Performance and stability of Terramesh® reinforced retaining walls during the 2010/2011 Canterbury Earthquakes

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ABSTRACT

The dozens of gabion Terramesh® retaining walls (mesh reinforced retaining walls) across the Christchurch Port Hills have generally performed well during the 2010/2011 Canterbury Earthquake sequence. The damage observed was consistent and usually involved translation and rotation of the top rows of baskets. These reinforced earth walls are often backed by loess soils which, provided the material remains dry, are considered to exert little or no lateral pressure on the walls. This paper presents the results of the analysis completed for a number of mesh reinforced retaining walls around the Port Hills using methods developed for mechanically stabilised earth (MSE) walls. Seismic loading was incorporated into the assessment. The walls around the Port Hills were built with reinforcement panels spaced vertically at 1m centres. The geotechnical analysis presented in this paper indicates that 1m spacings may be insufficient to prevent deformation during significant seismic events, such as the 2010/2011 Canterbury earthquakes. Further analysis suggests that reducing the spacing of reinforcement panels to a half a metre increases the resilience of the wall and may prevent deformation of the upper portion of the wall.

Keywords: terramesh, loess, retaining walls, Canterbury earthquake, gabion wall, SCIRT

1 INTRODUCTION

The investigations, assessment and analysis detailed in this paper were completed during the author's secondment from GHD Ltd to the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) from 2012 to 2014.

SCIRT was established to rebuild government owned infrastructure following the devastating February 2011 Christchurch earthquake. At its peak, the SCIRT professional services team was made up of around 200 designers and scientists from a number of local and global consultancy firms including Aurecon and GHD. The author and 13 other geotechnical engineers were tasked with assessing and designing repair and rebuild works for the Christchurch City Council (CCC) and NZTA owned retaining walls. The vast majority of the retaining walls were located in the hilly suburban areas of the Port Hills and Lyttelton. The focus of this paper is the Maccaferri Terramesh® gabion walls which will be referred to as mesh reinforced gabion walls for the purpose of this paper.

Mesh reinforced gabion walls were commonly used during subdivision works in the Port Hills. The SCIRT team was involved in the assessment of over 50 of these wall types and the damage sustained by these walls varied but in general the walls performed quite well. This paper outlines the inspection and assessment process for these walls and some of the outcomes from the assessment.

2 LOCATION, GEOMETRY AND SETTING

2.1 Location

The majority of the mesh reinforced gabion walls investigated by SCIRT were built in the 1990s to early 2000s and are located across the Port Hills area about 5km south of the Christchurch central city. The walls assessed by SCIRT were typical in the Port Hills suburbs of Cashmere, Huntsbury and Mt Pleasant.

A map showing the Christchurch CBD and Port Hills area is shown below.

