Design of the Counterfort Retaining Wall on the Barangaroo Headland Park Project, Sydney

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ABSTRACT: The paper presents an innovative design of the reinforced concrete counterfort retaining wall as part of the Barangaroo Headland Park project in Sydney. The counterfort wall is required to retain up to 18.5m of fill and support the roof of the underground Future Cultural Space building. The design solution comprises buttresses at 6 m centres supported on a narrow 5.5 m wide base slab with prestressed ground anchors located at the top of the wall for global stability. The front wall is continuous without movement joints over approximately 155m length. The overall stability of the wall system is provided by a combination of gravitational soil force acting on the base slab and an additional capacity by the ground anchors. A three dimensional Plaxis model was developed to assess the soil-structure interaction. Results obtained from the soil-structure interaction model demonstrated that the active soil stress state would be developed because the narrow base slab allows the wall to tilt. To control the displacement at top of the wall, the ground anchors are prestressed to a set lock-off load and the wall is built with a 1 horizontal to 120 vertical rake into the backfill. A detailed discussion of the design aspects of the counterfort retaining wall is provided herein.

KEY WORDS: counterfort retaining wall; ground anchors; soil-structure interaction; Plaxis; prestressed.

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1 INTRODUCTION

Barangaroo Headland Park project is part of the overall six billion-dollar redevelopment project of Barangaroo, a twenty-two hectare of Sydney’s harbour foreshore located on the western edge of Sydney’s CBD. Currently under construction, the Project will transform one of Sydney’s oldest industrial sites into a stunning six-hectare foreshore naturalistic parkland, which is formed by filling the existing site to a maximum height of 18.5m. The completed Headland Park will feature a naturalistic pre-1836 sandstone shoreline, native vegetation, bush walks, a new harbour cove and a new cultural centre built within the headland. The location of the Barangaroo Headland Park site is shown in Figure 1.

In June 2012, Baulderstone Pty Ltd (now Lendlease) was awarded the design and construct contract valued at approximately 163 million dollars by the Barangaroo Delivery Authority to build the Headland Park. Subsequently, Aurecon was appointed the Project lead civil and structural engineering designer as part of the Baulderstone design and construct team.

During the tender phase of the project, Aurecon collaborated with the construction team from Baulderstone to challenge the reference design and to develop alternative design solutions, taking into account Baulderstone’s construction strategy and preferred construction methods. This includes the design development of a reinforced concrete counterfort retaining wall solution to replace a reinforced soil wall, which was proposed in the reference design.

The retaining wall forms the boundary to the western edge of the Future Cultural Space. The wall is approximately 155m in length and it has dual functions, namely:

- It retains the build-up fill to forms the physical barrier between the fill and the Future Cultural Space. Maximum retained height is 18.5m from the top of the base slab.
- It provides support along the western edge to the roof and two future floors at RL8.5 and RL13.0 of the Future Cultural Space, respectively.

The Barangaroo Headland Park Project is well suited to adopting the reinforced concrete counterfort retaining wall solution for the following reasons:

- It maximises the general fill utilised behind the wall given the amount of general fill available on site.
- A concrete wall provides a more impenetrable barrier to water ingress and odours when compared to alternative reinforced soil wall system.
- The wall provides vertical support to the Cultural Space roof and lateral support (western direction only) and longitudinal support in the north-south direction to the roof during a design earthquake event.
- The wall will provide a fixing point for supporting the western edge of any floors that may be constructed in the future without the need for additional structural supports along the Future Cultural Space western edge.

As a result, the reinforced counterfort retaining wall solution was selected as the final design option.

![Figure 1: Barangaroo Headland Park Project Site Location](image1)

![Figure 2: Project site plan](image2)
In addition, an earthquake assessment of the counterfort retaining wall was undertaken in accordance with Appendix I, AS 4678-2002 Earth-retaining structure [2] because this standard provides a more detailed approach to earthquake design of retaining walls than its AS5100 counterpart.

3 DESIGN LOADINGS

3.1 SOIL AND SUPERIMPOSED LOADINGS

The main loading on the counterfort retaining wall is from the lateral earth pressure of the retained fill. This pressure was derived from the adopted soil parameters, namely:
- internal friction angle \( \phi = 28^\circ \)
- soil density \( \gamma_s = 18 \text{ kN/m}^3 \)

A soil-structural interaction study was undertaken using PLAXIS 3D software to determine the corresponding stress state of the soil and hence the appropriate lateral earth pressure coefficient to be used in the structural design. Detailed discussion of the soil-structure interaction assessment is provided in Section 9.2.

