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# Remediation of a Major Urban Rock Slope - Howard Smith Wharves, Brisbane

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## ABSTRACT

Howard Smith Wharves on the Brisbane River near the Central Business District (CBD) are currently being redeveloped as open space parkland. Overlooking the parklands is a 25m high, 500m long, vertical cliff face formed progressively by quarrying over the last 150 years. The cliff face consists of two dominant rock types, the Brisbane Tuff and phyllites of the Neranleigh Fernvale Beds. Between the two rock types and exposed in the face is probably the best example of a Triassic age unconformity in the Brisbane region. Prior to parkland construction, the first stage of redevelopment consisted of the design and construction work necessary to stabilise the cliff face. For architectural and space reasons, the adoption of rock fall fences or rock fall zones was not possible, hence the stabilisation works had to ensure the cliffs were remediated to a standard where the risk to park users was as low as possible. Potential future uses of the park also included recreational rock climbing on the cliffs, requiring minimal artificial change to the natural rock slope. The site is also heritage listed, and includes World War II air raid bunkers along the toe of the cliff. Scaling and remedial works in these areas required no damage to the shelters. This paper describes the design approach adopted for the remediation work, and the subsequent construction works undertaken during 2010. Treatment of the highly erodible unconformity is also described, and the development of a pathway along it, the 'geo-stair', to preserve the unconformity for educational and teaching uses.

*Keywords:* rock slope, stability, remediation, unconformity, heritage site

## 1 INTRODUCTION

During the mid to late 2000s Brisbane City Council (BCC) developed plans for the refurbishment and redevelopment of an area of the CBD known as the Howard Smith Wharves. This area was a 500m long strip of land beneath the northern abutment of the Story Bridge and contained heritage listed wharves and wharf buildings dating back to the time of the construction of the Story Bridge in the late 1930s (Department of Environment and Resource Management, 2012). Wharf construction included excavation of the adjoining hillside related to the Story Bridge construction and widening of the river. After closure of the wharves in the 1960s, the area became unused apart from the wharf buildings used by the Water Police and as storage by State Government Departments. Also located on the site are several 1940s "pipe" air raid shelters formed of precast concrete pipes with concrete entrances along their length. The existence of these shelters, thought to be unique to this site, contributes to the heritage listing of the site.

Brisbane City Council procured the land in the 1990s however it remained unused apart from a fenced off strip through the middle used as a pedestrian path and bikeway connecting the Floating Riverwalk at New Farm with the Riverside bikeways through the CBD. An aerial view of the site is shown as Figure 1. Forming the northern edge of the site is a 500m long vertical cliff, generally 20m high but up to 25m high in places. These cliffs were partly formed during wharf construction in the late 1930s, but historical photographs show quarrying operations on the site as early as the 1880s (National Library of Australia, 2012). The cliffs have not been stabilised or maintained over their lifetime and were prone to frequent rock falls and small collapses. For this reason a 20m to 30m wide zone along the base of the cliffs had been fenced off to prevent public access.

In the mid to late 2000s the BCC redevelopment proposals involved a possible hotel development at the Story Bridge end of the site, refurbishment of the wharves and conversion to recreational uses, and redevelopment of the bulk of the site as open parkland, including upgrading of the pedestrian walkway and bikeway. Recreational climbing on the cliffs was also proposed.



Figure 1 - Aerial view and main site features

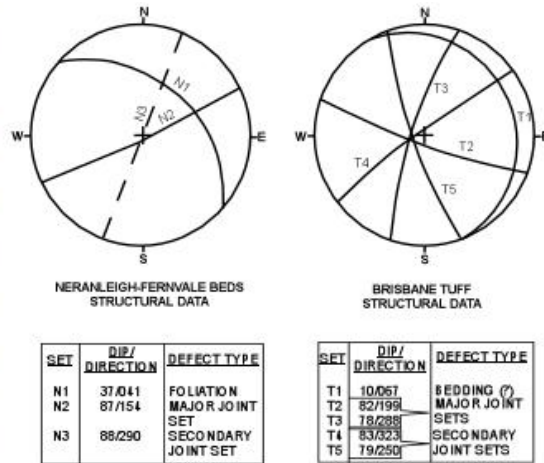


Figure 2 - Structural Mapping Data

## 2 SITE GEOLOGY

The cliff face and the wharf site occur on the boundary of two distinct geological formations. These are the Mesozoic age Brisbane Tuff and the Palaeozoic age Neranleigh-Fernvale Beds, as shown on Figure 1. The Brisbane Tuff is a porphyritic rhyolite tuff and typically occurs as a massive widely jointed rock of high to very high strength. The Neranleigh-Fernvale Beds are comprised of phyllite, a slightly metamorphosed and foliated fine grained marine sediment. The Tuff is thought to be about 40 million years younger than the underlying Neranleigh-Fernvale Beds, and the contact between the two forms a geological unconformity. This overlying Tuff forming the unconformity is generally considered to be 220 million years old and deposited as a result of one or at most several massive pyroclastic ash flows.

