 2021 (b) right hand side in June 2022

3.1 GEOLOGICAL SETTING

Cooney (1982) presents a readily available landslide inventory for the Skenes Creek and project area. The geology of Skenes Creek Road is well documented due to its proximity to major geological structures. For example, Cooney (1982) reported bedding typically dipping at 70 to 80° to the southeast with variation in dips inferred to occur due to proximity to the Skenes Creek Monocline, Figure 14. Furthermore, surface geology, local and regional structures in the vicinity of Skenes Creek were published by Medwell (1968), Cooney (1982), Duddy (1983), Geological Survey of Victoria (GSV), (1995) and Edwards (1996).

Various cross-sectional interpretations are available for the Skenes Creek folds (Medwell (1968) and GSV (1995) with differences in interpretation where a major regional fault is located. The varying interpretations along this section of coastline are not the purpose of this paper. The site is entirely within a region of sub-vertical to overturned beds with evidence of shearing that is universally referred to as the “Skenes Creek Monocline” by all the authors listed above. The author notes that the folding at the site could be readily interpreted as the southeast dipping limb of an asymmetrical anticline and the over-turned beds dipping at 85° towards the northwest may be aligned with major faults as suggested by GSV (1995). It is the Author’s opinion that the fold sequence from coast to hinterland aligns with Medwell (1968), Figure 14, and the reasons why Edwards (1996) has a different sequence is not clear. The published information highlights that complex structural conditions are to be expected at the site due to the close spacing of fold hinges, and steep bedding dips.

3.2 SITE INVESTIGATION

The extent of the site post vegetation clearing is highlighted in Figure 12. The site investigation was completed entirely with field mapping techniques that included:

- Detailed line mapping
- Mapping of defect dip/dip direction and persistence/spacing using a Diospatial photogrammetry model.

Typical excerpts from the photogrammetry-based mapping are highlighted in Figure 15. The mapping data from the site and photogrammetry mapping tasks was compared to Cooney (1982) to check for consistency with all data from line mapping and photogrammetry, Figure 16.

