WHY AESTHETICS NEEDS EARLY CONSIDERATION IN TUNNEL DESIGN AND EXCAVATION – A CASE STUDY FROM THE M8

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ABSTRACT

Road tunnels are more complex than the driving eye would surmise – hidden behind the dark ceilings and colourful wall panels are rock, support bolts, multiple layers of shotcrete, possible water drainage, access passages, fire control systems, electrical systems, and speed cameras. During the design phase of a tunnel project all these components are given significant consideration as they govern the ultimate size of the excavation that is needed. At construction, focus shifts from what will be added to what and how can rock be extracted quickly and safely. The crown and face condition come to the forefront as inputs into the ground support requirements and as short-term prediction of excavation conditions in the following days. Classification of the rock mass is skewed to encapsulate the face, shoulder and crown condition as well as the bolt zone above the crown. Side wall and floor conditions are noted where possible, but visibility is often limited to the current cutting (about 1.5m, with previous cuts already shotcreted) or not possible due to mud and rock waste. Once excavation has progressed, focus shifts to the functionality, endurance and aesthetics the general public will see – the smooth road surface, the painted ceiling with clear road signs, and the architectural panelling on the walls. For the latter two, consideration is required as to how these heavy items will be anchored to the roof and walls. For the M8, the broader face/shoulder/crown rock mass classification was found to be inappropriate to the narrow anchor zone for the architectural panels, which required anchoring specifically at a height 3m above the floor excavation level. This was particularly the case where narrow siltstone beds occurred with the sandstone rock mass and where dykes and shears intersected the tunnels. Fortuitously, compilation mapping including the side walls had been completed for another purpose for the project and was able to be repurposed to assist with panel construction design. Different bolt lengths were required for each rock class in sandstone, shale and dolerite (dykes) with the conditions specific to the zone 3m above the floor level reassessed by experience senior geological staff as the input for the design. A package of works was provided for each wall, indicating the rock class at the anchor zone, both as a map and tabulated. This improved construction sequencing, costing and allowed pre-purchasing of all materials before work commencement. Significant costs would have occurred had the daily mapping not captured the side wall conditions and had compilations been required solely for this purpose.

1 INTRODUCTION

The M8 is a newly opened twin road tunnel spanning some 9 km connecting the M5 at Kingsgrove to the on-off ramps at St Peters Interchange in Sydney's south and forms a crucial segment in Sydney's WestConnex Project. The mainline tunnels will ultimately connect the M5 to the M4-M5 link under construction beneath St. Peters and to the north-west, while at the surface the on/off ramps lead into the Interchange and will eventually link to the Sydney Gateway, Figure 1. The project was completed in three stages:

1. Design phase – completed by a joint venture team with scope including borehole investigation program, geotechnical model development, assessment of ground types, and design of support requirements suitable to each ground type.
2. Construction phase – this included all ground excavation mapping and installation of tunnel support.
3. Aesthetics phase – this included road surfacing, installation of lighting, safety systems, signage and architectural panelling on the tunnel side walls.

One aspect of the build was pertinent to all three phases – the geotechnical properties of the rock in which the tunnel was constructed.

This paper addresses the geological/geotechnical framework systems implemented for the project and how they focussed on tunnel support criteria. It presents the limitations of the framework in addressing the aesthetic works component and how this was overcome. It provides suggestions for future projects to include consideration of all end-users of mapping data collection to better plan how data is collected. This would improve efficiencies and could result in significant cost savings.