In addition to loadings from the general fill, superimposed loadings were also considered in the design of the counterfort wall in accordance with the project design brief, including:
- Public Space live loads: 7.5kPa
- Additional superimposed surcharge: 2.0 kPa to account for landscape planting

Loadings due to construction activities were limited to 10kPa. Any specific construction activities, which are likely to exceed this allowance, shall be assessed by the designer before being undertaken.

In addition, to minimise the compaction pressure on the wall, restriction on the use of compacting equipment is placed in the zone of 6m width immediately behind the wall.

3.2 FUTURE CULTURAL SPACE BUILDING ROOF AND FUTURE FLOOR LOADING ALLOWANCE

The counterfort retaining wall provides support to the roof along the western edge of the of the Future Cultural Space building via a slip joint detail between the sill beam and the soffit of the roof deck. Via this detail, the counterfort wall would not be taking any lateral actions induced by movements of the roof deck in the outward direction due to either creep and shrinkage or an earthquake event. In an earthquake event in the east or west direction, the roof deck will be ‘floated’ but bounded by the retaining wall supported by the soil mass on the western side and the rock ledge on the eastern side of the Future Cultural Space building. Hence, loading allowance on the retaining wall from the roof structure is only in the vertical direction, taking into account tributary span between the wall and the adjacent row of columns.

The counterfort retaining wall also provides support to two future floors at RL8.5 and RL13.0, respectively. It was assumed that these future floors will be connected to the wall such that no outward lateral loads will be imposed on the wall. Again, loading allowance for the two future floors on the counterfort retaining wall is only in the vertical direction. The loading allowance and assumption of the interaction between the wall and the future floors are clearly stated on the design drawings.

4 EARTHQUAKE ASSESSMENT

Assessment of the earthquake design category (EDC) was undertaken in accordance with AS4678-2002 Earth-retaining structures, taking into accounts the newly updated requirements from AS1170.4-2007 Earthquake actions in Australia [3]. The seismic design parameters for the counterfort retaining wall were determined as follows:
- Hazard Factor \( Z = 0.08 \)
- Probability Factor \( k_p = 1.8 \)
- Site factor \( S = 0.67 \)
- Structural Classification \( C \)

Based on the above parameters, the EDC was determined to be \( C_p \). For this EDC, an Ultimate Limit State load factor of 1.5 applied to the soil pressure is deemed adequate to account for the increase in earth pressure in a design earthquake event on the wall.

5 DESIGN FOR DURABILITY

As per the Design Brief, the buried counterfort retaining wall will have a design life of 100 years. A durability assessment was undertaken in accordance with Section 4 of AS5100.5 to determine the specific durability requirements for the counterfort retaining wall.
The exposure classification for concrete elements of the counterfort retaining wall was assessed to be as follows:

- B2 exposure classification for the back face of the wall, the buttresses and the base slab, which are in contact with the fill material.
- B1 exposure classification for the front face of the wall, which will be enclosed inside the Future Cultural Space building.

Concrete strength of 50MPa and a cover of 45mm were adopted to meet the above specific durability requirements.

In order to maximise construction speed and reduce future maintenance, the design of the counterfort wall includes no movement joints over its entire 155m length. Concrete cracking due to early thermal and long-term shrinkage and creep effects is controlled by a combination of the followings:

- A triple blended low heat and low shrinkage concrete mix.
- Adequate reinforcement. Clause 11.6.2. AS5100 states that minimum horizontal reinforcement ratio to control the long-term creep and shrinkage cracks in a fully restrained wall is 0.8%. The amount of horizontal reinforcement provided for ultimate structural strength of the wall far exceeds this requirement. In addition, extra reinforcement was provided in the wall at close to the base and at locations where the wall changes in thickness, and therefore exhibits different shrinkage behaviour.
- Casting sequence of the wall.

It was proposed that during construction concrete cracks due to the early thermal effects in the base slab and the wall will be mapped and repaired with cementitious bandages as per the Project Specification. To date, the construction of the counterfort retaining wall has been well progressed and there have been no reported issues with cracking in the wall.

