Design of reinforced soil retaining walls to AS 4678 – 20 years on

Michael Dobie
Tensar International Limited, Indonesia

John Buckley
Tensar International Limited, Australia, JBuckley@tensar.com.au

Gordon Stevens
Geofabrics New Zealand Limited, New Zealand

Eric Ewe & Dale Chaychuk
Geofabrics Australasia Pty Ltd, Australia

ABSTRACT: Publication of the AS 4678 Standard for earth-retaining structures in 2002 provided an opportunity to create innovative design methods by establishing general advice on design parameters and limit states but allowing organisations to develop their own detailed methods. Based on this, the two-part wedge calculation method for the internal stability of reinforced soil retaining walls was combined with the general guidance in AS 4678-2002 to create a new design method, offering significant advantages over the tie-back wedge approach. This was coded into the program TensarSoil™ which has been used widely in the ANZ region over the last 20 years. Case studies provide some examples of reinforced soil structures designed using this method.

KEYWORDS: reinforced soil, retaining wall, design, stability, case study.

1 INTRODUCTION

The publication of the AS 4678 earth-retaining structures standard in 2002 (Standards Australia, 2022) established the necessary background to develop new retaining wall design methods, thereby encouraging innovation in this application. The code provides general advice and the structure for a limit state design approach, but detailed methods of calculation are not prescribed. The scope of the standard states that: "This Standard does not prescribe specific methods of analysis". then "NOTE: Various organizations and authorities may develop detailed guides and specifications based on the principles set out in this Standard." Based on this recommendation, a design method for reinforced soil retaining walls was developed by the first author in which the internal stability checks were based on a two-part wedge analysis approach, rather than the commonly used tie-back wedge. The details of the method were published in the 11th ANZ 2012 Geomechanics Conference (Dobie, 2012).

This paper provides a brief outline of the method of calculation used as the basis of this design method for reinforced soil retaining walls, with specific attention given to the two-part wedge method of analysis used for the internal stability analysis. This calculation approach provides benefits in relation to various common design situations, such as: adding earthquake loading, taking account of connection strength between reinforcement and facing which is less than the reinforcement strength itself (which is the normal case) and a zone of higher design temperature directly behind the wall facing. The traditional tie-back wedge design method requires that simplifications and assumptions are made to take account of all three design situations mentioned above, which lead to uncertainty and, in most cases, over-conservative designs.

Following publication of AS 4678 in 2002 and the development of the two-part wedge method of internal stability analysis based on its recommendations, the first authors company created a module in its reinforced soil retaining wall design program known as "TensarSoil™" which has given ready access to this technique for many designers in the ANZ region. The paper describes case studies of reinforced soil retaining walls which have been designed using the method.

2 DESIGN OF REINFORCED SOIL RETAINING WALLS

2.1 *Outline of the design approach*

Design of reinforced soil retaining walls is carried out in two stages. In the first stage, external stability analysis determines the overall size of the reinforced fill block, namely dimension B (see Figure 1). External stability analysis is essentially a gravity retaining wall calculation and is much the same in all codes and guidelines. Although these calculations determine the length of the reinforcement, this length might also be affected by the later internal stability check. It should be noted that in many standards there is a limit on the ratio B/H as shown in Figure 1, and that this limit will often determine the reinforcement length rather than any other calculation.

