Muldoon's corner realignment: Design and construction of fill embankments and retaining walls

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ABSTRACT

The Muldoon's Corner Realignment project is located on the Rimutaka Hill Road, approximately 50 km north of Wellington, on State Highway 2. The project involved realigning approximately 1 km of road in rugged mountainous terrain by forming cuttings of up to 55 m high into existing hillsides, constructing fill embankments of up to 45 m high and upgrading and constructing a few retaining walls. The $16.5 million upgrade commenced in August 2009 and was completed in May 2012. Resilience of the Rimutaka Road, which is a vital link between Wellington and the Wairarapa, carrying approximately 5,300 vehicles daily, was a key consideration in the geotechnical design of the project. This paper presents the design and construction of fill embankments and retaining walls within the project and their design performance and resilience in a large earthquake event. Some of the high embankments were strengthened by geogrid reinforcement and high strength woven geotextile. The retaining wall components include a reinforced concrete soldier pile wall with rock anchors to tie-back to bedrock, two reinforced earth walls and strengthening of an existing crib wall by a hybrid-approach using rock anchors and fill buttressing with a high reinforced embankment. The design and formation of the rock cuttings is presented in a companion paper.

Keywords: earthquake, embankment, retaining wall, geogrid, anchor

1 INTRODUCTION

The New Zealand Transport Agency (formerly Transit New Zealand) commissioned Opus International Consultants to carry out design and construction management for the realignment of a section of State Highway 2 on Rimutaka Hill Road in rugged mountainous terrain, see Figure 1. The road realignment, involving substantial earthworks with approximately 230,000 m^3 of rock being excavated to form 55 m high cuts and 45 m high reinforced fill embankments, significantly increase the road resilience in major earthquake events. Several retaining walls which were vulnerable to failure under earthquake events were either upgraded or replaced to ensure adequate performance and resilience of the new road.

Site investigations were undertaken in stages in 2004 and 2007 to define the site geology for detailed design of the road realignment and the associated slope and retaining wall design. The scope of site investigations included 16 boreholes, 13 auger holes, 30+ trial pits, seismic refraction survey and engineering geological mapping.

Geotechnical assessment on cut slopes, slope stabilisation works, earthwork disposal, fill embankments and retaining walls was carried out following the site investigations. Several fill embankments were required within depressions and gully channels for the road realignment and at the disposal sites. Most of the embankments have side slopes of 2H: 1V. For steeper embankments, such as one with 1H: 1V side slopes and 45 m height, geogrid reinforcement was required to ensure stability. The stability of a few existing retaining walls was analysed and suitable wall upgrade /replacement solutions were proposed. New walls were also required where weak sidling materials were present by the road side. The final retaining wall scheme consists of a new reinforced concrete soldier pile wall with rock anchors to tie-back to bedrock, a new terramesh wall, a new geogrid-reinforced gabion wall and strengthening of an existing crib wall by a hybrid-approach using rock anchors and fill buttressing.

Figure 1. Overview of the Muldoon's Corner Realignment Site

2 SITE GEOLOGY & GROUND CONDITIONS

The site is underlain by fresh to completely weathered Wellington greywacke bedrock. Sandstones and siltstones are generally strong to very strong, resistant to weathering and have closely to extremely closely spaced joints. Mudstones (or argillite) are commonly found interbedded within the sandstones and siltstones and are generally weak to very strong with closely to extremely closely spaced joints. Bands of sheared rock (generally about 200 mm thick) are commonly found within the mudstone layer.

Fill and colluvium comprising mainly of gravels in a silt/clay matrix is generally present as surficial material above bedrock, along the outer edges of the state highway and slopes below and behind the existing retaining walls. The colluvial materials are likely to have originated from the hillsides above, as cut materials during road construction, or slope failure debris.

3 SEISMICITY

The site is situated on an uplifted block between the active Wellington Fault and Wairarapa Fault, which are both about 5 km from the site. The central segment of the Wellington Fault is capable of giving a magnitude 7.5 earthquake at a return period of about 900 yoears (Stirling et al, 2002). The Wairarapa Fault is considered as Class I active fault and is one of the major faults in New Zealand. It's rupture has the potential to produce earthquakes with a magnitude of 8.1 at a return period of 1500 years (IGNS, 2000), similar to the 1855 Wairarapa Earthquake.

