

Earthworks Design for Rail Infrastructure in a Multi-Hazard Environment: Tar Barrel Tunnel Bypass

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1 INTRODUCTION AND SCOPE OF WORK

Transport infrastructure located within tectonically active regions must withstand a range of natural hazards, including seismic shaking, slope instability, and ground deformation. Rail corridors are particularly sensitive to these hazards due to the strict alignment tolerances required for safe operation and the potential network-wide consequences of infrastructure disruption.

The Tar Barrel Tunnel Bypass project was undertaken to improve the long-term resilience of the Main North Line railway in the Marlborough region of New Zealand. The project replaced Tunnel 21, a 167 m long tunnel constructed in 1913 that passes beneath State Highway 1 (SH1). Over time the tunnel experienced structural deterioration, and the effects of the 2013 Seddon and 2016 Kaikōura earthquakes further increased concerns regarding its long-term stability (Henderson et al., 2025). Given the presence of the highway directly above the tunnel, a potential structural failure posed risks to both rail and road infrastructure.

To address these risks, a new rail alignment was developed to bypass the existing tunnel. The project involved approximately 1.5 km of rail realignment and associated road modifications, including the construction of a new rail underpass beneath SH1. A significant component of the works involved large-scale earthworks comprising excavation of approximately 400,000 m³ of mudstone, formation of deep cut slopes up to 36 m high, and construction of embankments across areas of compressible soils.

The key earthworks components of the project are illustrated in Figure 1.

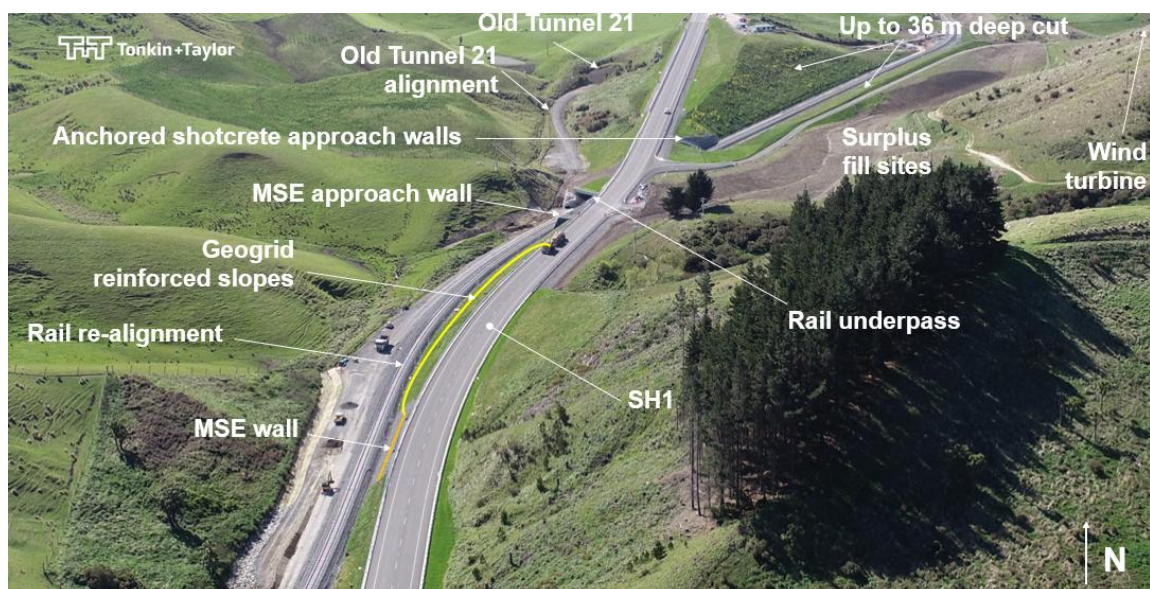


Figure 1. Layout of the Tar Barrel Tunnel Bypass showing major earthworks elements, including the rail cutting, underpass, and embankments.

