Retaining Wellington's Roads, Chaytor St Case Study

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Roads of Wellington city are often carved around steep greywacke rock terrain. Geotechnical engineers are faced with challenges to provide cost-effective solutions to retain the associated sidling fills, which often have marginal stability. This paper presents a case study of a tied back, concrete palisade wall that was constructed to retain a section of Chaytor St in Wellington.

The project was challenging given the significant depth of fill, site constraints and high seismic design accelerations. Significant effort was made during the development of the design to provide a cost effective solution that fulfilled both the requirements of the New Zealand Loadings Standard and the requirements of the client. The design that was adopted relied on the anchors resisting the majority of lateral load and avoided the more traditional approach of resisting part of the lateral loads through embedment of the wall piles into the underlying rock. The paper discusses the design philosophy of the tied back concrete palisade wall.

INTRODUCTION

During mid 2002 signs of creep and instability was evident by cracking and subsidence in the Chaytor Street carriageway.

Wellington City Council, the local road controlling authority, engaged Tonkin & Taylor Ltd to investigate the stability of sections of Chaytor St and then later design and supervise the construction of retaining walls to stabilise the outer edge of the carriageway. This paper discusses one particular wall that was constructed to retain part of the Chaytor St carriageway.

There were a number of design issues that provided a challenge in developing a cost-effective solution for the Chaytor St wall, these included:

- Significant depth of loose fill
- Site constraints
- High seismic design accelerations
- Steep topography
- 2m widening of the road for a bus lane

A number of retaining solutions were investigated however it was found that the most cost-effective solution for the site was the construction of a tied-back, concrete palisade wall. The constructed wall is shown in Figure 1.

The solution relied on the anchors resisting the majority of the lateral load. This was an alternative to the more traditional approach of resisting part of the lateral load through embedment of the piles into the underlying rock.

The preferred solution was developed in an interactive approach with the client. A variety of solutions, with differing levels of risk were presented to the client along with construction cost estimates. This allowed the client to make an informed decision based on the funding available and the level of risk that they were willing to accept. This approach is particularly important to authorities that need to prioritise work and ensure that they gain the maximum benefit from their limited budgets.

Figure 1. Completed Tied-Back Concrete Palisade Retaining Wall.

SITE DESCRIPTION

Chaytor St is a principal arterial route linking the largest Wellington suburb of Karori to Wellington city centre. The road has been constructed as a sidling cut to fill, where material cut from the inside of the carriageway was used to fill the outside of the carriageway.

Chaytor St traverses a steep slope where the existing ground below the wall slopes away at up to 50 degrees. Below the road there are signs of historic instabilities.

During mid 2002 signs of creep and instability became evident in cracking and slumping of the carriageway. The existing wall was in a poor condition and was providing little support to the carriageway. On the basis