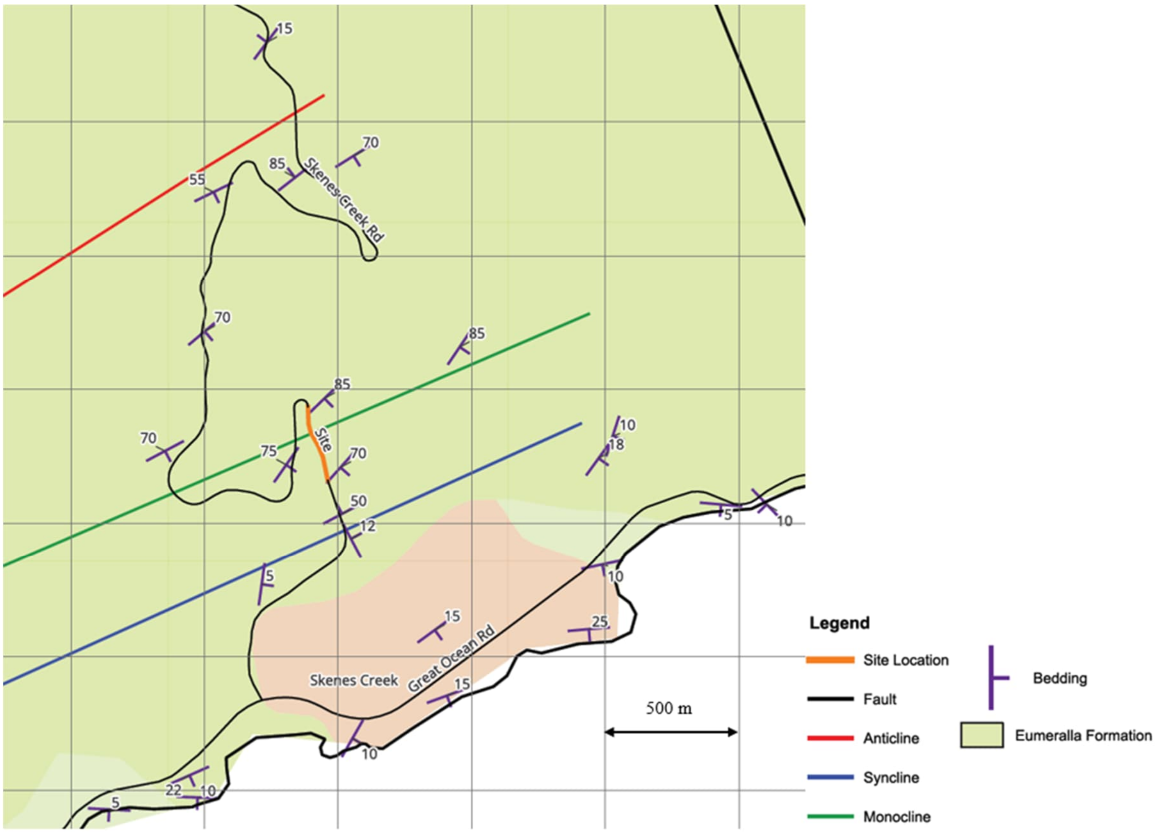
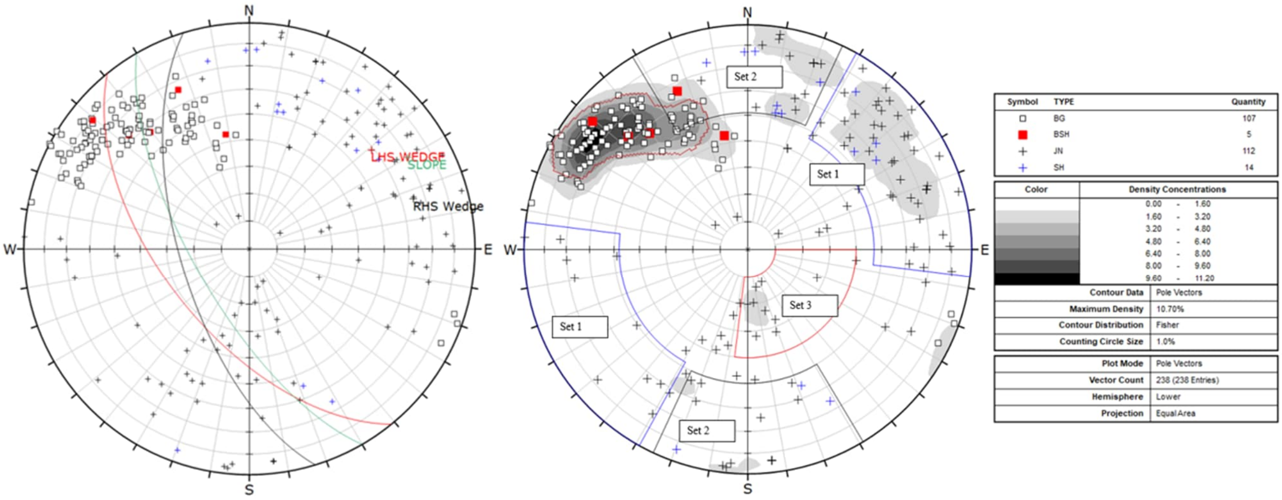


Figure 14: Regional geology with approximate published fold/fault locations based on Edwards et al, (1996), Cooney (1982), Medwell (1968) with minor variation on fold type from the Author

(a) (b)

Figure 15: Photogrammetry picks at the Ch. 85 wedge failure (a) bedding planes (b) joint planes



(a) (b)

Figure 16 (a): Skenes Creek – all defects with 2018 wedge details (b): Skenes Creek – all joints and joint sets (note bedding and joints assessed independently)

3.3 GEOLOGICAL MODEL

The geological units identified in cut slopes in the assessment area included:

- Colluvium (UNIT 1C of Figure 17): A mixture of Sandy Clayey Silt/Sandy to Silty Clay with cobbles/boulders of Highly weathered Sandstone/Siltstone
- Residual (Unit 1R of Figure 17): Typically, a Clayey Sand
- Sandstone, fine to medium, very low to medium strength, highly to moderately weathered. Blocky rock mass with very steep bedding from 60 to 80° to the south east
- Laminated Siltstone/Sandstone, fine grained, Siltstone beds very low to low strength. Sandstone beds very low to medium strength. Highly to moderately weathered. Highly fractured rock mass with defect spacings of 50 to 100 mm common and rock mass impacted by slake.

The photogrammetry model allowed for inferred weathering changes to be mapped in detail, Figure 12.

3.4 STRUCTURAL MODEL

Table 1 presents a summary of the discontinuity sets. With regards to the bedding characteristics, it was noted that:

- Persistence of partings extended across the full height of the cut (up to 15 m in height)
- The spacing of bedding partings in Siltstone was typically less than 50 mm however the partings are difficult to differentiate due to slaking of the rock mass.