2 METHODOLOGY

Geological and Hazard Context

The site lies within the Marlborough region of New Zealand, an area characterised by active faulting and complex structural geology associated with the boundary between the Pacific and Australian tectonic plates. The alignment is located within the Ward syncline and lies in proximity to the London Hill Fault, a mapped geological structure within the region (Rattenbury et al., 2006).

Subsurface conditions are dominated by mudstone of the Upton Formation within the Awatere Group. These materials are weakly indurated sedimentary rocks that exhibit varying degrees of weathering and fracturing. The combination of weak rock strength and weathering susceptibility required careful consideration in the design of the major rail cutting.

Seismic hazard was also an important factor influencing the project. The wider region experienced significant ground shaking during recent earthquakes, including the 2013 Seddon and 2016 Kaikōura events. These earthquakes demonstrated the vulnerability of existing infrastructure and highlighted the importance of designing replacement infrastructure that can accommodate ground deformation and slope instability triggered by seismic loading.

Earthworks Design

The rail realignment required excavation through a sequence of colluvium, weathered mudstone, and more competent mudstone units. Cut slopes were designed with varying batter angles based on the expected behaviour of each material unit. Gentler slopes were adopted within the weathered materials to reduce the risk of shallow failures, while steeper slopes were considered appropriate within less weathered mudstone.

Slope protection measures were incorporated to manage long-term weathering and erosion processes. These included drainage channels, progressive topsoiling, and hydroseeding of slopes to limit rainfall-induced erosion and surface deterioration.

Additional geotechnical challenges were encountered near the underpass location where the rail alignment crossed a low-lying gully containing compressible alluvial soils. Ground improvement was implemented through preload placement and monitoring of consolidation behaviour. Instrumentation including settlement plates, piezometers, and profilometers was installed to track settlement and pore pressure dissipation during construction.

Field Trials

Given the variability of the mudstone and uncertainty regarding its behaviour during excavation and compaction, field trials were undertaken prior to construction. These trials evaluated excavation productivity, rock ripping requirements, and the suitability of site-won materials for reuse as engineered fill.

The trials provided practical information regarding the behaviour of the mudstone under construction conditions and informed both the final design and construction methodology. The results helped reduce uncertainty associated with excavation rates and compaction performance, which was beneficial during both design development and contractor pricing.

3 RESULTS AND DISCUSSION

Construction of the Tar Barrel Tunnel Bypass provided valuable insight into the behaviour of weak sedimentary rock during large-scale earthworks in a seismically active region.

Excavation of the major rail cutting confirmed that the mudstone exhibited significant weathering sensitivity. Material that initially behaved as rock during excavation gradually degraded into soil-like material following exposure. This behaviour influenced both slope protection strategies and the handling of excavated materials intended for reuse as engineered fill.

Monitoring data collected during construction also provided insight into the performance of the embankment constructed over compressible soils near the underpass. Recorded settlements

were approximately 150 mm, with the majority of settlement occurring within the first several months after fill placement. Settlement rates subsequently reduced, indicating that primary consolidation had largely occurred before completion of the pavement structure (Henderson et al., 2025).

The project demonstrated the value of integrating field trials and monitoring with conventional geotechnical analysis. Early trials helped confirm excavation methods and material behaviour, while instrumentation provided confirmation of ground performance during construction.

From a resilience perspective, several design and construction decisions contributed to improved infrastructure performance. These included optimisation of the alignment to avoid areas of known slope instability, adoption of cut slope geometries that could tolerate limited post-earthquake deformation, and use of monitoring to guide construction activities in areas underlain by compressible soils.

The Tar Barrel Tunnel Bypass illustrates how geotechnical investigation, hazard assessment, and adaptive construction strategies can be combined to deliver infrastructure capable of functioning reliably in environments subject to both seismic and geomorphological hazards.

REFERENCES

Henderson, D., Dawson, M., Ramilo, R. (2025). Enhancing resilience: The Tar Barrel Tunnel Bypass for KiwiRail's Main North Line. Proceedings of the New Zealand Geotechnical Society Symposium 2025.

Rattenbury, M. S., Townsend, D. B., Johnston, M. R. (2006). Geology of the Kaikōura area: Geological map 1:250,000. Institute of Geological and Nuclear Sciences.