SCIRT Rebuilding Infrastructure LEARNING LEGACY

Lessons learned from one of New Zealand's most challenging civil engineering projects: rebuilding the earthquake damaged pipes, roads, bridges and retaining walls in the city of Christchurch 2011 - 2016.

Observed Earthquake Damage to Christchurch City Council Owned Retaining Walls and the Repair Solutions Developed

Story: Retaining Wall Design Solutions

Theme: Design

A paper which outlines the observed damage to Christchurch City Council owned retaining walls and the repair solutions developed.

Programme funded by

Christchurch City Council

New Zealand Government

city care Our people. Making it work.

Downer Relationships creating success

Fulton Hogan

McCONNELL DOWELL CREATIVE CONSTRUCTION

Fletcher

Programme funded by
Christchurch City Council
New Zealand Government

6th International Conference on Earthquake Geotechnical Engineering
1-4 November 2015
Christchurch, New Zealand

Observed Earthquake Damage to Christchurch City Council Owned Retaining Walls and the Repair Solutions Developed

L. Kendal Riches[1]

ABSTRACT

The Stronger Christchurch Infrastructure Rebuild Team (SCIRT) was established to repair Council owned horizontal infrastructure, including a significant number of retaining walls, following the earthquakes in 2010 and 2011. As part of the work conducted by SCIRT more than 2875 retaining walls have been assessed for damage with 440 of these remaining in SCIRT's scope. The walls in scope received further inspection, followed by the design of either refurbishment or rebuild solutions for those that required it. This paper presents a summary of how different wall types were observed to have performed under seismic loading and it discusses a number of the repair solutions designed and constructed at SCIRT.

Introduction

The earthquakes in 2010 and 2011 caused significant damage to retaining walls in Christchurch. This included many Council owned retaining walls which protect both the road network and other infrastructure. The Stronger Christchurch Infrastructure Rebuild Team (SCIRT) was established to repair the Council owned horizontal infrastructure, including a significant number of retaining walls. The author of this paper is on secondment to SCIRT and has been involved since 2011 with the design of rebuild and repair solutions for Council owned retaining walls.

The Stronger Christchurch Infrastructure Rebuild Team

SCIRT is an alliance of three client organisations and five delivery teams. They are Christchurch City Council, Canterbury Earthquake Recovery Authority (CERA) and New Zealand Transport Agency along with City Care, Downer, Fulton Hogan, McConnell Dowell and Fletchers. SCIRT was established in September 2011.

With regard to retaining walls, 2875 assets have been assessed with 440 of these being within SCIRT's scope. The walls in scope have a total length of more than 15km and the range of damage is from walls requiring only minor patch repairs to those which suffered complete collapse. Wall types include crib walls, timber pole walls, gabion walls, stone facings and mass concrete walls. In addition some assets which are not technically walls are also within scope. This has included rock stabilisation projects and the protection of steep slopes. Rebuilding all the infrastructure with in SCIRT scope is likely to cost around $2 billion dollars.

[1]L. Kendal Riches, Aurecon, Christchurch, New Zealand, louise.kendalriches@aurecongroup.com

Wall Damage

Observations following the earthquakes indicate that some wall types have performed better than others. However for all wall types workmanship and design quality will have played a significant role in the fate of the walls. In addition it is likely that the orientation of the wall with regard to the direction earthquake acceleration will have determined which walls were more or less damaged.

Crib Walls

Crib walls developed a poor reputation because of the performance of some walls in the earthquakes. There is little holding the crib units together except gravity, so under vertical accelerations the crib units were able to shake apart and catastrophic collapse of these walls was not uncommon. An example is shown in Figure 1. Other walls were less damaged, but significant volumes of fill were lost from the wall and this reduced the stability of the structure as shown in Figure 2. The tendency to use rounded river run as fill for the walls was particularly detrimental because these rounded stones were easily mobilised during shaking and lost through the front of the wall.

Figure 1. An example of a collapsed crib wall

Figure 2. A crib wall showing bulging and loss of fill

There are many reasons why some crib walls performed better than others. Walls which were constrained by concrete encasing the lower crib units and concrete capping beams can be seen to have sustained less damage. In addition highly vegetated walls in many places performed better and this could be attributed to the planting holding the structure together.

Timber crib walls generally were seen to have performed better that concrete crib walls. This may be because the timber structure is more flexible, but in many cases it may be due to the nailed connections installed between the crib units which added to the stability.

