# RISK ASSESSMENT AND EARTHWORKS MANAGEMENT PROCEDURES FOR CONTROLLED INFILLING OF A DISUSED QUARRY PIT

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## 1 INTRODUCTION

The Eastwood Brickworks is a former shale quarry that operated through most of last century to provide brick making materials that were manufactured on site into bricks. To enable the site to be redeveloped for residential purposes, engineered fill is being placed in the pit that is up to 30 m deep in places. In some parts of the quarry the pit walls were within metres of adjacent residential properties and public roads.

Approximately 1 million cubic metres of fill is required to reach design bulk filling level. Before the start of infilling, extensive sections of the pit walls were near vertical and with some sections undercut by the quarrying activities. A substantial landslide in the high wall of the quarry was a major geotechnical feature that had the potential to remobilise and regress during pit infilling. To enable engineered fill to be placed up to the pit walls, the landslide had to be remediated and the pit walls treated.

This paper discusses the pit wall stability risk assessments and earthworks management practices that have been carried out throughout the project. Detailed geological mapping and geotechnical assessment was carried out at the design stage to assess the risk of instability. Stabilisation measures, monitoring and earthworks methods were developed to manage the risk to workers from slope instability during the filling works that have been underway for over four years. The existing landslide was remediated by earthworks, installation of anchors, drains and batter mesh. Controlled filling up to the pit walls was achieved by a combination of earthworks methods including use of remotely controlled compaction plant, exclusion zones, method specifications for acceptance of fill within exclusion zones and stabilisation measures including scaling and batter mesh.

## 2 SITE DESCRIPTION AND GEOLOGY

### 2.1 SITE DESCRIPTION

The Eastwood Brickworks covers an area of about 15 ha and is located in the suburb of Eastwood, some 20 km north west of the Sydney CBD. The site is surrounded by residential development. Large sections of the quarry faces were near vertical and in some places are actually overhanging. In some sections of the quarry the pit walls were within a few metres of the boundaries with residential lots and public roads. Figure 1 shows the Brickworks site with the pit area outlined.

Figure 1: Site Plan – Eastwood Brickworks

The natural ground surface at the site before commencement of quarrying sloped from north to south at about 15° with a high point at about RL110 m in the northeast corner. The pit has been excavated to a current floor level of about RL70 m, giving a maximum excavated slope height of about 35 m to 40 m. Figure 2 shows a view across the pit.

For early part of the operational life of the brickworks shale was quarried and blasting was used. Quarrying ceased in the latter part of the operational life of the brickworks, and brick making materials were imported. The brickworks was still operating in 2002 when backfilling commenced.

## 2.2 GEOLOGY AND GEOTECHNICAL CONDITIONS

### 2.2.1 General

The brick pit has been entirely excavated in clay overburden and shale bedrock. Reference to the Sydney 1:100,000 Geological Series Sheet indicates that the site is located in Ashfield Shale, close to the boundary of the overlying Bringelly Shale. Both units generally comprise shales, mudstones and laminites that weather near the ground surface to clay soils of high plasticity. Ashfield Shale forms most of the quarry faces.

### 2.2.2 Geotechnical Units

Mapping of the exposed sequence of soils and rock types in the quarry face showed that the shale is generally sub-horizontally bedded with some signs of off-setting by steeply inclined faults. There was not sufficient differentiation between the units exposed to be confident of defining individual units, other than on the basis of weathering states. Accordingly, three bedrock units below the level of the residual soil were identified, as in Table 1:

Table 1: Geotechnical Units.

| Unit | Features |
|---|---|
| 1. Extremely and Highly Weathered Shale | • Immediately underlies residual soil exposed in the upper 1m to 3m of the quarry faces.<br>• Siltstone, mudstone and shale, generally pale brown in colour, with thin sideritic bands forming ledges on the cliff face.<br>• Tendency to form isolated ledges or blocks of sideritic shale surrounded by low to very low strength shale that are prone to fall following weathering.<br>• Low to very low strength shale.<br>• Fretting, desiccation and surface water erosion on exposed surfaces;<br>• Some iron infilled joint planes. |
| 2. Moderately and Slightly Weathered Shale | • Exposed around the mid-slope to upper levels of the quarry immediately underlying Unit 1, into which it grades over a distance of about 1 m to 2 m.<br>• Pale grey, clayey shale with common thin to very thin sandstone lenses and with rare sideritic bands.<br>• Siltstone, mudstone and shale, with some interlaminated and bedded siltstone and fine sandstone, generally grey brown to grey in colour.<br>• Variable strength – generally medium to high strength.<br>• Fretting, desiccation and surface water erosion on exposed surfaces.<br>• Some fretting upon exposure. |
| 3. Fresh Shale | • Exposed from the mid slope to the floor of the quarry immediately underlying the Unit 2, into which it grades over a distance of about 1 m to 2 m.<br>• Dark grey to black shale and more massive than Units 1 and 2.<br>• Siltstone and mudstone with indistinct bedding and lamination, generally dark grey to black in colour.<br>• Medium to high strength.<br>• Fretting and desiccation to gravel sized lumps on exposure to the atmosphere.<br>• Seepages of groundwater along bedding planes. |