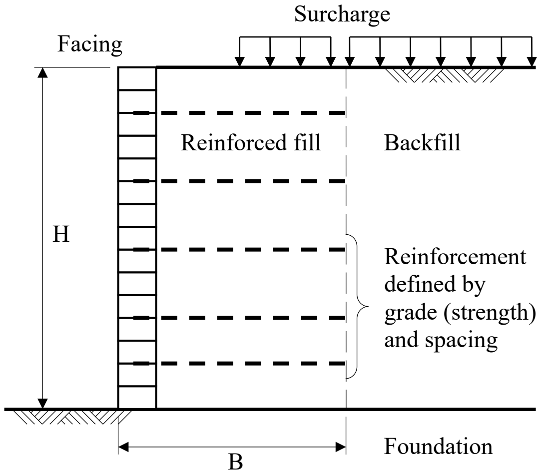

Figure 1. Main elements of a reinforced soil retaining wall

In the second stage of the calculation, an internal stability check ensures that the layout of reinforcement (grade/strength and vertical spacing) is sufficient. The internal stability calculation should also take account of design features such as the connection strength between the reinforcement and the facing. In most published design guidelines, the tie-back wedge approach is the method of calculation used for internal stability (ie. AASHTO, NCMA and BS 8006-1:2010).

The basis for the tie-back wedge approach is shown in Figure 2. For steep structures (facing angle greater than 80°), internal stability is assessed based on a single failure mechanism, namely the Rankine wedge, as shown. Due to this approach, assumptions and simplifications are required within the calculation procedure, particularly with regards to connection strength between the facing and the reinforcement. If connection strength is less than the reinforcement strength, which is normally the case, then the connection strength is assumed to apply over the full length of the reinforcement, which can lead to excessively conservative designs.

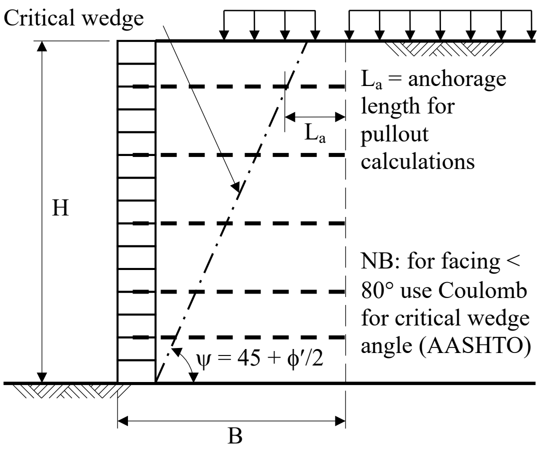

Figure 2. Defining the critical tie-back wedge (AASHTO)

2.2 *Two-part wedge method for internal stability*

The two-part wedge method of analysis for internal stability is outlined in Figure 3. The geometry is typical of reinforced soil structures, but the method of analysis can incorporate all features shown without simplifying assumptions. The method of analysis is that of limiting equilibrium, but with the important requirement that any mechanism used should be admissible and that all associated forces should be taken into account.

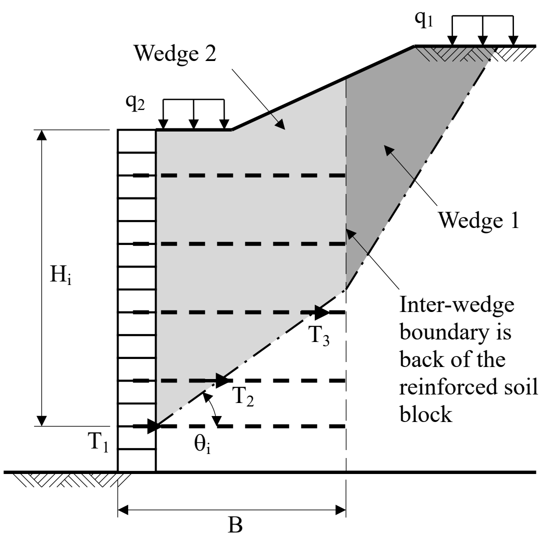

Figure 3. Basis of the two-part wedge method

A single wedge, located entirely within the reinforced soil block as depicted in Figure 2, may well be critical if the reinforcement is relatively long. However, for typical reinforced soil retaining wall aspect ratios, the two-part wedge is likely to be the critical mechanism, as demonstrated both by analytical approaches and by observing actual performance (Dobie & McCombie, 2015). The two-part wedge is also used in national design guides and codes, for example in Japan, and in the German National Annex to Eurocode 7 (EBGEO, 2011).