Timber Pole Walls

Both anchored and unanchored timber pole walls are common in Christchurch. The damage to these walls tended to be to individual elements or points or weakness. For example outside corners were often vulnerable, like the example shown in Figure 3, and lagging could pop out from behind the vertical poles. In other walls individual poles may splinter. However collapse of these walls was not routinely observed. One particular phenomenon was where anchors have small plates on the face of the timber poles and the shaking has caused the poles to move, but the anchors have remained in place. This often resulted in the anchor plate punching into the pole, as shown in Figure 4, or else the anchor head failing. Elsewhere walls may have deformed by moving forward during shaking and then the fill behind the wall has settled. This prevents the wall from returning to its original position and results in ground deformation behind the wall.

Figure 3. Damage to a vulnerable corner of a timber pole wall

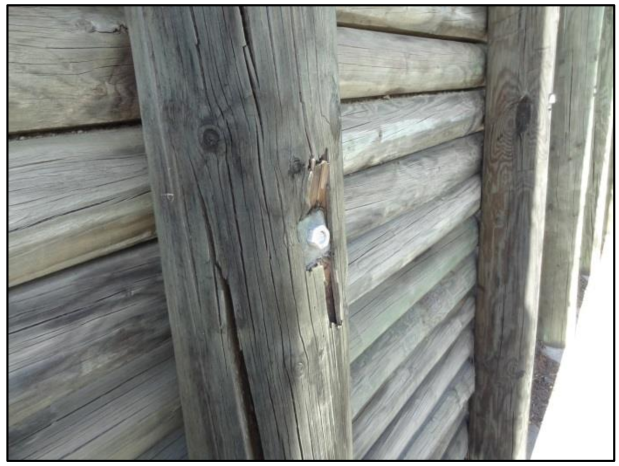

Figure 4. Damage around the anchor head of a timber pole wall

Gabion Walls

Gabion baskets are inherently flexible structures. Therefore during earthquake loading these walls tended to deform as can be seen in Figure 5. Generally baskets did not rupture and in the majority of cases the roads and infrastructure behind the walls remained serviceable, however deformation in both the wall a surface behind the wall could be considerable. Often where a road or footpath was above the wall, cracking could be observed in line with the back of the baskets. An example of this can be seen in Figure 6. Baskets filled with rounded river run or else loosely packed stone of any type often suffered greater deformation.

Figure 5. A badly deformed gabion wall

Figure 6. Footpath above a gabion wall showing cracking

Concrete Walls

The performance of concrete walls could often be attributed to the pre-earthquake condition of the structure. For example a poorly reinforced or badly maintained wall would be more likely to be damaged. Cracking was usually at points of weakness and often resulted in excess rotation, rather than collapse as shown in Figure 7. One wall which performed well had been constructed as part of a hospital complex c.1900. Despite the age of the wall it showed no damage, except to a parapet which retained no fill. This parapet cracked as shown in Figure 8.

Figure 7. A typically damaged concrete retaining wall

Figure 8. A concrete retaining wall c.1900 showing little damage

Stone Walls

There are many stone walls in Christchurch. Typically these were at least 100 years old and were not engineered. It was not uncommon for these walls to have suffered complete collapse as shown in Figure 9. In fact many of the stone walls act as a facing to protect the loess slope behind. So it was not uncommon that when the wall collapsed that the loess face remained stable. This can be seen at the top of the wall shown in Figure 10. While these walls were typically in the region of 100 years old, those which had been rebuilt more recently did perform better. This may be due to younger mortar having greater flexibility.

Figure 9. A completely collapsed stone wall

Figure 10. A partially collapsed stone wall showing typical damage

Refurbishment Solutions

Many different solutions were designed and constructed on a site specific basis, however some of the more common refurbishment solutions are described here.

Soil Nail Repair for Crib Walls

The analysis of a soil nail wall considers the nails to form a solid mass of soil which can resist soil and earthquake loading. In this case the existing crib wall is also considered to be part of this mass. An example of this can be seen in Figures 11 and 12.

Figure 11. Damaged crib wall due for refurbishment as a soil nail wall

Figure 12. A soil nail wall refurbishment with shotcrete facing

In order to install soil nails through this crib wall the nails had to be drilled through a PVC casing through the crib units. Ideally the angle of the nails would match that of the crib units so as they do not need to be drilled through the rear stretchers, but this location had shallow buried services behind the wall which meant that the anchors had to be steeper and therefore extra drilling was necessary. A shotcrete facing was applied as the final face and this would hold in place the existing crib fill in the event of a future earthquake and maintain the mass of the structure.