### 2.2.3 Rock Defects

As it was considered unsafe to approach the face for the purpose of geological mapping, the assessment of the rock structure was carried out by remote observations from across the quarry faces. There appeared to be two main sets of joints as described in Table 2:

Table 2: Rock Defects.

| Joint Set | Features |
|---|---|
| **1** North South | • These joints were noted principally along the eastern pit wall where they are near vertical (± $20^0$).<br>• Form a swarm of closely spaced joints along the eastern pit wall where the joints had opened up by as much as 200 mm, presumably due to toppling movement in the rock mass along the joints. These joints are also exposed in the northern face of the quarry.<br>• The dip of the joints in this area appeared to be either near vertical or dipping steeply back into the cliff face. The joints were not quite parallel to the pit wall but were seen to persist for distances as much as 20 m. |
| **2** East West | • These joints were noted principally along the northern pit wall.<br>• Appeared to be discontinuous and trended sub-parallel to the quarry face.<br>• The dips associated with this joint set were towards the south (out of the face) at angle of $45^0$ to $60^0$.<br>• There was a general tendency for the joints to form small wedge type potential failures in conjunction with the Set 1 joints. |

In addition, the sub-horizontal bedding plane partings formed a common set of defects within the bedrock.

Minor isolated sheared zones were noted in the quarry face.

Figures 2 and 3 show typical views of the north and east pit walls.

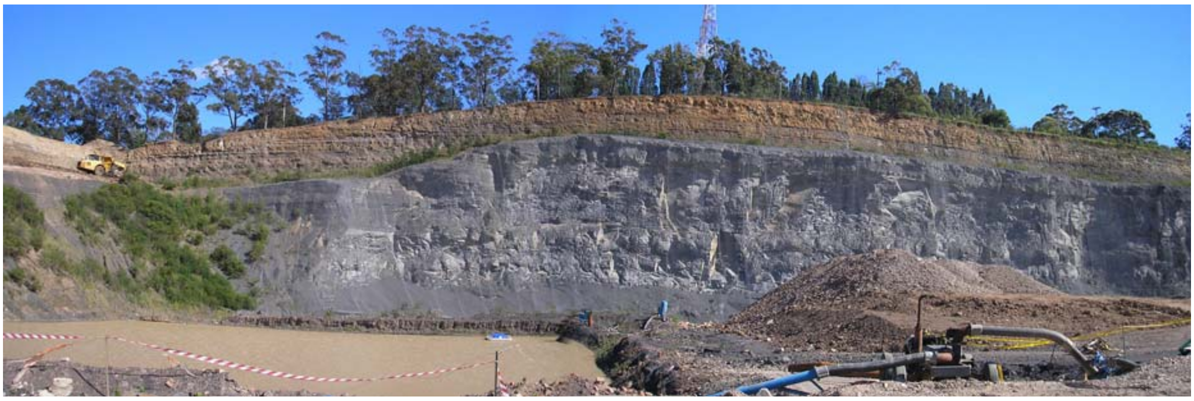

Figure 2: View of western half of north pit wall.

Figure 3: View of east pit wall.

### 2.2.4 Groundwater

Seepage from the eastern and northern pit walls, particularly following periods of wet weather, suggest that transient water tables may exist following wet weather. The pit may have intersected and locally lowered the regional groundwater table due to the length of time that the pit has existed.

Drainage of groundwater seepage and stormwater runoff has generally been addressed during infilling works by filling in sub-horizontal layers sloping towards temporary storage dams and sumps. Water has been used for dust suppression or pumped out of the pit and off site.

### 2.2.5 Existing Landslide

A major landslide had occurred in the north eastern corner of the pit before backfilling commenced. The landslide occurred on 26 September 1999 in an area where the natural ground surface at the site before quarrying sloped from north to south at about 15° with a high point at about RL110 m in the northeast corner.

The area had been quarried over many years, apparently without report of slope instability being an issue. However, it is understood changes were made to drainage at the crest of the pit and in the adjoining floor of the pit in the 12 months preceding the landslide.

The back scarp of the failure formed along two separate steeply dipping rock mass joint planes, one dipping at 65° into the pit, and one dipping at about 90° – being part of Joint Set 1, with a release plane being the east west Joint set 2. A joint plane at about 10° sub-parallel to the bedding apparently acted as the basal plane to the slide.