Brisbane Tuff is exposed east of the unconformity. It comprises a fine to coarse-grained porphyritic rhyolite tuff with generally well defined layering or bedding at  $5^{\circ}$  to  $15^{\circ}$ . The rock mass is generally slightly weathered. Weathered zones occur extending to the base at one location where the weathering is identified with the presence of a fumarole vent. The rock in these weathered zones varies between pale brown and off-white and rock substance strength is estimated to be low to high (City Design, 2008). Structural joint and bedding data for the Brisbane Tuff is shown on the equal area, lower hemisphere projection at Figure 2. One bedding set, two major joint sets and two secondary joint sets were identified.

Rocks of the Neranleigh-Fernvale Beds exposed west of the unconformity comprise phyllite, which is a slightly metamorphosed (hardened and slightly recrystallised), fine grained marine sediment. This rock has been subjected to folding and faulting which resulted in a pervasive, closely spaced foliation overprinting the original bedding and the partial solution and redeposition of quartz as veins mainly parallel to foliation. The phyllite exposed in the cliff face is slightly to distinctly weathered with the rock substance strength estimated to be medium to high (City Design, 2008). Three distinct defect sets were identified. The mean orientations of these three sets are plotted on an equal angle, lower hemisphere projection included on Figure 2.

The unconformity between the underlying phyllites and the overlying massive tuff varies up to 5m in thickness and comprises several identifiable layers. The overlying Brisbane Tuff is thought to have been the result of one or several large scale, extremely hot ash flows which, on settling became welded through their own heat and weight. At the base of this formation is a variable sequence of unwelded tuff, tuffaceous mudstones, sandstones and conglomerates (City Design, 2008).

The upper part of the interface zone on the site comprises alternating layers of unwelded tuff or tuffaceous mudstone (very stiff to hard clay) and low to high strength rock. This is underlain by a brecciated material comprising mainly fragments of phyllite in a siliceous matrix. During excavation several fossilised trees were also unearthed with the largest tree about 1m in diameter.

### 3 DESIGN DEVELOPMENT

Failure modes identified at the site were mainly small to medium sized ( $1\text{m}^3$  to  $3\text{m}^3$ ) block and wedge failures in the Tuff section, and smaller ( $0.5\text{m}^3$  to  $2\text{m}^3$ ) block, planar and wedge failures in the Neranleigh section. Significantly larger failures were also possible in the Tuff depending on jointing, with a  $40\text{m}^3$  wedge failure evident at the crest at one location (Figure 3), and blocks up to  $20\text{m}^3$  to  $30\text{m}^3$  identifiable above the unconformity. Original stabilisation measures proposed for the site, prior to detailed development proposals, involved rock fall ditches and rock fall fences combined with rockbolting, scaling and buttressing (City Design, 2010). This approach, particularly the rock fall ditches and mounds, is typically the lowest cost option compared to more extensive structural solutions. An early risk assessment for the cliffs, based on estimated failure frequencies and volumes and estimated pedestrian and cyclist traffic, indicated unacceptable risk levels without a sterile rock ditch zone or similar. Due to the site geometry however, a rock ditch would effectively sterilise up to 45% of the park area. Rock fences were considered to reduce the width of sterile zones, but the height and verticality of the cliffs would require massive structural fences to contain rock falls originating higher up the cliffs. The proposed use of some sections for recreational climbing, and the preference to allow public access to the air-raid shelters which were tucked into the base of the cliffs, resulted in the decision to exclude rock ditches or fences as a viable remedial measure (City Design, 2010).