6 GROUND CONDITIONS

Ground investigation and studies have been undertaken by various consultants engaged by the Barangaroo Delivery Authority prior to Baulderstone being commissioned to undertake the construction works. The ground investigation data provided an overview of the historic development of the site and the underlying ground and groundwater conditions. The various ground investigation reports identified variable materials on the site, but generally comprising the following strata:

- Made Ground
- Alluvium (occasional)
- Sandstone Bedrock (Hawkesbury Sandstone)

The previous studies were utilised for the assessment of the inferred ground conditions along the length of the proposed counterfort retaining wall. These borehole logs drilled to approximately 12m (from a ground surface level at RL +3.0mAHD) indicate that the ground conditions along the proposed alignment of the counterfort retaining wall are characterised by a mantle of Made Ground overlying by Sandstone Bedrock. Alluvium was not found to occur along this alignment.

The Made Ground was encountered from surface to a minimum depth of 0.84m and a maximum depth of 1.23m at all the evaluated boreholes.

According to the report on the Geology of the Barangaroo Development Area by Douglas Partners, the Sandstone Bedrock contains the following three sub-units:

- Layer 1 - Medium to coarse grained, banded and cross bedded sandstone with significant quartz over growth leading to ‘cementing’ together of many of the quartz grains.
- Layer 2 - Fine to medium grained, massive sandstone (“Yellow Block”)
- Layer 3 - Medium grained, banded and cross bedded sandstone

Point load test results indicated that the bedrock would be classified as Medium to High strength rock (according to AS1726 rock strength classification). Based on an assessment using the classification of Pells et al [5] the Sandstone Bedrock can be classified as Class III directly below the Made Ground to Class II at approximately RL-1.0 to -1.5mAHD and Class I below approximately RL-4.0m

7 DESIGN DEVELOPMENT

A number of design options of the counterfort retaining wall were investigated in collaboration with Baulderstone to optimise the construction speed and costs, taking into accounts Baulderstone preferred methods of construction.

7.1 CONCEPT DESIGN

At this stage, the reinforced counterfort wall solution comprised an L-shaped base slab and wall section tied together by sloping buttresses. The sloping buttresses were spaced at 6 m centres and 750mm in width. The front wall varied in depth in sections, namely:

- first 5m lift from top of base slab = 750mm
- second 5m lift = 600mm
- remaining section =400 mm.

The total base slab width was 7.2m i.e base slab width to retained height ratio is 0.47. The base slab was 750mm thick including an 1m wide front toe and 750mm deep by 1000mm wide shear key at the back.

Because the base slab width to retained height was small for conventional gravity retaining system, additional stability capacities were provided by vertical ground anchors comprising 27x15.2 super grade strands, minimum breaking load of 250KN per strand. These anchors were spaced at every buttress and positioned...
towards the end of the base slab to form a lever arm of 6.5m to the overturning point at the front toe.

There was a sill beam on top of the wall to provide support for the roof deck. The sill beam also provided stiffness to the front wall slab. The counterfort retaining wall solution at concept design stage is presented in Figure 4.

In addition, the base slab was extended to a total width of 11.0m to account for the removed stability capacities provided by the ground anchors. Because the buttresses are tied together with the base slab, these buttresses became larger as can be seen in Figure 5.

The system was assessed to be stiff and the structural design of the wall was required to be undertaken to account for an ‘at-rest Ko’ soil pressure using first principles and in accordance with the Australian Standard AS5100-Bridge design.

As part of the design development, some of these limitations were addressed at detailed design stage.

7.2 DETAILED DESIGN

Various design challenge workshops were held internally within the Aurecon design team and between Aurecon design team and Bauderstone construction team to overcome the limitations of the concept design. The omission of the ground anchors and converting the counterfort retaining wall into a conventional gravity retaining wall were the preferred solution at this stage.

The detailed design was similar to the concept design except that the wall thicknesses were varied in 6m lifts.

Because the base slab width to retained height ratio was 0.59, the total reaction was determined to fall beyond of the middle third. This meant the base slab would experience some lift-off towards its heel. This effect caused significant tension in the sloping back of the buttresses. As a result, a large amount of conventional reinforcement was provided diagonally at the back of the buttresses and 4 pairs of 32 diameter stressed bars were required to tie the buttresses with the base slab. The stressed bars were spaced at 1.0m centres and preloaded to 750kN per bar. These stressed bars were very efficient in limiting stress in the reinforcement at serviceability conditions to 200MPa in accordance with Section 8.6 of AS5100.5 for a B2 exposure classification.