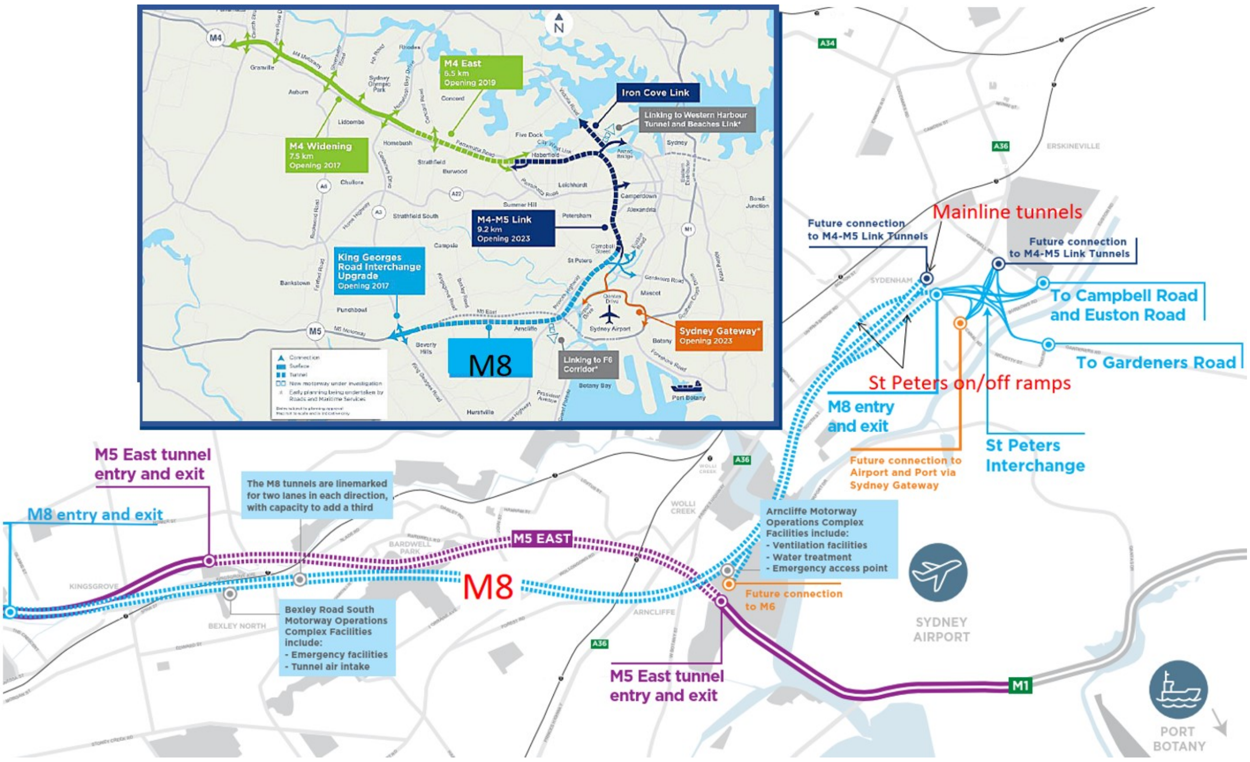


Figure 1: Map of the M8 within the WestConnex project (modified from https://www.westconnex.com.au/)

2 PROJECT GEOLOGY

The M8 mainline tunnels were predominately excavated in Hawkesbury Sandstone with the connection to the M5 in the overlying Mittagong Formation and Ashfield Shale. The on/off ramps at St Peters progressed through Hawkesbury, Mittagong and all four sub-units of the Ashfield Shale before breaking through to the surface. In addition, the tunnels intersected several dolerite dykes and steeply angled fault zones.

Within the tunnels, the Hawkesbury Sandstone sequence varied:

- Fine to medium grained cross-bedded quartzose sandstone with major bed partings typically spaced 1 to 3 m.
- Massive, medium to coarse grained quartzose sandstone that formed channels cut into the cross-bedded sequences.
- Shale breccia layers and lenses of siltstone were common along the bed boundaries. The thickness of the lenses ranged from a few centimetres to over 2 m.

The Mittagong Formation was a mix of interbedded to interlaminated sandstone and siltstone.

All four sub-units of the Ashfield Shale were present beneath St Peters, displaced by regional faulting. They comprised (in age oldest to youngest):

- Rouse Hill Siltstone – finely laminated dark grey to black siltstone with <5% sandstone lamellae;
- Kellyville Laminite – distinctly interlaminated siltstone and sandstone in approximately equal proportions;
- Regentville Siltstone – interlaminated siltstone with up to 25% sandstone;
- Mulgoa Laminite – interlaminated to finely interbedded siltstone and sandstone.

Due to the depth of tunnelling weathering was mostly restricted to the M5 connection and in the Mulgoa Laminite at the St Peters on/off ramps.