The failure model for the pit wall failure infers the presence of significant hydrostatic water pressures acting on the near vertical joints. The trigger mechanisms for the failure were inferred to be a combination of factors including the history of excavation of the drainage ditches at both the top and bottom of the pit walls combined with the change of drainage and groundwater conditions resulting from the construction of a house above the failure and its related drainage absorption trench constructed during the dry period prior to a wet period.

The back scarp was considered to be buttressed by the failure mass and not likely to slide further without disturbance. Figure 4 shows a view of the landslide with the buttress in place.

Figure 4: View of slip looking north west.

## 3 FILL SPECIFICATION

The overall objective of earthworks was to form a landform suitable for low and medium density residential development. The pit occupies a significant proportion of the site area and to produce a landform with acceptable settlement characteristics, rock fill was specified to be placed under a Level 1 inspection and testing regime, as defined in AS3798 (1996). The base of the pit was to be stripped of all loose material to expose shale bedrock.

The fill specification defined two material types as follows:

- Type 1 – rock fill material with a limit on plasticity (Plasticity Index to be less than 20%) and fines content (less than 30% to pass 75 μm sieve).
- Type 2 – material with a limit on plasticity (Plasticity Index to be less than 30%).

The fill was zoned, with material placed greater than 20 m depth from the final site grade to be 100% Type 1. Material between 2 m and 20 m from the final site grade was to be not more than 50% Type 2 and material within 2 m of final site grade to be 100% Type 1. All fill was to be compacted to at least 98% Standard Maximum Dry Density. To reduce the risk of collapse settlements as the groundwater table re-establishes within the infilled pit, a moisture criteria of -1% to +2% of Standard Optimum Moisture Content was specified.

This specification was applied to site materials that included clay, shale and reject bricks. Imported fill was exclusively sandstone and shale from major tunnelling and basement excavation projects. No recycled materials, demolition waste, small scale soil or other rock sources were accepted. Some relatively poor quality site materials including ash and silty clays were used in the pit infilling. However, these materials were generally mixed with imported rock fill at ratios of not more than 50% site material to not less than 50% imported rock fill.

## 4 STABILITY ISSUES

To achieve the design objectives of clearing the base of the pit of all loose material and infilling with engineered fill the major issues identified were:

i. General stability of the pit walls and the risk to workers from the placement and compaction of fill up to the pit walls. This was addressed by the following stabilisation measures and work procedures:
    - Scaling of the pit walls using a long reach excavator;
    - Installation of batter mesh;
    - Installation of horizontal drains along the eastern pit wall;
    - Maintaining exclusion zones where access to plant and personnel was restricted.

ii. Achieving compaction of the fill and validation of fill compaction near the pit walls. This was addressed by developing method specifications to reduce the need to carry out field density tests within exclusion zones and the use of innovative plant to achieve compaction.

iii. The presence of a large mass of landslide and loose buttressing material extending across a relatively large part of the pit. This was addressed by designing and installing stabilisation measures for the pit walls combined with staged excavation of the material.

    Initially the mass of the fill buttress against the failed slope was augmented by adding fill at the bottom of the slope then creating a stable configuration to allow more fill to be placed at the top of the failed mass. The augmentation of the fill mass allowed safe access for construction plant to the top of the slope for installation of anchors, horizontal drains and mesh.

    The spoil pile was gradually removed in stages to enable the next line of support measures to be installed.

## 5 GENERAL STABILITY

### 5.1 SCALING

It was impractical to scale the whole of the surface of the pit walls due to the height of the pit walls which reached 30 m in places. However, by using a long reach excavator it was possible to scale to a height of over 20 m. Figure 5 shows the long reach excavator scaling.

Figure 5: Scaling using long reach excavator.

Although many tonnes of potentially unstable rock were scaled down, rock was observed falling and heard falling from the pit walls throughout the years of filling. Thermal effects are likely to be a contributing factor to ongoing instability with the face going through diurnal and seasonal variations in temperature.

### 5.2 BATTER MESH

It was recognised that scaling alone would not be effective in reducing the incidence of relatively small rock falls and therefore draped batter mesh was employed with the aims of retaining material on the face, catching fallen material and reducing the run out of fallen material. The mesh specified was hexagonal mechanically woven mesh wherein the joins are formed by twisting each pair of wires through three half turns (commonly called Double Twist). The minimum wire diameter was specified as 2.7 mm and the nominal mesh size of 80 mm x 100 mm.

Figure 6: Batter mesh installed on north pit wall.

Figure 7: Rock fall captured by mesh.