Due to the complexity of the geometry, as well as the resulting forces and resistances, the critical two-part wedge arrangement (see Figure 3) cannot be predicted in advance. Therefore, it is necessary to use a search procedure, in which the geometries of both wedges are varied, as well as the starting point for the wedges above the toe of the wall (see Figure 4). In each calculation, the required reinforcement resistance is determined (ie. T_1, T_2 and T_3 in Figure 3) such that the optimum arrangement of reinforcement may be found. This process is not conducive to manual calculation (although individual or critical cases may be checked by manual calculation), such that an automated procedure is required, best set up in a suitable computer program.

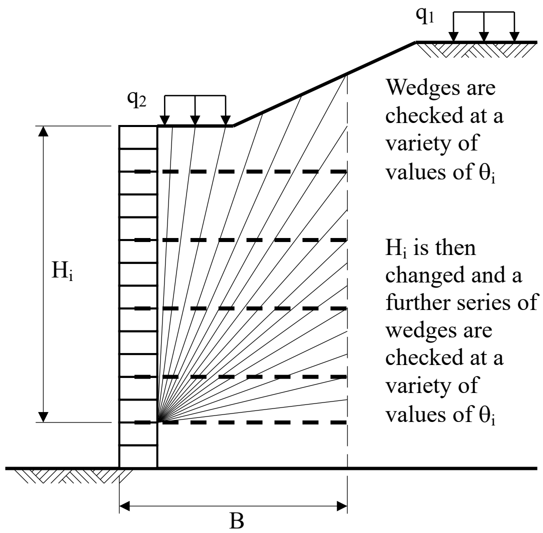

Figure 4. General search of two-part wedges

2.3 *Contribution of reinforcement and facing*

One of the major advantages of the two-part wedge method is that the contribution of the reinforcement and the facing, including connection strength, may be accounted for rigorously.

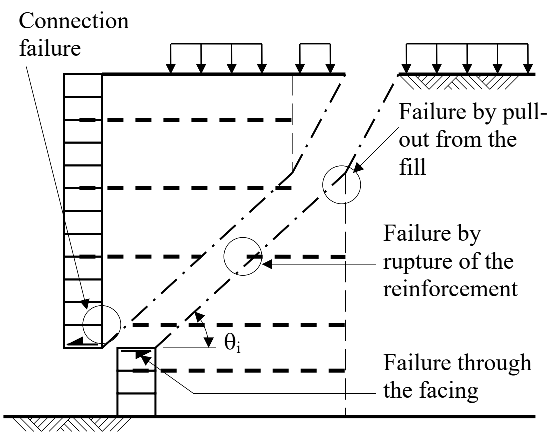

Figure 5. Likely mode of failure of two wedges

Considering the actual mechanism of failure (see Figure 5), contributions to the resistance preventing failure of a two-part wedge may come from reinforcement pull-out, reinforcement rupture or detachment from the facing. These resistances may be calculated and summed for each two-part wedge considered. A helpful way to illustrate these concepts is the "envelope of available resistance" (see Figure 6).

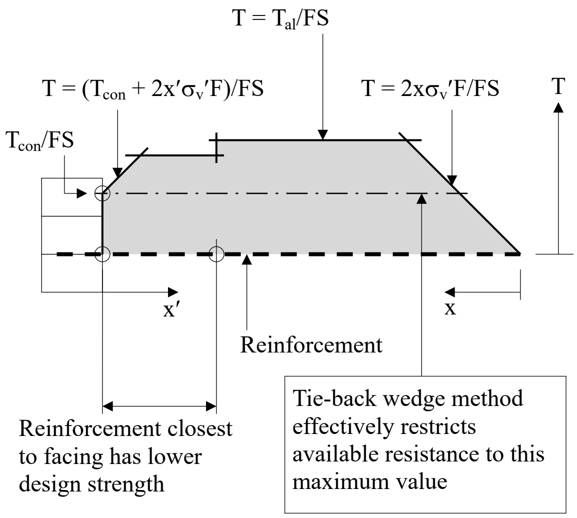

Figure 6. Envelope of available resistance

In this view, the facing is on the left where resistance is limited by connection strength. Moving to the right there is a length of reinforcement with lower rupture strength due to higher in-soil temperature, beyond this a higher rupture strength, then on the right, resistance is limited by pull-out. This envelope is developed for each layer of reinforcement so that available resistance may be determined at all levels (Figure 7).