3.4.1 Joints

The evolution of the joint development is as per the Wye River case study albeit, significantly more evidence of shearing is observed at Skenes Creek. With regards to the mapped joints the three assigned joint sets are in good agreement with anticipated structure and gentle to moderate dip joints of Joint Set 3 are inferred to be underrepresented in the data set. For example, when comparing Figure 18 (a) and Figure 18 (b) these joints dip orthogonal to bedding and will vary in dip with bedding variations. i.e., a set that dips at 10 to 40° to the north west was anticipated.

3.4.2 Shears

Several shears and shear zones were mapped. Examples included bedding parallel shears Figure 18 (a), where bedding trends are highly variable within the shear zone, shears sub parallel to Joint Set 2, Figure 19 (a) and the closely spaced joints of Joint Set 1, Figure 19 (b).

Given the linear nature of the adjacent gully, Figure 12, it was inferred that the southwest dipping joints (Joint Set 1) may have relatively long persistence in the order of 10's to 100's metres which has contributed to the gully formation.

Similarly, due to the inferred presence of a significant fault, Section 3.1, it was considered likely that Joint Set 3 would have similar persistence.

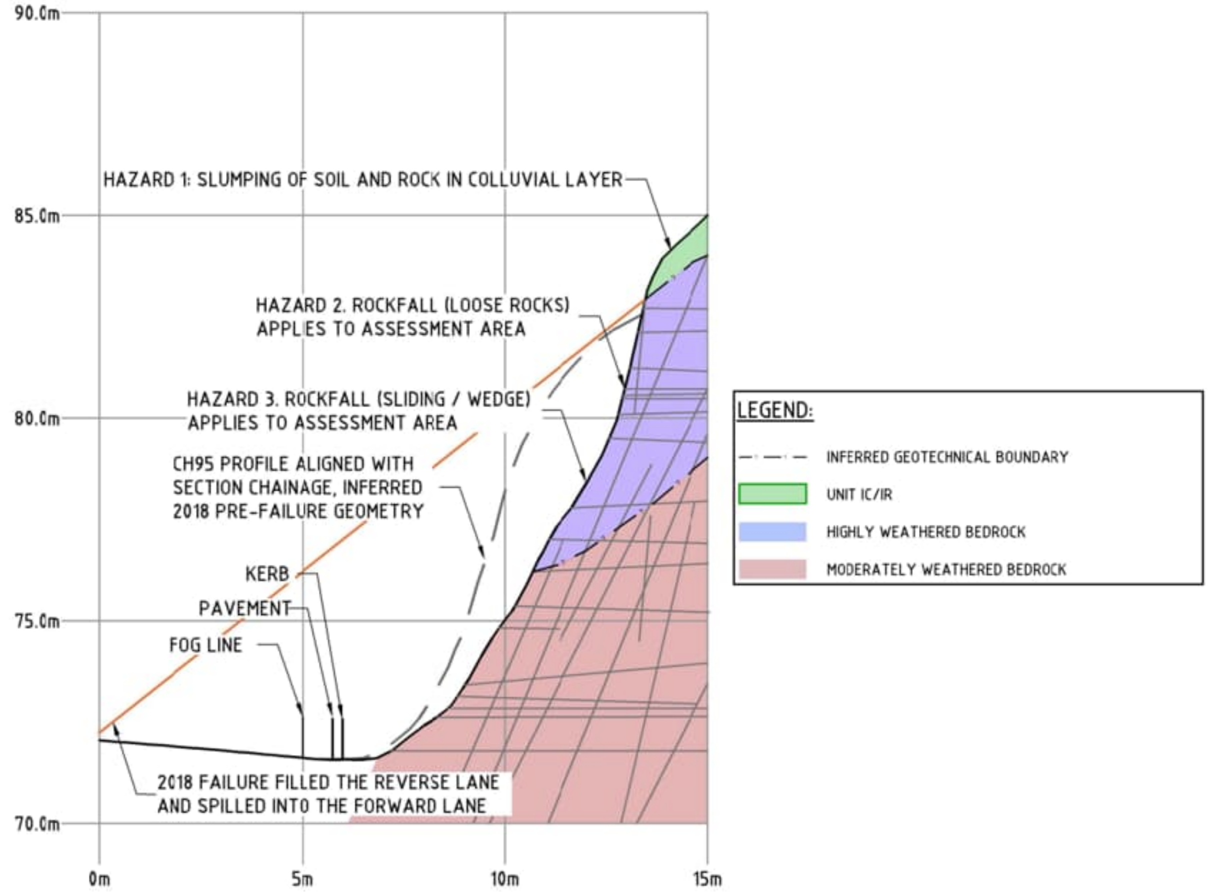


Figure 17: Section 1 with geological model and hazards

3.6 ROADSIDE HAZARDS

Three roadside hazards identified were broadly applicable to the entire cutting and involved a vehicle impacting debris at speed rather than the vehicle itself being struck by debris.