3 TUNNEL CONSIDERATONS

The tunnel design phase is complicated and many facets control the ultimate excavation footprint – not just whether the road has as two or three lane capacity. Amongst others, designers need to consider height allowances for trucks, inclusion of breakdown bays, emergency egress passages, space for electrical and fire suppression systems in the crown, space for speed cameras, height allowance for road signage and drainage requirements. Secondary to this comes achieving a design that will allow for such a footprint and will support the encountered geology. To facilitate support installation and improve cost effectiveness, the geology is classified into groups of similar rock-mass conditions and support requirements to suit each class are developed. This allows geological/geotechnical modellers to predict quantities of each ground type, thereby assisting budgeting and in some instances purchasing of specific bolt sizes/lengths, shotcrete and other support infrastructure, including plant machinery.

At construction, the focus shifts to what is being excavated and how quickly and safely it can be completed. Site geologists/geotechnical engineers are used to map the excavation as it proceeds and advise the current ground conditions. The information feeds into support type selection and continued excavation is permitted. From a practical standpoint, the classification of ground conditions is scaled to define a single ground type for the excavation except in rare circumstances, like where the face crosses a lithological contact. It is also skewed towards assessing the crown and shoulders, more so than the lower face and walls, as the crown conditions dictate the support requirements at that location. The face conditions may provide a preview to assist in predicting any future changes to conditions.

At the time of mapping, only a couple of metres of unsupported rock are exposed. Side walls are mapped in the newly exposed faces, but observations may be limited due to dust and plant obscuring the view. The previous cuts are covered in shotcrete which may include complete coverage of the side walls, depending on the lithology intersected and durability limitations of that lithology. As such, the ability to back-capture all the side wall information is limited.

At the completion of excavation, focus turns to the functionality, endurance and aesthetics of the tunnel. It was at this stage of the project that it was recognised that the classification of ground conditions was of limited suitability for anchor design for the architectural panels.

4 TUNNEL SUPPORT ROCK MASS CLASSING

At design phase, the Hawkesbury sequences and Mittagong-Ashfield lithologies were segregated into rock mass classes based on the site investigation data collection (Golder, 2017). The classing system was similar in principal to the Sydney Rock Mass Classification Scheme of Pells et al (1998) though the boundary conditions were modified to suit the project specifics and tunnelling criteria. Five classes were established for the Hawkesbury and five for the Mittagong/Ashfield and incorporated:

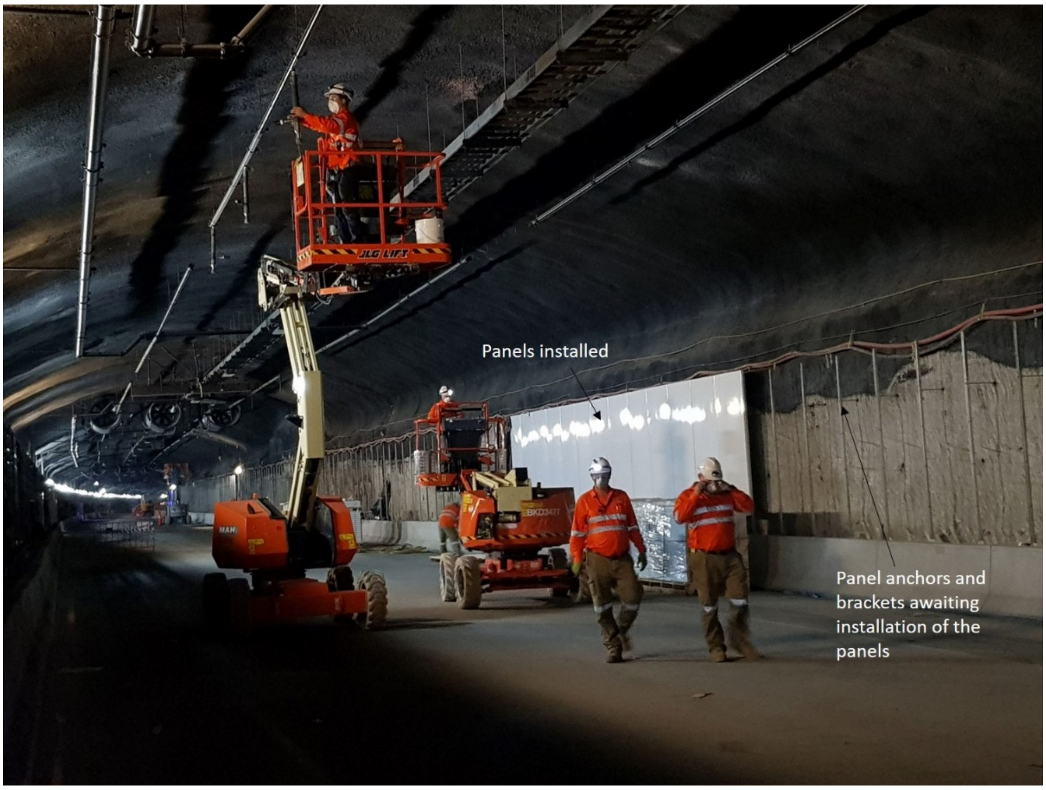
- UCS strength
- Spacing of discontinuities (overall and specifically related to bedding and joints) and
- Percentage of seams within the zone.