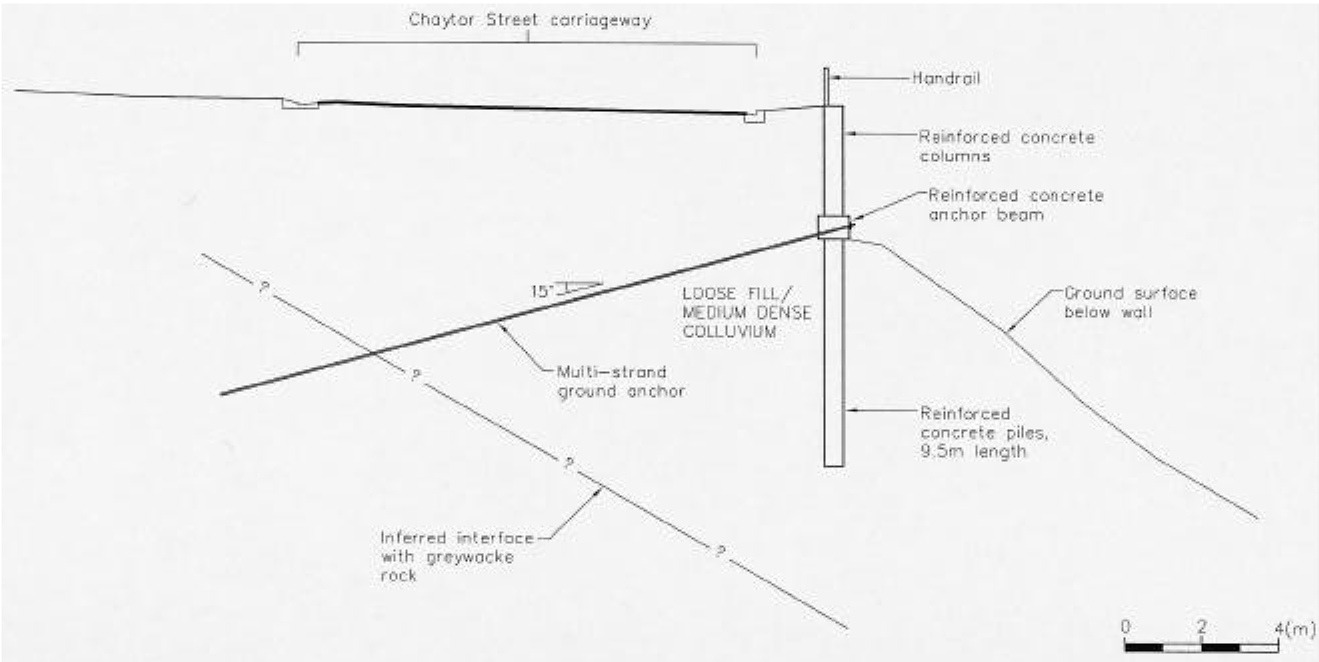

Figure 2. Typical Retaining Wall Detail.

of Tonkin & Taylor's recommendations Wellington City Council decided that the wall would be replaced over a 50m length.

SUBSURFACE CONDITIONS

An investigation comprising boreholes, cone penetrometer tests and geological logging of rock exposures was undertaken by Tonkin & Taylor Ltd. The investigations indicated that the proposed wall traversed an infilled gully. There was 15m of loose fill underlying the footpath at the centre of the valley alignment. The fill was underlain by approximately 3m of colluvium over greywacke rock.

A section through the centre of the infilled gully is shown on Figure 2.

SITE CONSTRAINTS

There were a number of site constraints that had to be assessed and allowed for during design. These included:

- The steep slope below the wall.
- The significant depth of loose fill.
- The distance behind the wall to greywacke rock. This meant that some anchors had to extend 20m from the wall through loose fill to encounter rock.
- Minimising the impact on traffic. Chaytor St carries a significant amount of traffic and it was necessary to keep both lanes open during construction.
- Minimising the impact on the local residential community.
- Widening of the road for a bus lane.

SEISMIC LOADING

The active Wellington fault passes within 200m of the site and dominates the seismic hazard for the site. The New Zealand Loadings Standard NZS4203:1992 requires that the wall be designed so that it remains stable following a 450-year return period earthquake. This is equivalent to a movement on the Wellington fault of M7.6 magnitude. Such a seismic event is expected to impose peak accelerations of up to 0.5g. In addition to the requirements of the New Zealand Loadings Standard it was agreed with the client that we would also assess the potential deformation of the wall and carriageway following a 450-year return period earthquake.

STABILITY MODELLING

The majority of the stability modelling was carried out using the finite element, soil modelling program Plaxis.

A site model was developed from the investigation information, topographical data and soil parameters obtained through back analysis of the previous retaining wall and observed instabilities on the existing fill slopes.

It was assumed that the existing slope at the wall location would have a factor of safety in the order of 1.15 under static load conditions. This is consistent with the observed creep defomation observed at the site.

The soil parameters obtained from the back analysis of the previous slopes were then used in the design and stability modelling of the new wall.

A critical component of the design process was modelling the behaviour of the slope below the wall under ultimate limit state conditions. The static factor of safety of a slip below the wall was far less than the required 1.5 and the return period of a seismic failure was less than a 100-year event. Therefore the potential depth of material that could slip away below the wall was assessed for both the static and seismic ultimate limit state cases. The ground model was then modified by removing that depth of soil that was unlikely to provide passive support to the structure under the ultimate limit state case.

The stability modelling of the wall showed that the seismic case was likely to be the critical load case. The most probable failure under the seismic load case was a large rotational failure. A typical plaxis output is shown in Figure 3. The large rotational failure was one of the main considerations that influenced the selection of the wall design. To achieve a reasonable level of seismic stability the wall needed to be embedded below potential failure surfaces and anchors needed to develop load/bond beyond the failure surface.