While the developed detailed design overcame the challenge of fully buried and inaccessible anchor heads, there were other limitations, namely:

- The system was still very stiff with little deflection and would be required to be designed for ‘at rest Ko’ conditions, which resulted in high design loadings and subsequently large quantity of reinforcement.
- There was an increase in material costs due to the increase in the base slab width and extents of the buttresses in relation to the tender design.
• Sloping buttresses would increase the cycle time on the construction of the wall segments and pose challenges in the design of formworks, which would result in costly temporary works.

The challenges were put to the design team to find an optimal design solution to reduce the construction costs and simplify the required formwork systems.

7.3 FINAL DESIGN

At this stage, several design options for the counterfort retaining wall were investigated by the Aurecon design team, taking into consideration the construction staging that was beneficial to the design. These design options were then workshopped with the construction team to determine the most economical design solution that suited Bauderstone construction techniques. The key challenge was to find a solution that is structurally adequate to take the design loadings but flexible enough to allow soil movement so that ‘active’ soil stress state would be mobilised behind the wall to reduce the design loadings. Due to the anticipated complex soil-structure interaction through various construction stages, this interaction needed to be investigated thoroughly to provide the design team with confidence that soil loadings had been adequately considered in the final design.

The final design solution comprised an L-shaped base slab and wall section tied together by vertical buttresses at 6m centres. The front wall and the base slab thicknesses remained unchanged from the two previous stages. However, the total base slab width was significantly reduced to 5.5m with 1.0m front toe and a 1.0m deep shear key in the heel as seen in Figure 6.

The extent of the buttresses from the front face of the wall reduced significantly to a uniform 4.0m width, including the front wall thicknesses. The buttresses are 550mm thick with a widened end flange of 1000mm width by 600mm depth. The uniform vertical buttresses simplified formworks design significantly and reduced cycle time of construction because all formwork would be reused.

Due to a narrow base (base slab width to retained height ratio of 0.27), the ground anchors were reintroduced at every buttress to provide the required additional stability capacities. The ground anchors heads were located at a constant height of 2.0m below the soffit of deck to maximise lever arm to the overturning point at the front toe, typically 16.75m. The ground anchors were also inclined at 45 degrees to the horizontal axis. In this arrangement, the anchor heads would be inspectable and maintainable in the future if required.

The narrow base slab width of 5.5m would be adequate to maintain the wall overturning and sliding stability for backfilling behind the wall to reach a maximum height of 9.0m above the top of base slab. The ground anchors would then be installed and stressed to a pre-determined lock-off load to provide the additional stability capacities. After the anchors have been installed, backfilling is then continued to the final design finish surface level. The required construction sequence is noted on the drawings to this effect.

![Figure 6: Final design](image-url)

The final design with a narrow base slab width overcame all challenges identified from various design development stages. The retaining wall system would be flexible enough to mobilise the ‘active’ soil stress state as it is shown in Section 9.2.

8 GEOTECHNICAL DESIGN

8.1 STABILITY ASSESSMENT

The assessment on the external stability of the counterfort wall followed the principles involved in conventional earth retaining structures. The failure modes of sliding and overturning were assessed. A geotechnical reduction factor of 0.55 was applied in accordance with AS5100.3 for sliding and overturning.

Based on the above assessment, a VSL or an equivalent permanent ground anchor system comprising 25 x15.2 super grade strands (minimum breaking load of 250kN per strand) were required to satisfy the global stability of the counterfort wall system.

For global stability, systematic bolting would unlikely be required based on existing borehole information and observation on site. Design for spot bolting will be carried out if required as part of the inspection on the
8.2 SOIL-STRUCTURE INTERACTION

To verify the lateral soil pressure coefficient used in the structure design and to determine the required prestressed in the ground anchors to control deflection at tip of the wall, a soil structure interaction analysis was undertaken using the PLAXIS 3D software. The full three-dimensional model considered true thickness of the wall and the base slab and stiffness of the ground anchors. All loading on the wall together with the construction staging were also modelled.

From the PLAXIS model, maximum vertical pressure in the Class III sandstone below the base slab was found to be 1300 kPa or 1.3 MPa at the serviceability limit state. This peak bearing stress occurred at the toe of the wall due to the relatively narrow base slab in comparison to the retained height of fill.