The design horizontal peak ground acceleration (PGA) has been derived based on the New Zealand Earthquake Loading Standard, NZS 1170.5: 2004 and Transit New Zealand Bridge Manual (2nd Edition, 2003) and subsequent Provisional Amendment in December 2004. The site subsoil class was classified as Class B (Rock). Considering that the proposed road realignment is located on the major state highway SH2, an earthquake of magnitude equivalent to a 1/1500 year return period event was adopted in the design. These provide a design PGA of 0.6g.

4 REINFORCED SOIL EMBANKMENTS

4.1 Design Philosophy

Reinforced soil embankments (RSEs) were adopted to enable the construction of steeper fill embankments to allow for reduced footprint without extending the down the steep gully slope into the stream below, and without protruding beyond the site designation. RSEs have the advantages that they can be constructed like normal embankments, but incorporating geogrid reinforcements, and without the need for temporary or permanent facing. RSEs of up to 45 m high and at 35° to 45° were designed and constructed at two fill retention sites and at the main alignment embankment site. RSEs of this order of height are rarely constructed in New Zealand.

The 45 m high RSE at the main site was constructed in front of an old crib wall above a deeply incised gully, see Figures 2 and 3. This RSE was put to innovative double purpose - to carry the road embankment without the fill extending down the slope into the stream, as well as buttressing the high crib wall with a steep cliff below. An earlier design concept involved a bridge across the deeply incised gully instead of the RSE design. By using the 45 m high RSE, the construction cost was substantially reduced. RSEs are also more resilient than bridge structures in an earthquake event as they are more flexible and less vulnerable to failure and will take less time to recover. The embankments were designed in such a way that stability is ensured under normal static conditions (FOS > 1.5) and under large storm events (FOS > 1.0). Limited displacement of less than 200 mm was accepted in large earthquake events.

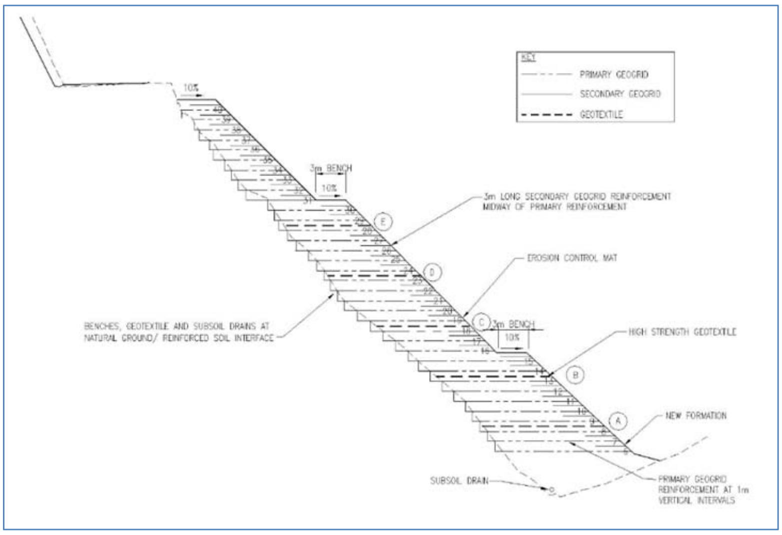

Figure 2. Typical Section of 45 m High RSE Buttressing an Existing Crib Wall and Steep Slope

Figure 3. Construction of Reinforced Soil Embankment at the Realignment Site

4.2 Fill Materials

The RSEs are required to perform satisfactorily in large earthquakes given the high seismicity of the region. Therefore, better quality soils from the cuttings were selected to be used as fill materials for the RSEs. Residual soil and other overburden deposits of poorer quality from cuttings were used for general fill embankments of 2H : 1V side slopes and up to 5 m high.

The fill materials for RSEs are generally unweathered to moderately weathered greywacke comprising silty sandy gravels. This is to ensure adequate soil strength and appropriate drainage characteristics and that the fill strength and stiffnesses would not degrade significantly during an earthquake event. The maximum particle size of the fill was limited to 75 mm to control the damage to the geogrid and geotextile reinforcements.

4.3 Soil Reinforcement

Geogrid reinforcement made of high density polyethylene (HDPE) was used as the primary and secondary reinforcements for the RSEs. It was considered that HDPE geogrid is relatively low cost and able to provide satisfactory durability and robustness against damage, given the selected fill were gravels derived from excavated competent rocks from the cuttings within the site. The geogrid was predicted to provide an adequate design life exceeding 100 years (FHWA, 2000), although these grids have not been in use for such a long period yet. The primary geogrid was placed at 1 m vertical intervals with appropriate length to ensure internal and external stability as well as displacement performance of the embankments during a large earthquake. To prevent locally shallow failures, secondary geogrid of 3 m in length was placed midway between the primary geogrid at the slope face. At the 45 m high embankment, additional soil reinforcement comprising high strength woven geotextile was placed at every 5 m interval vertically to provide extra resisting strength in all directions.