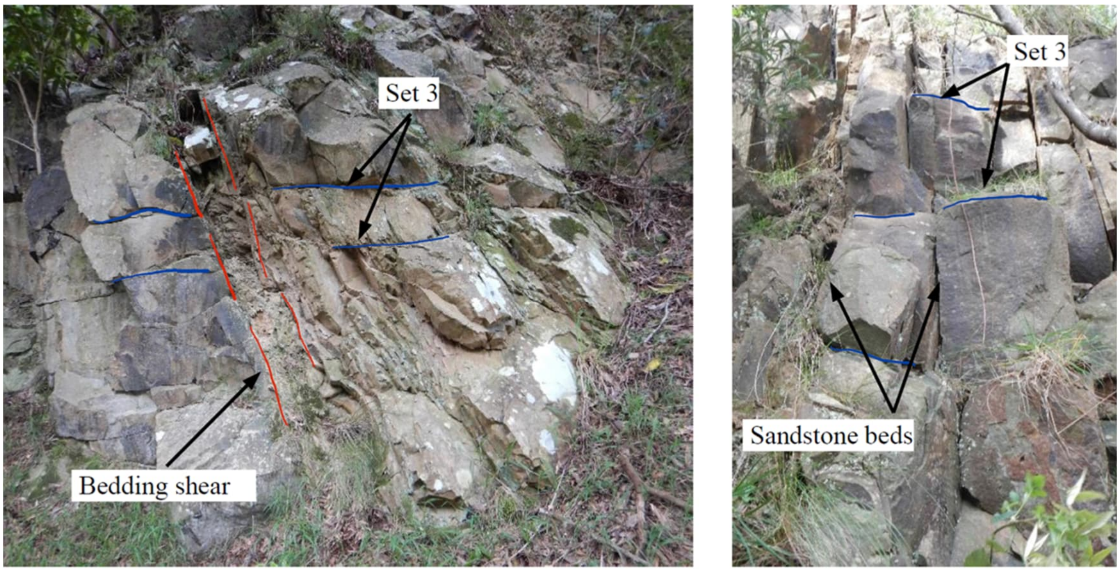
The typical block sizes from Table 2 are used to inform the likely size of blocks that may be impacted by a vehicle. A summary of the three hazards is presented in Figure 17 and includes vehicle impacting debris from the colluvial layer (Hazard 1), vehicle impacting debris from rockfall (Hazard 2) and a vehicle impacting debris from a much larger mass associated with planar/wedge failure in the rock mass (Hazard 3).

To mitigate the hazards, two domains were established with the boundary at the contact between the blocky Sandstone and in the interbedded Sandstone and Siltstone at Ch. 60, Figure 12. Both mesh drapery and spot bolting techniques were considered inappropriate due to the highly fractured nature of the rock mass and the observed failure volumes likely to damage drapery systems and require high maintenance.

Proprietary pattern bolt and mesh systems were the preferred DTP design solution and with the design considering the planar/wedge mechanisms as well as the capacity of the mesh to restrain colluvium, smaller blocks in the sandstone and slaking rock mass in the interbedded sequences. Testing of short bond lengths well in advance of construction validated the adopted bond strengths that were established based on field mapping estimates, Figure 11a.

Table 2: Typical discontinuity sets – Skenes Creek Road cutting

Bedding Set	Joint Set 1 – Transverse	Joint Set 2 – Shear	Joint Set 3 - Longitudinal
Bedding	Joint strike Orthogonal to bedding strike	Cross cutting bedding	Joint strike parallel to bedding strike
ORIENTATION (TRUE NORTH) DIP/DIP DIRECTION			
45 to 90/115 to 160 (70/140)	45 to 90/210 to 275 (65/240) 50 to 90/030 to 095 (65/060)	50 to 90/165 to 200 (60/180) 55 to 90/330 to 020 (70/000)	15 to 40/275 to 005 (25/330)
EFFECTIVE LENGTH (m)			
Regional folds indicate 100's of metres	3.0 to 10 to 15	3.0 to 10 to 15	0.5 to 10 to 15
	Observations limited by the height of the cut slope		
EFFECTIVE SPACING (m)			
0.3 to 3.3	<0.25 to 1	< 0.25 to 2	<0.25 to 3
Upper quartile of 1.2	Upper quartile of 0.75	Upper quartile of 0.75	Upper quartile of 1.5
CONDITION			
Typically planar, slightly rough to rough, iron-stained, parallel bedding shears with clay infill	Typically planar, slightly rough to rough, iron stained with some seams (clay and rock fragment infill) and smooth surfaces.		