Pells et al \[5\] suggested a serviceability bearing pressure of 0.5 UCS that is 5 MPa below the counterfort wall. The bearing capacity of the Class III sandstone was considered to be adequate to withstand the design bearing pressure exerted at the toe of the wall. The counterfort wall was to be founded at RL 1.0 where the founding material was determined to of Class III or better. During the preparation of the wall foundation, a qualified geotechnical engineer would confirm that the design parameters would be achieved on site prior to the base slab being poured. This requirement was stated on the design drawings.

The predicted instantaneous outward displacement at the top of the wall was determined to be approximately 34 mm. This value considered the construction staging and...
stressing force applied to the model. A backward lean of 1 horizontal to 120 vertical into the fill behind the wall was specified to make sure the wall would not lean forward. At the highest point, this lean would provide a pre-set inward displacement of approximately 150 mm which would be adequate for long term creep within the soil and concrete and relaxation of the anchors.

The assessed soil pressure behind the wall is shown in Figure 11. It can be seen that the assessed maximum effective soil pressure behind the wall was in the order of 95 kPa with an inferred lateral soil pressure coefficient of 0.325. In addition, the estimated displacement of the wall was 34mm, approximately 0.18%H, which is consistent with the typical displacement to mobilise the active stress state in cohesionless soils. This confirmed that the soil pressure on the wall would be in an active state.

![Figure 11: Lateral soil pressure behind the wall](image1)

![Figure 12: Lateral stress on the base slab shear key](image2)

The assessed horizontal rock pressure acting at the shear key at the base slab heel was assessed to be 300kPa as shown in Figure 12. The shear key at the heel of the wall was designed for this pressure with a load factor of 1.5 to bring it to the ultimate limit state stress.

8.3 GROUND ANCHOR DESIGN

From the counterfort wall internal stability assessment, soil structure interaction analysis and associated sensitivity study, it was determined that the anchor load at serviceability limit state is 2400kN. Based on AS5100.3, it was determined that a VSL or an equivalent permanent ground anchor system comprising 25 x 15.2 super grade strands would be adequate to provide the required stability capacities to the counterfort retaining wall system.

The bored holes required to fit the 25x15.2 strand ground anchors are of 254mm diameter. The bond length in rock of the ground anchors was determined to be 10m in accordance with AS5100.3 using a geotechnical strength reduction factor of 0.35, an importance category factor of 0.7 and ultimate bond strengths of 1.0 MPa, 2.0 MPa and 2.5 MPa for class III, Class II and Class I Sandstone, respectively. Testing requirements for the anchors were nominated on the design drawings. The anchors were also required to comply with the New South Wales Road and Maritime Services (RMS) specifications for ground anchors B114.

The design of the ground anchor bond lengths was undertaken based on the currently available geotechnical data. During the construction phase, the actual bond lengths would be determined by the ground anchor subcontractor based on their assessment of the geotechnical ground conditions and testing in compliance with the above specifications.

9 STRUCTURAL ANALYSIS AND DESIGN OVERVIEW

The system was broken up into discrete zones as follows:

9.1 DESIGN OF FRONT WALL

The structural behaviour of the front wall was modelled in SPACEGASS as a local grillage, which was fixed on four sides. It was found the front wall spanned horizontally between the buttresses from approximately 3 m above the base slab. This section of wall was designed as a simple continuous slab that resists the “At Rest” lateral soil and surcharge loads. Below 3 m, the wall spanned to both the buttresses and the base slab.

The geometry of the grillage and the beam sections was modelled to the true centralines with the torsional stiffness constants reduced by 80% to account for reduced transverse distribution when the section is fully cracked in accordance with Clause 7.2.5, AS5100.5. The front wall slab was then reinforced to take bending and shear design actions determined from the grillage analysis. The concrete shear capacity was taken as the slab capacity in accordance with Clause 9.2, AS5100.5 and shear reinforcement was determined in accordance with Clause 9.2.2, AS5100.
Due to the relatively large spacing of the buttresses and the high lateral earth pressures on the wall, shear reinforcement was detailed in the first 6 m lift to optimise the wall thickness. Horizontal hanger reinforcement was detailed in the buttresses to transmit the horizontal bearing pressures from the soil and surcharge loads, which applied on the front wall slab, to the buttress beams. Additional reinforcing bars are included at the first two horizontal construction joints in Lift 1 and 2 as shown in Figure 14. These additional bars would assist in the controlling cracks in the wall at the fixed edge against thermal and shrinkage cracking.