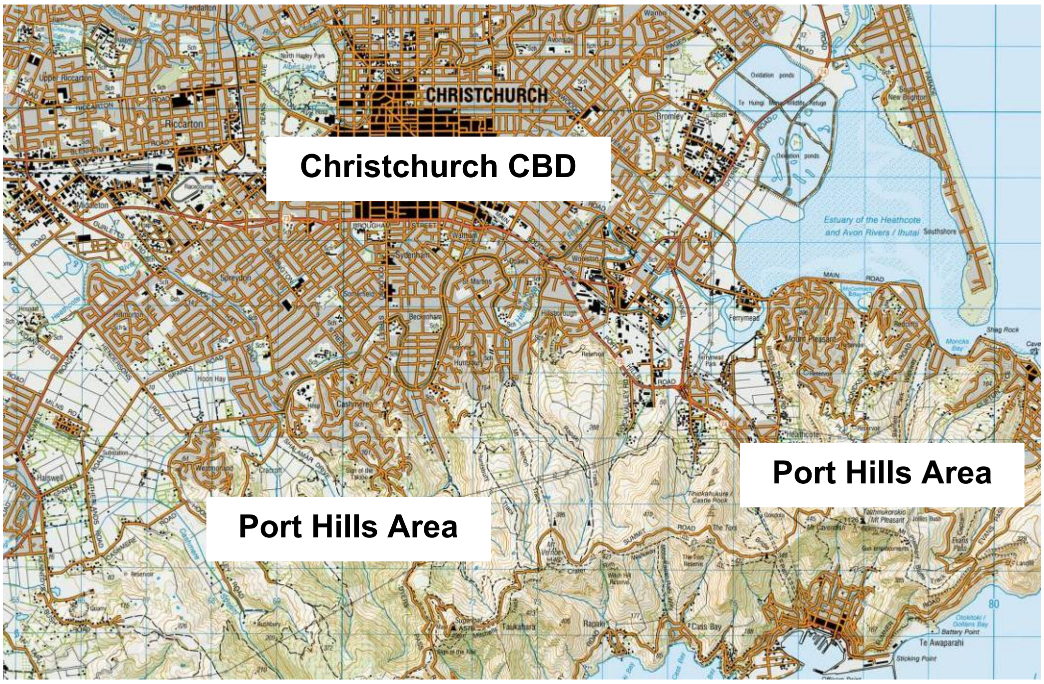

Figure 1. Map of south Christchurch and Port Hills area (source: LINZ)

2.2 Wall Geometry and Layout

The mesh reinforced gabion walls assessed by SCIRT varied in length, height and width and were generally constructed to support the roads around the Port Hills.

The following provides a summary of the mesh reinforced walls included in SCIRT's scope of work (i.e. Council or NZTA owned):

- Over 50 mesh reinforced gabion walls were visited for the purpose of assessing the damage, geometry and other characteristics.
- The height of the walls ranged from about one metre to a maximum of around 6m with the length of the walls ranging from several meters to over 200m, although typically the length did not exceed 50m.
- Almost every wall assessed was downslope of the road and built for the purpose of supporting the roadway during subdivision work.

The mesh reinforced walls are formed by pre-assembled gabion units (facing or front units) and double twisted, plastic coated wire mesh. The mesh panels are fixed to the underside of the gabion basket with high tensile clips to form a single unit and continuity between the gabion facing and mesh reinforcing.
The Maccaferri produced unit is shown below as Figure 2.

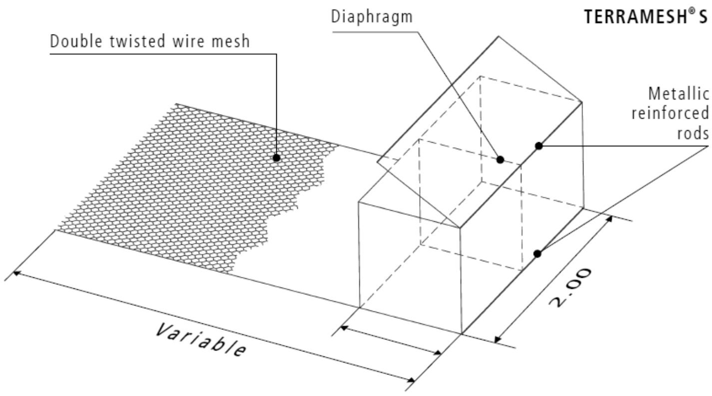

Figure 2. Mesh reinforced gabion unit (courtesy: Maccaferri NZ)

The gabion facing units were usually filled with locally sourced rounded greywacke cobbles and boulders or angular basalt fragments sourced from nearby quarries. The reinforced zone was formed using a gravelly soil such as the commonly used AP65 (all passing 65mm sieve) dug from the braided river channels of the Canterbury plains.

Units were placed one on top of the other to build the height of the wall. A typical wall detail is provided below as Figure 3.