(a) (b)

Figure 18: (a) Bedding shears and low angles joints at Ch. 60 (Set 3) (b) Sub-vertical sandstone beds at Ch. 147

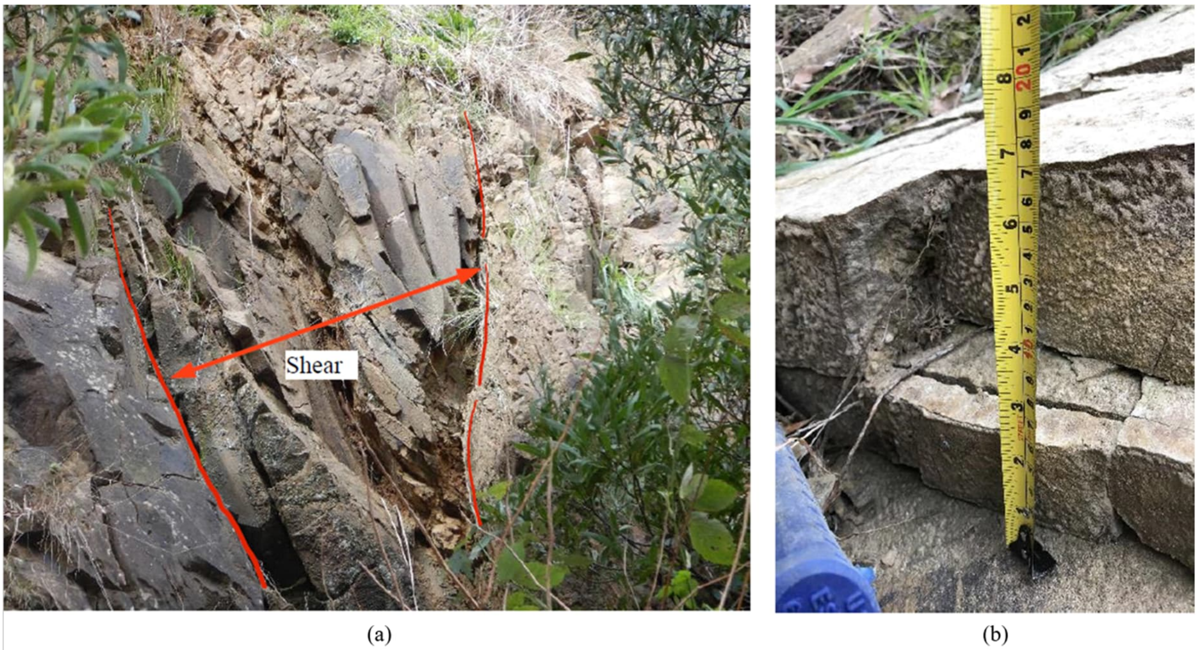


Figure 19: (a) Shears of Joint Set 2 at Ch. 149 (b) Lower bound joint spacing of Joint Set 1 at Ch. 85

4 SUMMARY

The two case studies presented illustrate the diversity of hazards in this terrain and the utility of combining local-scale field observation and range-scale geologic mapping to understand those hazards. Compiling engineering geological models in the Otway Ranges is well supported by a large database of valuable structural insights. A considerable proportion of the data is provided by the GSV and archived state publications.

The engineering geological model at Wye River assisted in avoiding overly conservative remediation. The structural model supported that the pavement was not likely subject to movement due to landslide but traditional pavement subgrade failure and that translational slide may occur north of the fault. Importantly, the fault controlled the geometry of both hazards. A learning post construction of the remedial solution was that a more concentrated effort in investigations to identify the edge of buried shore platforms beneath the side cast fills of the GOR may be warranted at similar sites.

The site at Skenes Creek presented unique challenges owing to the complexity of the regional structure. This site provides valuable insights into the hazards to road users on slope aspects cut perpendicular to the dip direction of bedding. These sorts of exposures are less common on the road network owing to the nature of the location of the GOR and the inland routes to the coastal towns.

Although mapped structure is relatively consistent across the shore platforms of Wye River and Separation Creek, the reader should exercise caution when referencing mapped structure at Skenes Creek. Owing to the likely presence of regional faults in that area, significant changes in structure are to be anticipated. That is structure within the established township of Skenes Creek itself may be significantly different.

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CRediT authorship contribution statement

Dane Pope: Investigation, Formal analysis, Methodology, Writing - original draft.

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