Figure 4. Installation of Erosion Protection Mat on the Face of Reinforced Soil Embankment

5 REINFORCED SOIL WALLS

Two geogrid reinforced soil walls (RSWs) with gabion facing were designed and constructed below the realignment to support the road, see Figure 5. These new walls replaced the existing walls which were considered as unstable under the design earthquake. The RSWs are up to 6 m high and founded on weathered greywacke bedrock. The walls were designed to satisfy both external and internal stability in static and seismic conditions.

The RSWs were considered as an effective and cost effective solution for replacing the existing walls. The high flexibility of the RSWs also allows sufficient resilience during intense ground shaking. The wall construction was carried out after the formation of the cuttings on the opposite uphill side of the road for the new road. This arrangement resulted in sufficient road width for maintaining two-lane traffic and minimised disruption to traffic due to wall construction. Upgrading the walls as part of the realignment construction resulted in substantial cost-saving to the stakeholders and less disruption to traffic. If the strengthening or replacement is undertaken separate from the construction of the realignment, it would need to be undertaken at a much higher cost and disruption to road users.

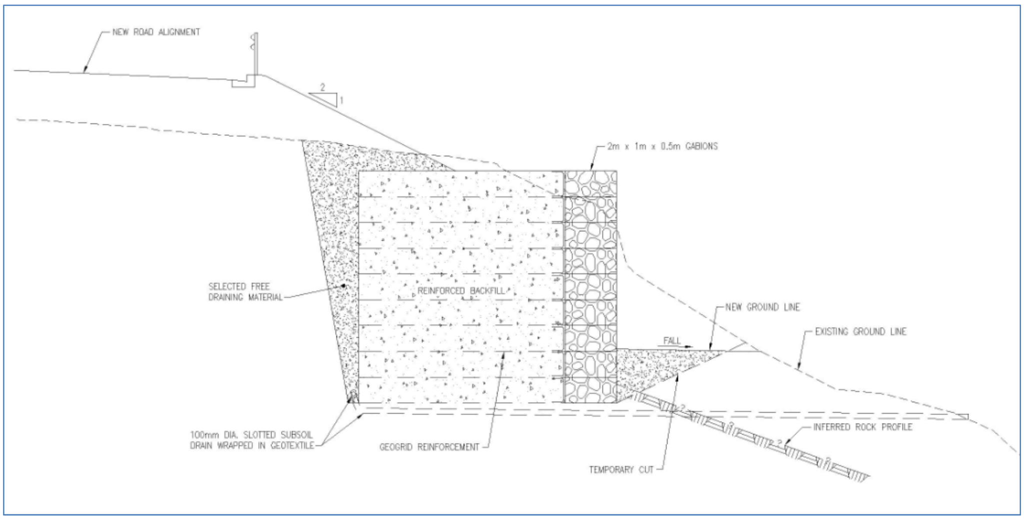

Figure 5. Typical Detail of Reinforced Soil Walls at the Realignment

6 ANCHORED REINFORCED CONCRETE SOLDIER PILE WALL

An old crib wall of about 30 m in length and 6 m exposed height below the realignment was replaced by an anchored soldier pile wall with a concrete facing, see Figure 6. The new soldier pile wall was able to resist the design earthquake loads and to retain an extra thickness of fill for the new road construction. The wall consists 25 reinforced concrete piles at 1.2 m spacing. Each pile is of 600 mm in diameter and about 10 m in length. The piles were socketed 4 m into the bedrock and tied-back by rock anchors. The new wall was constructed behind the existing crib wall, of which the top couple of meters were removed for the new wall construction.

Figure 6. Replacement of an Old Crib Wall with an Anchored Soldier Pile Wall

There was a high risk of failure of the old crib wall in storm or earthquake events. Stability analysis showed that the old wall was marginally stable under the existing static conditions. Any storm events that would cause significant temporary increase in groundwater level could cause the wall to fail. The wall would also fail by overturning in earthquakes. Due to its close proximity to the new road alignment, failure of the wall would cause damage to more than one lane of the new road. The disruption to the road users and the expected cost of repairing the wall would be substantial. By replacing the old wall with the new soldier pile wall during construction of the realignment, the road resilience was greatly improved. The approach also resulted in substantial cost savings and minimised disruption to traffic compared to procuring the wall replacement under a separate contract.