It was a wholistic approach that worked well in construction practise. The boundary conditions recognised and incorporated tunnel scale such that an entire face and crown would typically satisfy all criteria for one particular class. An excavation cut that may warrant two or more classes being assigned would be where dykes or other contacts were intersected. The mapped classifications then became a key component in the selection of the ground type and subsequent tunnel support to be installed and approval process for the permit to tunnel.

Of critical interest to the subsequent aesthetics phase the Hawkesbury classes were inclusive of any siltstone lenses or shale breccia present within the stratigraphic unit. The presence of the siltstone resulted in a downgrading of the sandstone class. However, the overall strength and discontinuity spacing conditions in the Hawkesbury class were still better than the equivalent category for the Ashfield Shale. The scale of the classing system was therefore not suitable for installation of architectural panels. Dykes were also incorporated into the class of the surrounding rock rather than be classified uniquely.

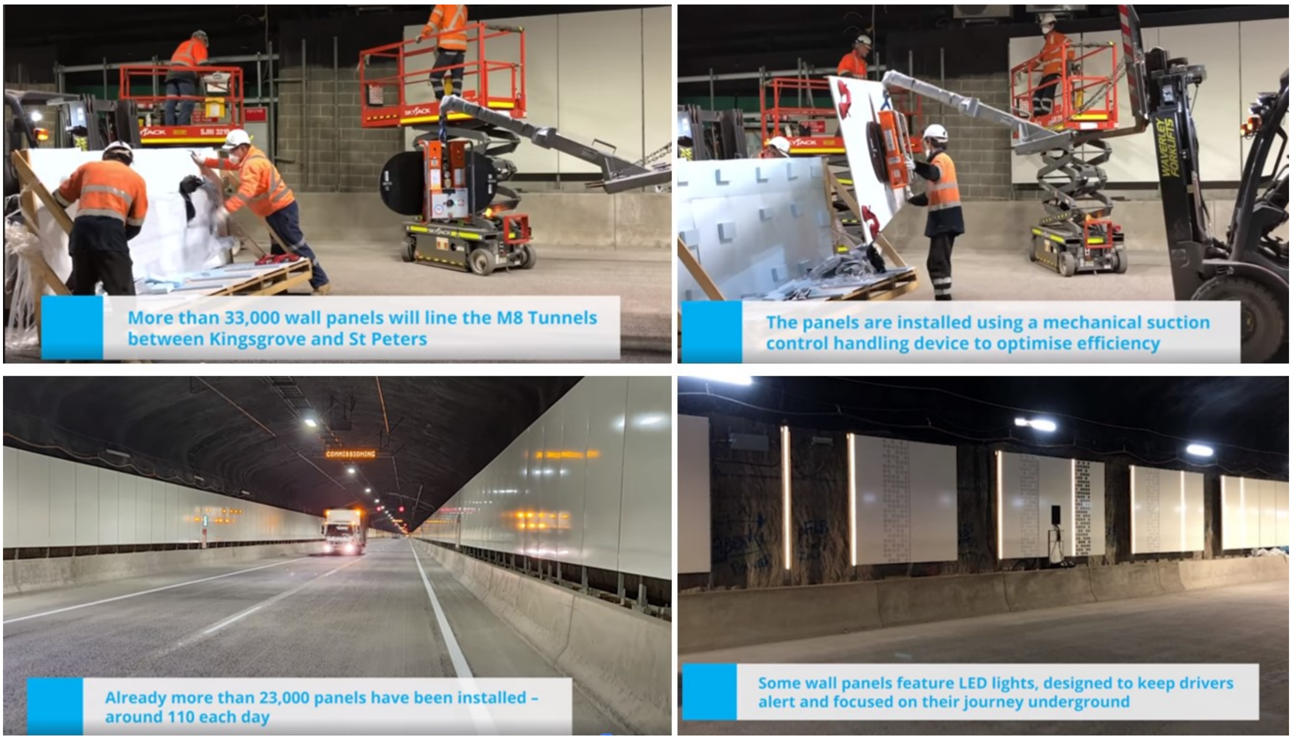
5 ARCHITECTURAL PANEL SPECIFICATIONS

Following paving of the roadway and installation of the electrical and drainage systems, architectural vitreous enamel wall panels were installed along the tunnel side walls to hide the infrastructure from view, Figure 2. In the case of M8 the panels also provide location information and assist drivers in maintaining focus for the seven-minute drive, Figure 3. The typical panel support system used on the project consisted of a bracket system with threaded rods, “C-channels” with shoulder bolts, connection bolts and chemical-grouted anchors. Stainless steel (grade 316) were used for the embedment into the tunnel walls