Figure 3 - Typical Tuff jointing with wedge failure at right at crest

Consequently it was necessary to fully stabilise the cliffs, such that the risk to park users was at an acceptable level, while still allowing full public access to the toe of the cliff line. This would allow full use of the site as parkland, access to the heritage air raid shelters, and recreational climbing on some sections of the rock faces. The original moderate level of bolting, scaling and buttressing was then increased significantly to allow for stabilisation to achieve the required risk levels. This final design approach involved 3m and 4m long galvanised rock bolts, fully grouted, to achieve a factor of safety of 1.5 for identified blocks and wedges potentially sliding on unfavourable joint planes. Typically half height water pressure was included on sliding planes. In addition to bolting, reinforced shotcrete buttressing was adopted to support overhanging blocks. Analysis also indicated that reinforced shotcrete, pinned to the rock with grouted 15mm diameter galvanised bars, was effectively more efficient at supporting potentially overhanging or sliding blocks than individual rock bolts. The buttressing provided full support for jointed blocks, which normally might require several rockbolts to guarantee adequate support.

Because of the prominence and aesthetic value of the cliffs, coloured sculpted shotcreting was specified. The successful contractor used his own system, registered as 'Natracliff'. This resulted in a finish which matched the existing rock face, effectively hiding the presence of shotcrete. Rock bolts were also specified as having recessed heads, sunk 100mm into the rock face and covered with coloured mortar to disguise their position. Figure 3 shows a completed section of Tuff face.

As part of the design, a maintenance plan was developed to ensure the likelihood of future rock falls did not increase with time. The plan included three levels of inspection and specified the differing levels required at various times after completion.

#### 4 TENDER QUANTITIES

Initial estimates of stabilisation quantities were undertaken for the preparation of tender documents. Inspection of the cliff face was initially obscured by dense vegetation with an estimated 70% of the cliff face covered. The vegetation included large trees including figs and a wide variety of weed species and grasses. Where the rock face could be inspected, an assessment of the rock quality together with likely scaling, bolting and buttressing volumes was completed. Once the quantities were determined, a 30% contingency buffer was added to the initial estimates to cover unforeseen stabilisation requirements, given the limited areas that could be assessed prior to clearing. The unconformity section was considered to contain the most unknowns, with almost all of this section covered with dense vegetation (Figure 4).



Figure 4 - Original cliff appearance at unconformity location, showing heavy vegetation and proximity of bikeway.

#### 5 CONSTRUCTION

Prior to work commencing an arborologist inspected the site to identify protected trees and shrubs which were tagged to ensure they were not damaged during the works. The vegetation was mostly weed species, with only figs and some natives requiring protection. Clearing the vegetation was completed using hoes and chain saws from the elevated working platforms which were capable of carrying up to three people. Once the vegetation clearing was completed it was discovered that significant soil deposits covered many ledges and infilled the rock joints. The clearing of the vegetation and soil debris was complicated by hundreds of discarded needles which were found lodged within the vegetation. Two Heritage Listed air raid bunkers were located at the base of the cliffs, and protection of these structures was necessary to ensure these were not damaged during these clearing and scaling works. These bunkers were in poor condition prior to commencement of these works with some damage evident where large boulders had previously fallen from the cliff, punching through the thin concrete shells. The contractor protected the bunkers by covering them with a combination of steel plates, plywood and segmented pontoon blocks, and then burying them under about 0.5m of loose soil. This system provided adequate protection and no damage occurred during the scaling works.

Scaling the rock above 12m height was completed mostly by manual means from elevated working platforms using crowbars and small wrecking bars. An air activated jack was also used to assist with the scaling process and although this was a much slower process it was successful in removing several large rock wedges and columns that were predominant with the Brisbane Tuff rocks. Scaling the rock in the lower 12m from the base was undertaken by a long reach excavator. The scaled spoil was stockpiled along the toe of the cliff which then provided a ramp for the excavator to reach greater heights. This excavator was very effective in removing large quantities of vegetation and scaling loose

rock although a required a highly skilled and experienced operator to ensure this was undertaken safely.

Scaling quantities exceeded by more than six times initial estimates, with 1100m<sup>3</sup> of rock scaled from the face (Table 1). This quantity was calculated by surveying the stock piles of soil and smaller rocks, and using accepted bulking factors to determine the insitu volumes. The larger rocks and boulders were removed from site and rock weights calculated using weigh bridge docketts. Unit weights of the rock were determined by laboratory testing with an average unit weight of 23kN/m<sup>3</sup> adopted for all rock boulders. This then allowed the weights to be converted to the insitu rock volumes.