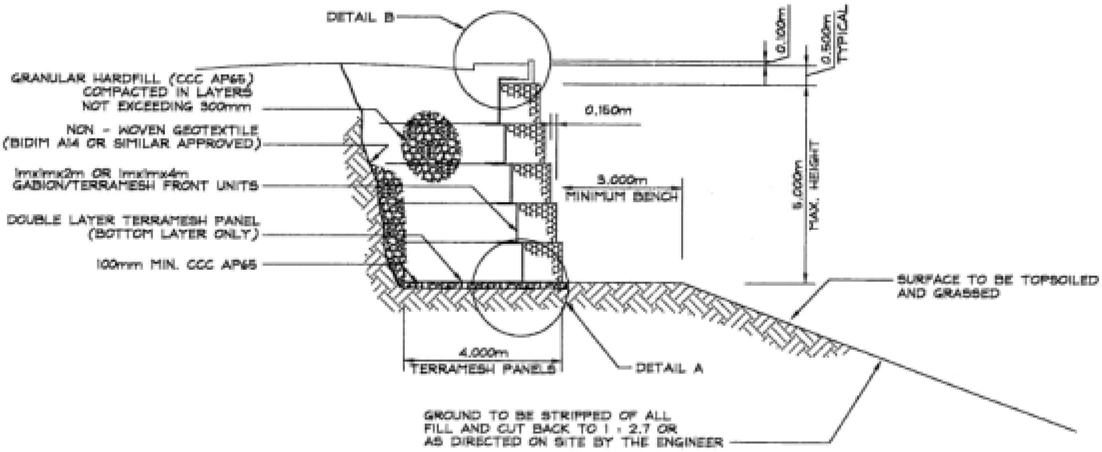

Figure 3. Typical mesh reinforced gabion wall detail (courtesy: geotech consulting limited)

2.3 Regional Geology

The geology of the Port Hills area is predominantly loess and loess colluvium soils overlying the variable rock profile of the Lyttelton and Mt Pleasant volcanic units. The loess soils of the Port Hills are generally sandy silt and silt, are highly erodible and vary in thickness across the hilly areas with the lower slopes usually having a greater thickness. The underlying volcanic rock was well incised and eroded prior to the windblown deposition and is formed by both pyroclastic and lava deposits. The geological and engineering properties of the loess soils have been well researched and documented by numerous authors.

The walls investigated were constructed to provide width for road construction and were usually supporting loess and loess colluvium soils. One of the favourable characteristics of the loess is its ability to stand vertical without support. However this phenomenon is likely a product of the soils suction and cementation and is easily reduced and even destroyed by increasing moisture in the soil. Examples of near vertical loess faces are shown below in Figure 4.

Figure 4. Near vertical loess faces, Alderson Avenue, Christchurch

3 OBSERVATION OF SEISMIC PERFORMANCE

3.1 SCIRT Work

The Christchurch area has been subjected to a number of large, violent earthquakes and thousands of aftershocks commencing with the 7.1 magnitude Darfield earthquake on 4 September 2010. The city had been quite lucky with the location and timing of the Darfield earthquake. The shallow magnitude 6.3 22 February 2011 earthquake struck at lunchtime within 10km of the city centre and caused injury, death and widespread damage. Shaking intensity in the city and surrounding areas was much greater than the September 2010 earthquake. The Christchurch strong motion sensor network recorded the ground motions during the events with some of the strongest motions ever recorded anywhere, including over twice the acceleration of gravity at the Heathcote Valley School at the base of the Port Hills area.

In the Port Hills area the presence of shallow rock can result in seismic waves which are largely unattenuated. The effects of ridges and other topographic features in the Port Hills can result in concentration of energy and more intense shaking and it is therefore quite difficult in the hilly areas to estimate the level of shaking which has occurred.