Crib Wall Repairs using Vegetation

Many heavily vegetated crib walls performed well under earthquake loading, even when adjacent un-vegetated walls were badly damaged. So, where a crib wall was found to be stable, but was at risk of further loss of fill, a repair methodology was considered which improved the condition of the wall by adding vegetation. This was seen to have many benefits including cost, improving aesthetics and the biodiversity gains. However ultimately this option was not developed further at SCIRT because there would be a delay in the planting offering the required support plus in the event of a fire the stability would be reduced.

Minor Crib Wall Repairs

Some walls had minor damage to individual crib units and were at risk of loss of fill. These could be repaired by adding something to the front of the wall to block the front of the crib units. Options developed for this included cast in place concrete or geotextile strips. An example using concrete is shown in Figure 13. This would ensure the stability of the wall. Where the front of the wall became a solid face, drainage weep holes were also included in the design.

Figure 13. A crib wall with minor repairs to prevent future loss of fill

Timber Pole Walls

Typically timber pole walls needed little repair and in some instances it was sufficient to replace damaged elements on a like for like basis. Where, for example, corner sections had been damaged additional poles or anchors were added.

Anchoring of Gabion Baskets

Often the most economical solution was to patch the road behind the wall and assume that in future earthquake events more deformation will occur. However adding anchors could provide a more resilient solution.

The anchored solution, shown in Figure 14, is designed to prevent further deformation under future seismic loading. In this case a PFC waling will span between anchors on the face of the wall. Drilling anchors through the gabion baskets was achievable, but there were some particular lessons learnt:

- Drilling of the anchors was possible and while the basket mesh at the rear of the basket was awkward to penetrate, it could be done.
- During grouting there is no grout recovery and therefore there is less certainty regarding how complete the grout is. Therefore all anchors were load tested.
- The testing regime needs careful consideration because measuring deflection was challenging because the baskets did not provide the required reaction for the jacking during testing.
- The gabion baskets were damaged by the plate used in testing. Therefore using a textile layer or other protection under the plate is recommended.

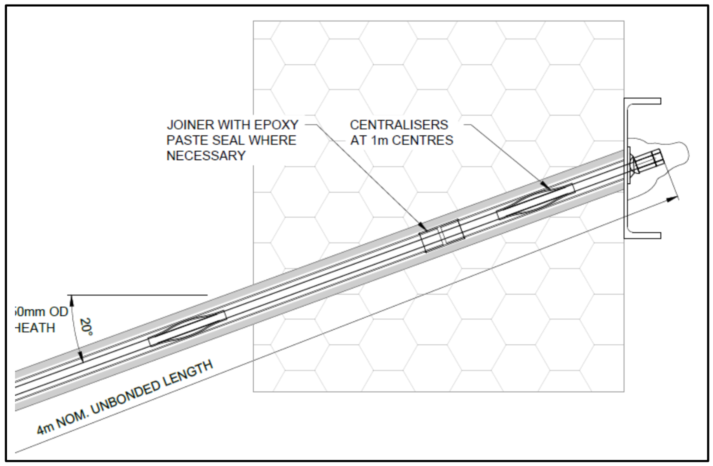

Figure 14. Sketch showing arrangement of anchors through gabion baskets

Anchors through Stone Walls

Where stone walls were only marginally damaged often cracks could be repointed to restore the wall. However some walls, especially those of a significant height, required additional support in the form of anchors.

This method of refurbishment has been utilised in particular where the damaged retaining walls are of special significance in the area and it is advantageous that the original wall remains visible. This method allows the wall to stay in place and the anchors strengthen the existing structure. The anchors require large plates to support adjacent stones. While this will not transfer the load from every block to the anchors, in the event of a future earthquake, it will stiffen the system and provide increased resilience to the damaged wall. To assist in this the wall can also be repointed and a concrete capping beam constructed. Our designs included recessed anchor heads to ensure sharp elements did not protrude from the wall onto footpaths.

Conclusion

A large number of damaged retaining walls have been assessed by SCIRT. Some of these required complete rebuild, however it was possible to achieve cost savings and design more sustainable solutions by repairing or refurbishing some walls. Often the most efficient way of doing this was to add anchors to increase the stability of the structure under earthquake loading.

Acknowledgments

I would like to acknowledge my colleagues Ian Froggatt, Aurecon, and Annalisa Contawe, Jacobs, for their project solutions which feature in this paper. I would also like to acknowledge Aurecon, my employer while I was on secondment to SCIRT.