It was typically a more effective stabilisation method to remove large overhangs and loose boulders within the Brisbane Tuff than support them using bolts and shotcrete buttressing. Where removing the overhangs was not practicable, or removal would cause further instability or cause undercutting of the rock above, the rock was stabilised using either bolting, reinforced shotcrete, reinforced buttressing or a combination of these methods. Buttressing was generally most effective in providing support to overhangs, as bolting was both expensive and occasionally caused cracking of the rock during the drilling. Occasionally buttressing the larger overhangs incorporated both bolting and reinforced concrete buttresses. Shotcrete was defined as concrete applied up to 0.15m thick. Shotcrete concrete volumes over the theoretical 0.15m thickness was paid as buttress concrete.

Rock bolts were utilised to stabilise many rock columns, wedges and overhangs. The bolts most commonly used were 3m in length with 4m long bolts used where required. Wedge analysis and joint measuring was utilised to determine the number of bolts required in each instance. The lower rock bolts were installed using an air track drilling rig mounted on an excavator which was capable of drilling a 100mm hole. Large soil stockpiles were placed against the toe of the cliff to provide higher access, up to approximately 12m height. The bolts positioned higher up the cliff face were drilled using a custom made air track drill rig capable of being mounted within the elevated working platform basket, and also hand drills capable of drilling 75mm holes. The bolts were 25mm, 575MPa galvanised 'Reid Bar'. The rock bolts were tightened to a nominal tension with load testing completed on 6% of the bolts installed. All of the rock bolts were required to be recessed with the surface patched with shaped, coloured mortar to blend with the adjacent rock face. Table 1 below provides a comparison of the quantities estimated at the tendering stage and the final quantities. All other contract costs including establishments, traffic control, clearing, spoil removal from site, demolition works, and other consumables have not been included in this cost summary. The total contract cost for all the works was approximately \$1.35million.

*Table 1 – Summary of quantity estimates and actual construction quantities*

Activity	Tender Estimate	Actual Quantity
Scaling (m <sup>3</sup> )	174 m <sup>3</sup>	1100 m <sup>3</sup>
Shotcrete (m <sup>2</sup> )	409 m <sup>2</sup>	723 m <sup>2</sup>
Buttress (m <sup>3</sup> )	224 m <sup>3</sup>	73 m <sup>3</sup>
Number of Bolts (3m long)	387	216
Number of Bolts (4m long)	5	12
Cost (stabilisation only)	\$630,000	\$850,000

A significant reduction in the number of bolts required from the initial estimates was achieved. This was largely attributed to significantly higher scaling volumes that removed columns and wedges that would have required support. Several hundred cubic meters were removed from the unconformity area. Tree roots from several large figs had cracked large volumes of rock in this area which significantly increased the scaling volume. Since completion in August 2010 no rock falls have been identified from the 500m of cliff, even through the prolonged and intense rains of December and January 2011. The only failure was on the erodible unconformity, which was left exposed initially to gauge its performance.

## 6 GEO-STAIR

A stair case titled the 'Geo-Stair' was proposed to be constructed at the unconformity location to provide access to view this unique geological feature and also provide a good viewing position to see

the river and CBD. Within the unconformity, up to six large fossilised tree trunks could be clearly identified, together with the contact of the Brisbane Tuff over the Neranleigh-Fernvale Phyllites. The highly weathered unconformity zone had caused under cutting of the upper strong Tuff deposit which led to toppling failures over the years. When the scaling had been completed in this area, the unconformity zone was cleaned to less weathered rock resulting in a wide bench between the toe of the unconformity and stronger Tuff above. The initial intention was to leave the unconformity unsupported and visible as this was one of the best exposures within the Brisbane area. However due to the highly erodible nature of this material, once exposed and subjected to rainfall, the material slaked and eroded. This led to slumps and failures, including a larger slip in January 2011 following prolonged intense rainfall. Rather than covering the uniformity with shotcrete, a rock bolt and mesh design was implemented (Figure 5).



Figure 5 - Unconformity treatment after initial collapse in January 2011.

## 7 CONCLUSIONS

With intensive clearing and scaling, and comprehensive support measures, it is possible to remediate a cliff face to a standard where the conventional rock fall ditches or fences can be eliminated. Treatment methods can also be selected to have negligible visual impacts. On this project the intensive scaling volume equated to a 0.11m thickness of rock over the entire face area. Partly this was due to extensive root invasion into joints. Ideally an initial contract for clearing only would allow better quantity estimates. Shotcreting for support resulted in an area equal to 7% of the total face area, with an extra 68% of concrete required over the theoretical volumes. Bolting installed averaged 1 bolt per 44 m<sup>2</sup>.

## 8 ACKNOWLEDGEMENTS

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