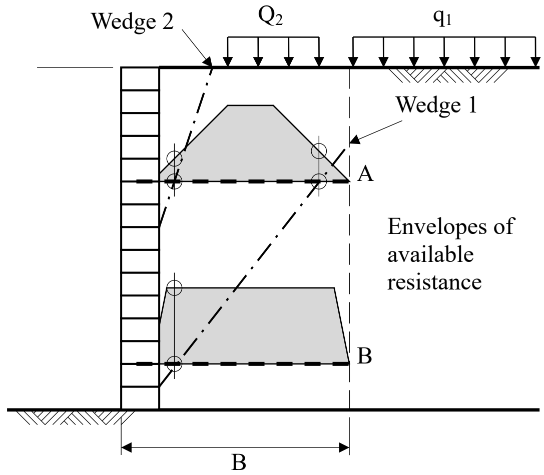

Figure 7. Analysis using available resistance

The concepts outlined above are illustrated in the desktop view of the TensarSoil™ program (see Figure 8). The red wedges have insufficient resistance, so changes are required to arrive at a satisfactory design.

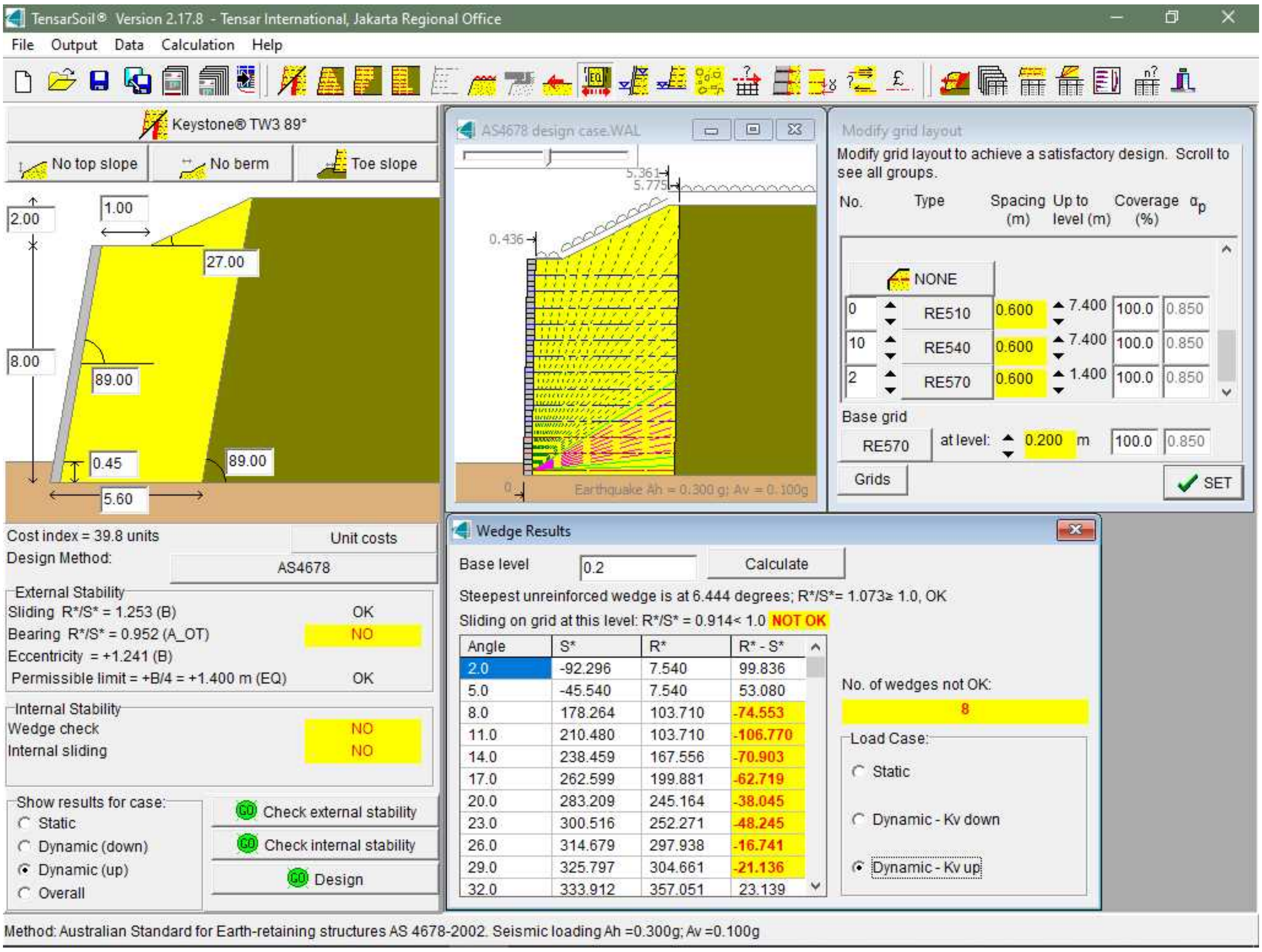

Figure 8. Desktop view from the TensarSoil™ program showing various aspects of the calculation procedure and results

3 CASE STUDIES

3.1 *Usage of the AS 4678 two-part wedge design method*

The program TensarSoil™ was developed to include the two-part wedge analysis method following the guidance and limit states provided by AS 4678-2002 soon after release of the standard in 2002. Since that time over a thousand engineers in the ANZ region have registered to use the program. Distribution of the software has generally been in conjunction with design workshops and technical seminars to provide users with detailed information about the background to the methods as well as operation of the program. It can, therefore, be assumed that a significant number of reinforced soil retaining walls have been designed and built based on the two-part wedge design method included in TensarSoil™. This section describes a small selection of these projects.

3.2 *La Residence Du Lac, Queenstown, New Zealand*

The development of this residential site adjacent to Frankton Road, the main arterial route into Queenstown, required cutting into the existing sloping ground to form an access road to the proposed car park and buildings. The height difference between the existing Frankton Road and the proposed car park area required a retaining structure up to 7.2m in height. The proposed retaining wall had to be designed to provide access for all construction vehicles, including delivery trucks, during the construction of the apartments. In addition to normal daily traffic loading, the retaining wall was designed to resist a horizontal ground acceleration of up to 0.4g.