with the chemical grout. The panels were attached through pre-fabricated keyhole slots and comprised a vitreous enamel front face and a backing board of calcium silicate in order to achieve flatness and for antidrumming purposes (Ceratec, 2019), Figure 4 (Ceratec, 2018). The vitreous enamel panels had a specified reflectance value of 60% in order for the tunnel lighting design to achieve a minimum sustainable outcome.


Panels installed

Panel anchors and brackets awaiting installation of the panels

Figure 2: Architectural panel installation in progress (courtesy of @WestConnex Facebook page)


More than 33,000 wall panels will line the M8 Tunnels between Kingsgrove and St Peters

The panels are installed using a mechanical suction control handling device to optimise efficiency

Already more than 23,000 panels have been installed – around 110 each day

Some wall panels feature LED lights, designed to keep drivers alert and focused on their journey underground

Figure 3: Installation of architectural panels in the M8 (courtesy @WestConnex Facebook page)

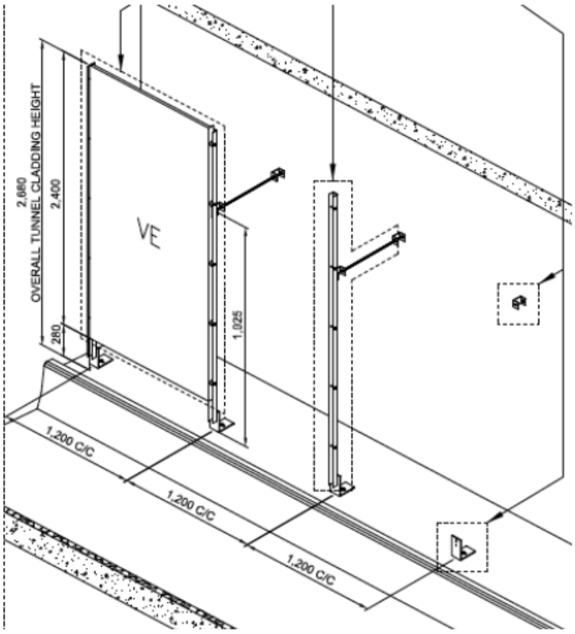


Figure 4: Typical Ceratec Hook-on Vitreous Enamel (VE) panel system

The panels were 2.4 m high by 1.2 m wide and weighed 78 kg each. Brackets were anchored to the side walls at a standard height 3 m above the tunnel invert. The length of the anchors was directly related to the rock class attributes assigned at that particular height above invert and designed to account for both dead weight and the live load attributed to wind or vehicular gusts. Once bracketing was in place, the panels were lifted into place with a mechanical suction control handling system to maximise efficiency of installation as over 33 000 panels were required for the M8 project. The total length of tunnels covered by panels is in excess of 40 km (each wall of each tunnel).