The concept phase at SCIRT required an assessment of the retaining walls including the level of damage and expected repair or rebuild methodology. The retaining walls were inspected by SCIRT geotechnical and structural engineers. The types of walls inspected varied and included timber king post walls, concrete crib walls and various gravity type structures. The following provides a general summary of the damage observed across the number of mesh reinforced walls inspected:

- All observations are of the external damage to the wall. The internal damage was not investigated.
- The damage commonly observed was translation and rotation of the upper row or rows of baskets. The amount of translation or rotation was generally proportional to the overall height of the wall, with up to about 500mm of translation observed in some cases. The bottom row or rows of baskets did not translate forward but often showed signs of bulging.
- The gabion facing baskets often displayed signs of distress including bulging and vertical compression of the baskets.
- The pavement, kerbing and landscaping above the wall was commonly damaged with the formation of tension cracks and separation of kerbing from the pavement.
- The horizontal offset between baskets was reduced and often the walls become vertical.
- Complete failure and rupturing of the gabion baskets was rare.

Several post-earthquake photos are shown in Figure 5 and Figure 6.

3.2 Previous Work

John Wood of John Wood Consulting assessed approximately 160 retaining walls around the Port Hills and flat urban areas of Christchurch following the 2010/2011 Canterbury Earthquakes (Wood 2012) – including 47 gabion type walls with no distinction between gabion gravity walls and gabion Terramesh® walls. The assessment concluded that the gabion walls performed poorly with 83% assigned to average or poor performance noting that the outward movement was caused by stretching of the baskets and rotation about the base of the wall. The paper discusses the contributions of the mass and flexibility of the wall to the deformations observed during the recent seismicity and also highlights that none of the gabion walls assessed had collapsed.

Figure 5. Damage of mesh gabion wall – Yelverton Place, Huntsbury

Figure 6. Damage of mesh gabion wall

4 WALL ANALYSIS

4.1 General

At SCIRT, each retaining wall required an assessment of the damage and a proposal for the level of repair through an understanding of the walls current stability. The results of the analysis were reported to the Client body and a decision was made as to whether the proposed works would be undertaken.

The method of assessing the wall stability of the mesh reinforced walls was similar to the methods available for Mechanically Stabilised Earth (MSE) walls and included an estimate of the external, internal and global stability.

The following sections outline the soil and seismic parameters used and provide a general description of the methods of analysis. A summary of the results is provided at the end of the section.

4.2 Soil Parameters

The mesh reinforced walls around the Port Hills typically retain cohesive soils of the Bank Peninsula loess. The soil parameters adopted are based on extensive work done by industry and Canterbury University. The table below summarises the soil parameters adopted for the loess soils for analysis.

Table 1: Adopted Soil Parameters for Port Hills loess

Parameter	**Value (range)**	**Unit**
Bulk unit weight	18	kN/m^3
Drained friction angle (ϕ')	30	°
Drained cohesion (c')	10 – 30	kPa
Undrained cohesion (c_u)	50+	kPa

The drained and undrained cohesion is highly dependent on the moisture content of the soil. The introduction of water to a mass of loess can drastically reduce the soils 'cohesion' and cause instability as commonly seen around the hills after prolonged rainfall. Work completed by a University of Canterbury Masters student in 1989 (McDowell 1989) shows the trend of cohesion and moisture content and is reproduced as Figure 7 below.

As shown in Figure 7 the dry, friable loess can exhibit 'cohesion' in excess of 150kPa. Once water is introduced the cohesion steadily drops to near saturation where the 'cohesion' becomes close to zero. Fortunately the soils retained by the mesh reinforced walls around the Port Hills are often protected by pavement and vegetation and excessive water infiltration into the soil is quite uncommon.