The ground conditions comprise medium dense to very dense glacial sediments of varying depth underlain by a slightly weathered schist bedrock. A layer of colluvium is present within the upper 1m. Groundwater was established to be located approximately at the glacial sediment/schist interface. The glacial sediments were found to be approximately 4.5m deep along the length of the proposed wall.

Initial wall designs to retain the access road included proposals for anchored walls using steel universal columns and timber. A Keystone TW3 modular block reinforced soil wall system incorporating Tensar HDPE geogrids was subsequently developed for this site using the TensarSoil™ software (see Plate 1). The design followed the recommendations provided in the Australian Standard AS 4678-2002 for Earth-retaining structures and used a two-part wedge technique which can accommodate a large number of potential failure mechanisms for the internal stability calculations. This design approach allowed for the mechanical connection between the concrete modular block facing and HDPE geogrid to be considered for all design load cases including seismic.

Plate 1. View of the Keystone TW3 wall at La Residence Du Lac

3.3 *Dashwood Overbridge Realignment, New Zealand*

The existing Dashwood overbridge crossing the railway and built in 1932 no longer met seismic standards and required replacement. The site has a relatively high seismic hazard with the Awatere and Vernon faults located within a 2km radius of the site. A magnitude M_w = 6.5 earthquake on 21st August 2013, centered at 12km from the site and at a depth 17km, was a reminder of the importance of seismic considerations in the design. A detailed account of the construction and performance of this retaining wall was published in the 13th ANZ 2019 Geomechanics Conference (Stevens & Dobie, 2019), with a brief summary provided below.