Installation required the drilling of anchors into the sidewalls. The anchor bond lengths varied depending on the lithology and quality of the material present in the side walls. Due to the narrow zone where anchoring would be undertaken, each anchor needed to be specific to the material encountered at that location to ensure longevity of the panel adhesion. This was particularly critical where the lithology encountered at the level 3 m above invert differed to the overall lithology of the wall – like where siltstone beds were present in Hawkesbury Sandstone or dykes were intersected. Dykes were of particular interest to the panel installers as they were subvertical structures, with often comparable width to a panel. No classing framework had been established for dykes as part of the design phase – they were incorporated into the ground type classification of the intruded stratigraphy.

The location of geological structures was also important to the panel team as these could cause very localised degradation to the rock mass that may intersect the panel installation zone. Both the Hawkesbury and Ashfield Shales exhibited subvertical fault zones where there were concentrations of very closely spaced joints over distances of less than 2 m separated by improved, less fractured rock mass. Panel installation across the fault zone would require long anchors and bond length to accommodate the reduction in strength and rock quality. The fault zones were typically treated with shotcrete at the time of excavation to assist in maintenance of side-wall integrity so physical review of the walls at the time of anchor installation was not an option.

Sub-horizontal or gently dipping bedding shears were narrow features common in the Hawkesbury. The shears were typically around 100 mm wide but continuous for many tens of metres. For anchor integrity it was important to recognise where these features would cross the anchoring level.

6 MAPPING (UN)SUITABILITY

Upon request from the panels team to provide rock mass classifications for the side walls to assist their installations, it was quickly recognised the routine daily mapping and rock classing would be insufficient to suit their needs. The scale of the classifications was too large. Fortuitously the daily maps had already been compiled into a single detailed map for each tunnel and these were repurposed to guide the panel installation. There would have been several weeks of work involved in compiling and cross-checking daily maps to define the rock mass class of the anchor zone had this not been available. This would also have delayed purchasing of anchors and potentially delayed the start of installations.

The compilation maps were assessed for specific class along the anchoring level 3 m above the invert and provided to the installation team as a site guide, Figure 5.

Anchor bond length requirements for each established rock class were calculated. Classification parameters were also established for dyke and the appropriate anchor bond lengths for those conditions calculated. Tables of quantities of tunnel metres in each class were given to the design team to enable purchasing.

7 RESULTS

The quantities assessment in the Mainline tunnels (99% excavated in Hawkesbury Sandstone) indicated:

- 12% of the material along the anchor level classed using the design daily mapping system as "sandstone class" was relegated to a siltstone class.
- This equates to 4 km worth of wall being reclassed as siltstone.
- Dyke intersections comprised just over 300 m length of tunnel walls. This equates to over 250 panels installed in dykes.

In the on/off ramps, mostly excavated in Ashfield Shale:

- 45 panels were anchored to dykes.
- 500 m worth of siltstone side walls were downgraded by at least one rock mass class along the anchor level.

These results indicate had the daily mapping design classing system been adopted more than 10% of the length of walls requiring panels would have had installations where the anchor bond length was less than optimal to achieve the design purpose. This would have posed a potential safety hazard and may have reduced the life expectancy of the panel anchoring system.

From a cost perspective, 10% of the panels required longer and therefore more costly anchors than would have been budgeted based on the daily mapping classification. However, the anchoring was now suited to the purpose and uniqueness of the excavation. The reduction in risk by appropriately anchoring the panels to the rock conditions far outweighed the cost of additional anchor length.