7 HYBRID APPROACH OF WALL STRENGTHENING

An old crib wall along the realignment was strengthened to provide adequate resilience in the design storm and earthquake conditions. Located above a steep slope of about 50° to 55°, the crib wall has a total length of 60 m and up to 8 m to 9 m high. It was inferred that the wall is founded on bedrock. Stability analysis indicated that the wall was likely to be marginally stable under the existing static conditions. A large storm event with significant increase in groundwater level could lead to failure of the wall. The wall would likely fail in an earthquake event. There is also the risk of failure of the steep rock slope below the toe of the retaining wall under seismic shaking. Since the wall is in close proximity to the realignment, failure of the wall will remove more than one lane of the new road. Therefore, the old crib wall was strengthened during construction of the new road to ensure adequate resilience.

An innovative hybrid wall strengthening approach was adopted. The approach involved:

(i) strengthening the southern 20 m of the wall with a reinforced soil embankment (RSE) buttress (as shown in Figure 2); and

(ii) strengthening the northern 40 m length of the wall by rock anchors with double corrosion protection (Figure 7).

The fill buttressing would mitigate the risk associated with the stability of the steep slope below the southern 20 m of the wall. At the northern side, a row of rock anchors were installed on the steep slope below the wall to ensure stability. Sub-horizontal drainage holes were also installed to maintain low groundwater table in large storm events.

Figure 8 shows the crib wall before and during upgrade with fill buttress.

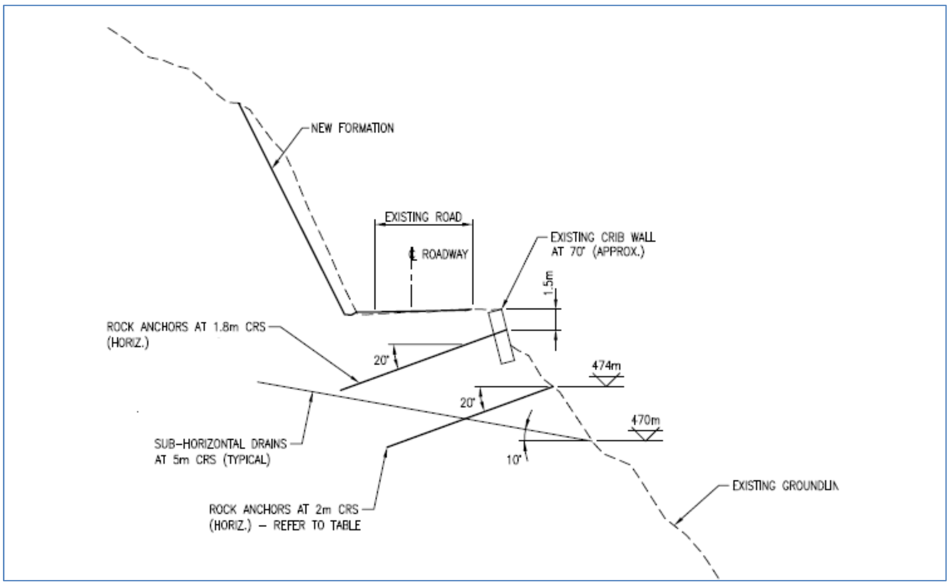

Figure 7. Strengthening Part of an Old Crib Wall with Rock Anchors

Figure 8. Strengthening of an Old Crib Wall with Fill Buttress and Rock Anchors

8 CONCLUSION

Resilience was a key consideration in the Muldoon's Corner Realignment project. This project demonstrated that innovative use of reinforced soil embankments, reinforced soil walls, ground anchors and soldier piles in supporting new roads and strengthening existing walls could result in cost effective, resilient and robust solutions for our road networks.

The project involved the use of reinforced soil embankments of 45 m height and reinforced embankment of such order of height are rarely constructed in New Zealand. Through careful consideration of the alignment and solutions, the reinforced embankments served the dual purpose of providing a resilient solution instead of a costly bridge across the gully, while also buttressing existing substandard walls and steep slopes that are vulnerable to failure in earthquakes.

9 ACKNOWLEDGEMENT

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