Walls were required to provide support for the slope sides at either end of the new 54m long steel culvert. The wall design incorporated a Keystone TW3 modular block face mechanically connected to Tensar RE500 uniaxial HDPE geogrids used for soil reinforcement. A limit state design approach, following the Australian Standard AS 4678-2002 for Earth-retaining structures, was used to analyse both external and internal stability, the latter based on a two-part wedge method. The seismic load case for 0.6g ground acceleration was found to be the critical load case, resulting in relatively long reinforcement compared to the wall height.

On 14th November 2016 a magnitude M_w =7.8 earthquake occurred in the upper South Island with its epicentre near Kaikoura. A linear interpolation of the horizontal ground accelerations measured by seismic strong motion instruments at Seddon Fire Station (0.76g) located about 7km north and Blenheim Marlborough Girls College (0.27g) located around 16km south-east implied that the wall experienced a peak ground acceleration (PGA) of 0.60g which matches the PGA used in the design. It should also be noted that significant components of vertical acceleration were measured.

Visual inspections of the wall following the Kaikoura earthquake showed no signs of damage or wall movement, including at slip joints (see Plate 2), which were unaffected by the ground motions. This provided a good validation of the Keystone TW3 wall system and design approach used.

Plate 2. View of the Keystone TW3 wall at Dashwood with the slip joint visible

3.4 *New Maitland Hospital TW3 Wall, Metford, NSW*

To meet the growing health service needs for the surrounding communities of the Hunter Valley, the NSW Government developed the new Maitland Hospital, which was constructed on a 17-hectare site at Metford. Following a review of 35 possible sites and a rigorous selection process, the Metford site was determined to best meet the criteria for the new hospital which included environmental and geotechnical factors, consideration of flood prone areas and the implications for access and operation during flooding as well as land characteristics such as slope, elevation and orientation.

A reinforced soil structure was required for the grade separation of the external road around the site. The Keystone TW3 modular block system reinforced with RE500 uniaxial HDPE geogrids was chosen for its ease of construction and high-capacity connection system between the geogrids and the facing blocks. These main components of the retaining wall system can be seen early in the construction process (Plate 3).

Plate 3. Construction of Keystone TW3 wall for Maitland Hospital

The retaining wall has an overall length of 100m, with maximum height of 7.4m. Both the top of wall and foundation elevations change continuously from one end of the wall to the other, such that the use of the modular block technique was particularly convenient due to its flexibility in this situation. The wall cross sections were designed using the two-part wedge method in TensarSoil™, resulting in reinforcement length generally being determined by the limiting L/H ratio of 0.7, despite the presence of relatively low quality backfill.

3.5 *Oakdale Industrial Estate, Horsley Park, NSW*

The Oakdale Industrial Estate is a large development project that forms part of the broader Western Sydney Employment Area (WSEA). The project has also been identified for employment generating purposes and will be home for international companies such as on-line retailers, automotive users, logistic and pharmaceutical products. The development site consists of Oakdale Central, Oakdale South, Oakdale West and Oakdale East with a total developable area of more than 300 hectares. It is also strategically located with connection to the M7 & M4 motorways.

There was the need to construct multiple retaining walls across the entire development site for grade separation of the warehouse lots. Among them, Reinforced Soil Wall 2 is the longest wall in Oakdale West with length exceeding 330m. The wall height ranges from 3.0m to the tallest section at 13.4m high.

Due to the height of the walls, speed of installation became an essential consideration, with geogrid spacing identified as one of the critical factors. The TW3 facing block with mechanical connection to the reinforcement allows the maximum utilisation of geogrid strength, thus wider vertical spacing (3 facing blocks) is possible versus the closer geogrid spacing (1 or 2 facing blocks) required if using a frictional connection. The design of the walls was carried out using the TensarSoil™ software with the AS4678 2-part wedge method for internal stability analysis.