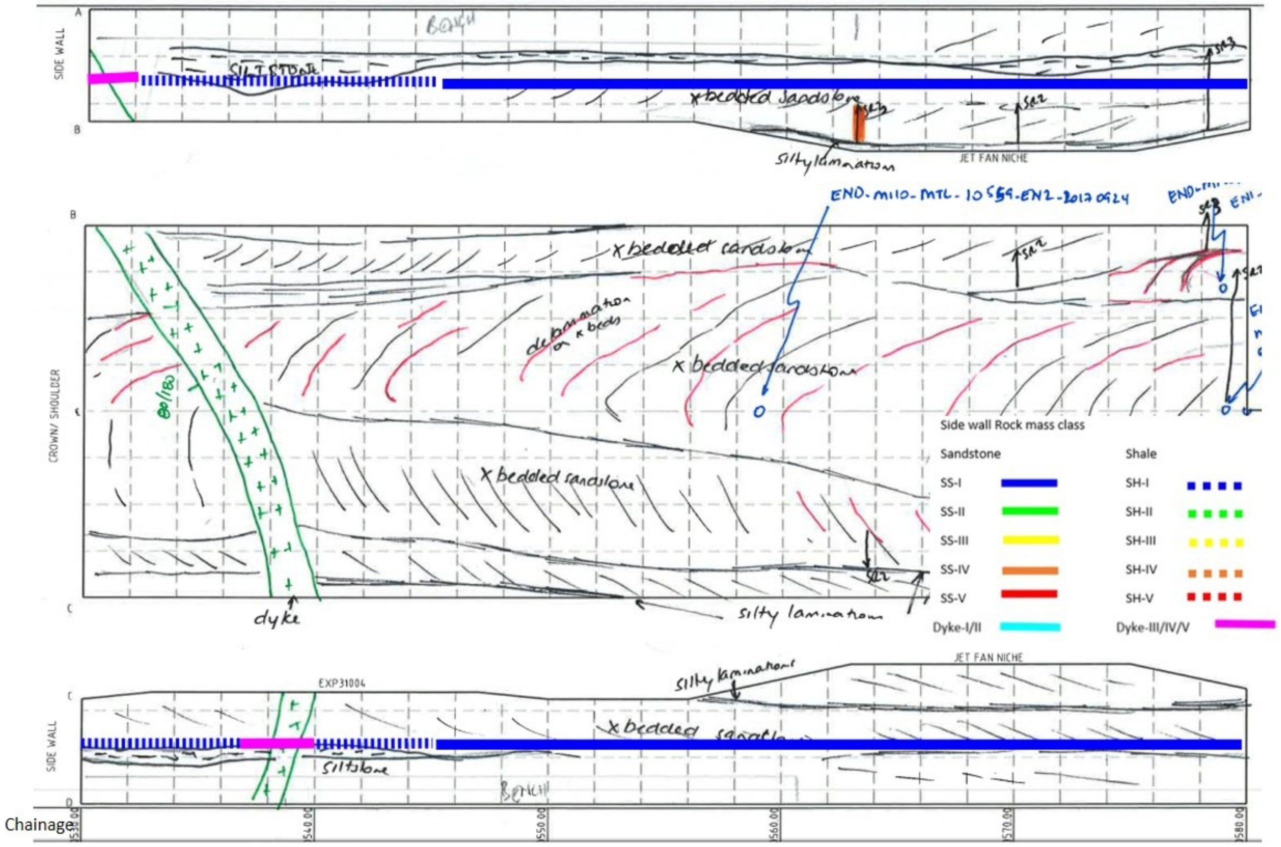


Figure 5: Example compilation map with indicated rock class at level 3 m above invert. (Not to scale. Data and legends not pertinent to this paper have been removed.)

8 WAY FORWARD AND CONCLUSIONS

For future projects consideration should be given to all end-users of the daily geotechnical maps and how the rock mass classing systems relate to later programs. Had mapping incorporated a specific rock classification for the level 3 m above the invert as part of daily routine, additional work could have been avoided.

For the M8, by undertaking a dedicated review of the rock classing along the anchor level, the likelihood of anchor failure has been significantly reduced. The purchasing of anchors was specifically suited to the projects unique geological profile.

9 ACKNOWLEDGEMENTS

The Authors would like to thank CPB Dragados Samsung Joint Venture who were responsible for the design and construction of the project and the asset owner/ operator, WestConnex | Transurban for permission to publish this paper.

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@WestConnex Facebook page – timeline photo dated June 2, 2020.

@WestConnex Facebook page – video post dated June 12, 2020. *With over 75% of wall panels now fully installed, the M8 is getting ready to open in the coming months.*