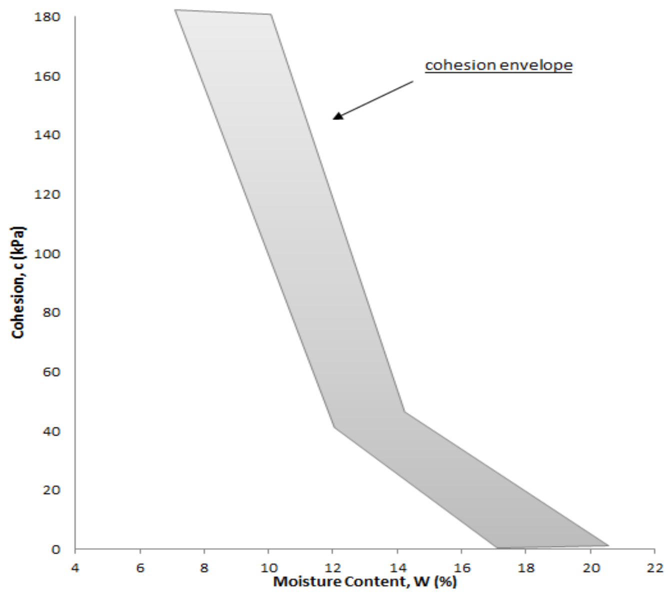

Figure 7. Cohesion and Friction Angle Trends (original: McDowell 1989, reproduced: M Lazzaro 2014)

4.3 Seismic Loading

The seismic case requires a design Peak Ground Acceleration (PGA) during an Ultimate Limit State (ULS) earthquake event. The PGA is derived from an assessment of seismicity at the site and is derived from the elastic site hazard spectrum for horizontal loading in accordance with NZS1170.5:2004.

Following the earthquake sequence of 2010/2011 the Christchurch City Council (CCC) prepared a design brief for the repair and rebuild of CCC owned retaining walls. The brief provided the Annual Probability of Exceedance (APE) for ULS for walls on various road types. The table is reproduced below.

Table 2: Seismic Design Annual Probabilities of Exceedance

Wall Type	**Annual Probability of Exceedance (APE) for ULS**
Walls located on Arterial Roads	1/1500
Wall located on Collector Roads	1/1000
Walls located on Local Roads	1/500
Walls located on Local Roads with less than 250vpd and less than 3m high	1/250

Using the APE values above and the method outlined in NZS1170.5:2004 the ULS elastic site hazard spectrum or PGA ranges from 0.4g for local road to 0.52g for collector roads in the Port Hills area.

Current design methods for MSE walls use a horizontal seismic co-efficient (k_h) to derive the seismic earth and inertia forces on the wall. The horizontal seismic co-efficient is related to the site PGA and is usually about 0.5 to 0.7 of the site PGA. A seismic co-efficient of between 0.3 and 0.4 was commonly used for the sites around the Port Hills.

4.4 External Stability

The purpose of the external stability check was to verify if under current conditions the wall was seismically stable. The results of this assessment would determine if any stabilising works would be required.

The external stability of a mesh reinforced gabion wall was undertaken using conventional methods developed for MSE walls. The stability assessment provides a Factor of Safety (FoS) against sliding, overturning and bearing capacity.

The seismic soils forces on the reinforced wall were estimated using the method of Mononobe-Okabe which is an extension of static Coulomb theory. The M-O method increases the static active force by applying an inertia force and flattening the critical failure surface of the active wedge. The M-O equation has been developed for purely cohesionless soils such as sands and gravels. An extension to the M-O equation to include the effects of cohesion has been developed by a number of researchers. In addition to the modified M-O equations, the use of General Limit Equilibrium (GLE) methods, such as Slope/W or SLIDE, can overcome some of the limitations of the standard M-O equation. The use of the GLE method for seismic active forces is detailed in the National Cooperative Highway Research Program (NCHRP) report number 611 (Transport Research Board 2008).

The extended M-O equation for c-ϕ soils and GLE method show that adding cohesion to the soil properties significantly reduces the seismic soil forces. Even for small cohesion values the seismic soils force can reduce to nothing for walls of heights of 4m or less. Adopting a small or even no seismic soil force is not unreasonable in the Port Hills loess considering the number of vertical loess slopes that remained vertical following the recent seismic shaking.

4.5 Internal Stability

A standard method for assessing the internal stability of mesh reinforced gabion walls is not available and the methods developed for MSE walls are most applicable for the analysis. The internal stability checks completed include pullout and reinforcement rupture. A pullout failure in a mesh reinforced wall will occur when the forces applied to the mesh exceed the resistance provided between the mesh and backfill (gravel in this case). A reinforcement rupture occurs when the applied mesh forces exceed the ultimate tensile capacity of the mesh reinforcement.