The base slab width was sized to provide adequate stability capacities, which allow the backfilling operations to progress to 9 m above the base slab without the need for ground anchors. Once the fill reaches 9 m, the ground anchors are to be installed and stressed to 1000 kN to provide the additional stability capacities before backfilling is continued to the final design level.

The base slab also includes a shear key located at the heel. The shear key provides sufficient sliding resistance to the system under the full height of fill.

The base slab was designed to be fully suspended between the buttress beams. This provided the reinforcement for the bending moment and shear force demand in the base slab. The shear key was designed as a continuous beam spanning the buttress regions. The slab was designed from the bending moments, torsions and shear force outputs of the model under ULS and SLS load combinations.

Based on the shear forces generated under this condition, hanging reinforcement from the buttress beams was sized to transfer the high downward soil pressures from the fill or restoring soil forces back to the global beam system.

The buttresses resisted in-plane forces from both the front stem wall and the base slab. The buttresses were designed as an I-beam of a constant cross section between the upper anchorage and the base slab. The back face of the buttress beam had a widened section measuring 1000 mm wide by 600 mm deep to house the reinforcement required to tie the buttresses with the base slab. The slab was designed from the bending moments, torsions and shear force outputs of the model under ULS and SLS load combinations.

Hanging reinforcement was provided to tie the buttress to the stem wall and the base slab as discussed.
10 DRAINAGE AND WATER-TIGHTNESS

The following details were integrated into the overall design solution with regard to water tightness, odour control and build-up of water pressure from behind the wall. The quality of the fill material being all 30 plus material, coupled with the seepage drainage layer design influenced the final design solution adopted for the design.

The wall thickness and percentage of reinforcement were the first line of defence with regard to water ingress, crack control and odour ingress. The thickness of the wall (Lift 1) within the first 6 m was 750 mm. The water and odour penetration through a 750 mm thick wall was determined to be very low.

A vapour membrane comprising a 2 mm thick single layer polyethylene membrane in accordance with AS2870-2011 was detailed behind the front wall slab. The vapour membrane would also increase the life of the concrete on the back face of the wall which is not accessible for maintenance and repair. This vapour membrane will also reduce the risk of odour penetration into the Future Cultural Space.

A GEOSHEET CS15F by Geofabrics or approved equivalent was detailed to direct any water pressure from building up behind the wall. The risk of water penetration through the wall was more likely if there was a constant head of water build-up behind the wall. In the case of the counterfort wall, the only water source that could result in water build-up behind the wall was the seepage water through the Headland Park hill. The Geosheet was sized to resist the soil pressures imposed on the wall. At the seepage drainage layer interface, the Geosheet and vapour membrane overlapped with the GCL membrane to capture the seepage water from behind the retaining wall and direct it to the seepage drainage system. At each change in thickness to the wall, the Geosheet and vapour membrane overlapped and a localised drainage layer was included.

11 CONCLUSIONS

The paper presents the most important design aspects of the counterfort retaining wall as part of the Barangaroo Headland Park Project in Sydney. The final design solution comprises

- an efficient front wall slab with thickness varying from 750mm to 400mm in 6m lift sections
- a narrow base slab of 5.5m total width including a 1m wide front toe and a shear key in the heel. The base slab is 750 thick.
- uniform vertical buttress of 4.0m depth including front wall thickness
- ground anchors comprising of 25x15.2mm diameter super grade strands (minimum breaking load of 250kN per strand) installed at a 45° inclination to the horizontal axis at every buttress. The bond length for the ground anchors is 10.0m

The narrow base slab width allows the wall to tilt so that an ‘active’ soil stress state would be achieved to reduce design loadings on the wall. The uniform vertical buttresses reduce formwork and cycling time on the buttresses. These innovative design features enabled the design to achieve great construction cost savings. The final design solution was estimated to be approximately 27% cheaper to build than the proposed design at the tender phase.

It is important that soil-structure interaction is comprehensively understood for the design of retaining wall systems, in which the lateral soil loading cannot be readily estimated. For the case of the counterfort retaining wall discussed in this paper, the soil-structure interaction study provided a better understanding of the soil behaviour leading to a more efficient and cost-effective design solution.

REFERENCES

1. Australian Standards. AS5100-2004 Bridge Design
3. Australian Standards. AS1170.4 –Earthquake actions in Australia