The challenges included incorporating a noise barrier at close distance from the front face of the retaining wall. The foundation design of the noise barrier wall was dealt with separately, with deep poles embedded from the finished level. Corrugated pipes were installed at designated locations during the filling and installation process for later placement and grouting of the noise barrier wall foundation posts.

Plate 4. Installation of the Keystone TW3 wall with corrugated pipes for noise barrier foundation

The upper 1.0m portion of the reinforced soil wall was designated as a "no geogrid zone" to allow space for installation of services. This was modelled as a top slope without geogrid in the TensarSoil™ software, with an additional 20kPa surcharge load on the slope portion to allow for the fill and self-weight of the blocks. This 1.0m upper portion between the TW3 block facing and the noise barrier wall was further strengthened with no fines concrete and 2 layers of geogrid each 2.0m long.

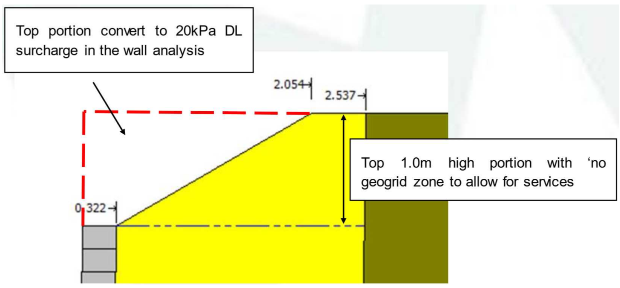

Figure 9. Design approach used for the top of the wall

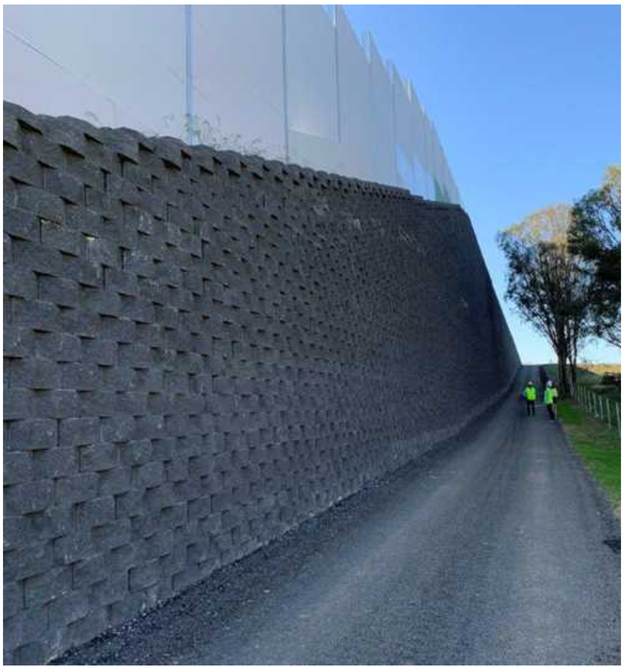

Plate 5. Completed Keystone TW3 wall with noise barrier wall on top

4 CONCLUSIONS

Publication of the AS 4678 Standard for earth-retaining structures in 2002 (Standards Australia, 2002) provided an opportunity to create an innovative design method for reinforced soil retaining walls.

The two-part wedge method of internal stability analysis was combined with the general recommendations and limit states defined in AS 4678-2002 to create a new method for designing reinforced soil structures which was incorporated into the design program TensarSoil™.

This method overcomes many of the issues related to assumptions and simplifications necessary to create designs using the traditional tie-back wedge method, and results in more cost-effective designs, at the same time addressing important design issues such as connection strength between reinforcement and facing, as well as earthquake loading.

The TensarSoil™ program has been used extensively in the ANZ region over the last 20 years, resulting in many successful designs of reinforced soil retaining walls following the guidance provided in AS 4678-2002.

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