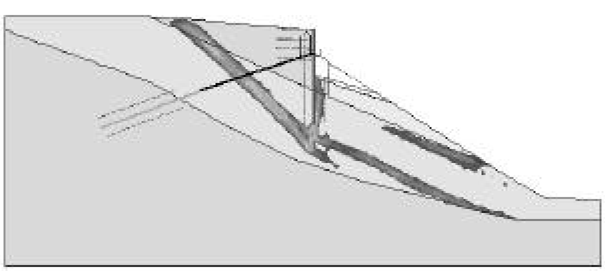

Figure 3. Plaxis Strain Modelling Output for a 450-year Return Period Earthquake (Ultimate Limit State Seismic Case).

During design optimisation it became apparent that the cost of a wall, where permanent displacement would be negligible following a 450-year seismic event, would be prohibitively expensive. Therefore alternative solutions were also presented to the client where the wall remained stable following a 450-year seismic event but minor displacements were expected. These solutions satisfied the New Zealand Loadings Standard but were not as robust, however the estimated construction cost of the chosen design was half of that for a solution where negligible permanent displacements were expected.

DEVELOPMENT OF DESIGN

In the early stages of the design process many concept designs were considered for the retaining wall including; a gravity wall, a soil nail wall and a concrete palisade wall with tie back anchors extending to either greywacke rock or deadman. The level of risk, construction cost, impact on traffic and the impact on the residential community were then considered in the development of the final design.

The option of a gravity wall such as a geogrid reinforced fill embankment was considered as the fill at the site was reasonably granular in nature and would be suitable for compacted fill. However this option would have required substantial earthworks to found beyond potential failure surfaces under the seismic load case. The option would also have caused significant impact on existing services, traffic flow and the residential community.

Stabilising the slope through the use of soil nails was considered. This solution required the full length of slope to be nailed to provide adequate stability. Soil nails would need to be 10 to 15m in length to extend beyond the potential seismic failure surface. The number, length and installation options (through granular fill) did not make this solution cost effective.

A tie-back concrete palisade wall with multi-strand anchors extending into rock was chosen as the most cost effective solution. The wall had a clear retained height of 3.5m and piles at 1.5m centres extending 9.5m below the base of the anchor beam. The main benefits of this design over the other concept designs are:

- The wall piles have sufficient embedment to resist the potential global rotational failure under seismic shaking;
- Minimal impact on the traffic and residential community during construction;
- Minimal impact on services within the carriageway due to reduced amount of earthworks;
- The use of multi-strand anchors over the more traditional bar anchors was adopted to space anchors at greater centres, significantly reducing the total length of drilling required;
- The cost of the wall was significantly less than other solutions providing a similar level of stability improvement.

With this solution the wall is expected to remain stable following a 450-year return period earthquake with displacements in the order of 200 to 300mm. Following the earthquake the road is likely to be passable and it is anticipated that the earthworks required to level out the seismic displacements are likely to be relatively quick and low cost. Furthermore the seismic hazard is comparable to other hazards along the road, such as rockfalls, that would need to be cleared prior to the road reopening.

In order to prevent displacements following a 450-year event the piles would need to be embedded in the underlying rock. Given the level of risk and low cost of remedial works following the 450-year seismic event the solution with the piles not extending to the underlying rock proved to be the most cost effective.

CONCLUSIONS

Geotechnical Engineers are faced with challenges to provide cost effective solutions to retain the roads of Wellington city that are often carved around steep greywacke rock terrain. The associated sidling fills are often marginally stable and the design of retaining solutions can be complex.

This paper presented a case study of a retaining wall along Chaytor Street, Wellington. An interactive approach with the client was successful in providing a cost effective solution to the client.

The case study shows a project where a variety of solutions were presented to the client. A clear description and estimate of risk was presented for each option along with the expected construction cost. This allowed the client to prioritise the wall against other works and make an informed decision on the most cost-effective option to Wellington City Council.

The case study is an example of a project where the final solution was not the most robust solution but proved to be the most cost-effective. The wall design satisfied the requirements of the New Zealand Loadings standard by remaining stable under the ultimate limit state cases. However by accepting displacements under the maximum design earthquake, while still ensuring that the wall remained stable, the cost of the project was half that of the more typical robust solution of embedding the piles into the underlying rock.