The figure below shows the two internal failure mechanisms for mesh reinforced walls.

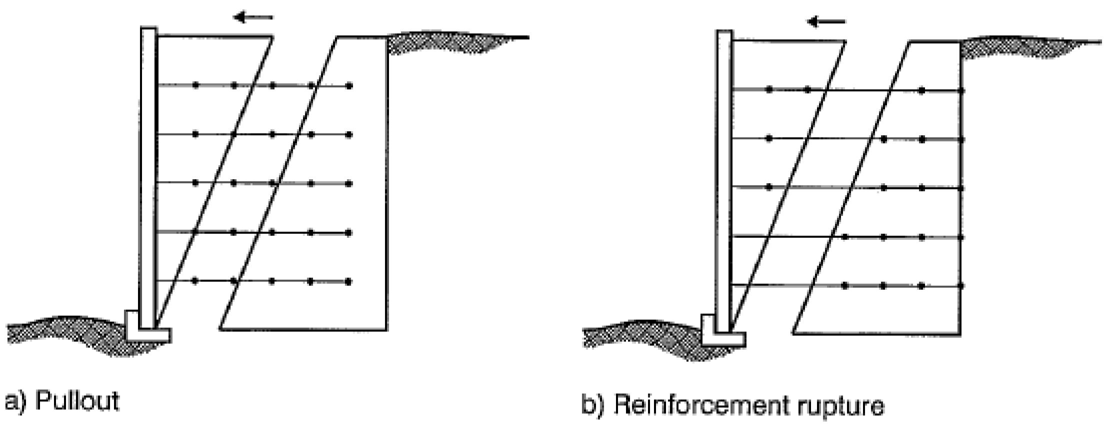

Figure 8. Internal Stability Modes of Failure (source: Transfund NZ Research Report 239 2003)

The interaction between the mesh panels and the backfill is dependent on the manufacturing of the mesh and its mechanical properties. Manufactures of the reinforcement material should be able to supply the mechanical and interaction parameters. The supplier of the mesh panels commonly used around the Port Hills (Maccaferri) provides the parameters through a technical notes series.

4.6 Summary of Analysis

Several of the key aspects of the analysis are detailed above and some of the key outcomes from analysing the mesh reinforced walls are as follows:

- The reinforced walls were assessed as being externally stable. This is based on adopting a cohesion value and having a reduced earth force behind the wall.
- Internal stability calculations (using methods for MSE walls) indicated the walls were either marginally or not internally stable and the walls were vulnerable to mesh pullout or reinforcement rupture. MSE walls are commonly built using vertical spacings between reinforcement of 0.5m or less. Reducing the mesh reinforcement to 0.5m increases the stability and may prevent or limit seismic deformations.

5 CONCLUSIONS

Mesh reinforced walls around the Port Hills typically performed quite well with only a small fraction showing significant deformation and displacement. Considering the level of shaking experienced around the Port Hills the walls appear to demonstrate a good resistance to earthquake activity, possibly do to the lack of earth force behind the wall and its flexibility.

Work by John Wood (Wood 2012) indicates that majority of the 47 walls assessed performed poorly with large deformations measured. However, the paper does mention that none of the walls assessed collapsed and that the deformation is due to the mass and flexibility of the structure and not the failure of elements of the wall (i.e. baskets or mesh panels).

The analysis completed indicates that the mesh reinforced walls are generally seismically stable and that walls constructed in the future may benefit from the reduction of spacing between mesh panels from 1m to 0.5m. This will increase the internal stability which is indicated to be lacking under seismic loading.

The majority of walls assessed were not upgraded with only the pavement, footpath and handrails repaired. In cases where repair of the wall was proposed one of the more cost effective methods for repair was to install ground anchors in the upper portion of the wall to provide resistance to future deformation.

6 ACKNOWLEDGEMENTS

Thank you to SCIRT for supporting the preparation of this paper and GHD for their support during my secondment at SCIRT.

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