Figure 6 shows the draped batter mesh after lacing to form a continuous layer across the pit wall. The mesh was fixed at the crest using two, 20 mm diameter, 3 m long rock bolts per roll. Figure 7 shows typical material that is retained on the pit face by the mesh.

The mesh is most effective when in close contact with the face. In undercut sections it was not possible to achieve close contact as it was too dangerous for workers to install rock bolts to fix the mesh to the face, as could have been achieved on less fractured rock faces.

The batter mesh is sacrificial and is progressively buried during pit backfilling. The mesh comes under tension as the filling rises and covers the pit walls. In undercut sections this can prevent the placement of fill up to the face and the mesh has to be cut to release the tension.

### 5.3 HORIZONTAL DRAINS

Along the eastern site boundary, immediately adjacent to a heavily trafficked public road, a series of deep sub-horizontal drains were installed to reduce the risk of a build up of hydrostatic pressures in joints. Drains were also installed as part of the landslide remediation works described in Section 7.

The horizontal drains were 75 mm diameter holes and were generally about 20 m long. A 50 mm diameter slotted PVC pile was installed in each drain hole. Where the drains resulted in concentrated groundwater flows onto the fill being placed in the pit the PVC pipes were connected to a manifold and piped to the water storage dams.

### 5.4 EXCLUSION ZONES

It was assessed that large scale rock bolting was impractical due to the large area of pit walls that were undercut and the highly fractured nature of the shale. A feature of the design of the infilling was that the fill grades from the southern pit wall at 1V:20H and then has a 1V:2H batter to the northern pit wall. The shape was developed in part recognition of the practical construction and performance issues associated with residential development within about 20 metres of the northern pit wall. This decision in turn allowed exclusion zones to be declared, thus overcoming the need to install pattern bolting of the walls of the pit and avoiding unacceptable construction safety issues.

Within the declared 8m to 10m wide exclusion zones, no plant such as dump trucks or compactors, or personnel on foot were allowed to work. Fill was placed using an excavator operating perpendicular to the face. Exclusion zones were applied to most of the northern pit wall, which was significantly undercut and which experienced ongoing instability ranging from gravel size rocks to falls involving many tonnes of rock.

Figure 8 shows a large fall that occurred adjacent to the 1999 landslide. The run out zone was limited to about 5 metres from the pit wall.

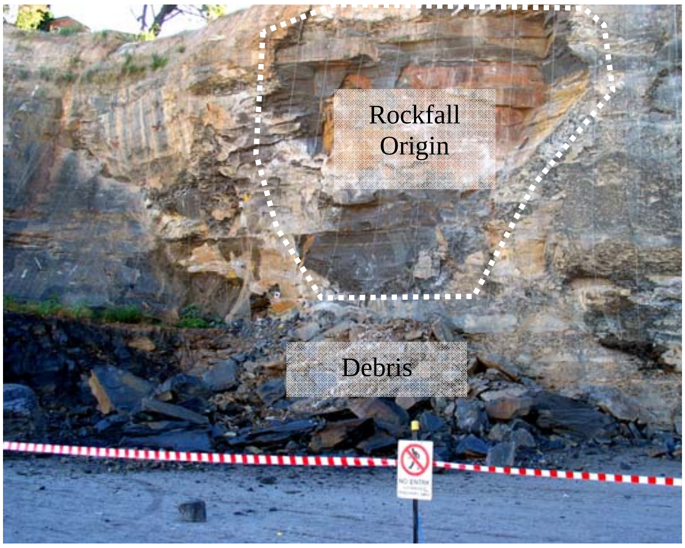

Figure 8: Large rock fall from north pit wall.

The other pit walls were generally less steep, less extensively undercut and lower than the northern wall and exclusion zones were considered unnecessary. However ongoing geotechnical assessment, including monthly visits by an experienced geotechnical engineer, were carried out in the early years of filling to assess pit wall stability. Exclusion zones were removed from sections of the pit walls where the fill had risen above the level of undercut pit walls.

Earthworks technicians and geotechnical professionals regularly advised the earthworks contractors on safety issues and maintaining the integrity of the exclusion zones. While there was generally a strong appreciation of safety, on occasions warnings had to be issued where operators of plant directly dumped material within the exclusion zone and therefore directly against unstable rock faces.

## 6 FILL COMPACTION

Various techniques were trialled to achieve compaction of fill up to the pit walls. Early trials using a pad foot wheel compactor attached to the excavator boom proved ineffective (Figures 9 and 10). Such equipment is generally used to compact trench backfill where the fill is laterally confined. Working perpendicular to the pit wall the lack of lateral confinement resulted in poor compaction. Even if compaction could have been achieved, the productivity of this equipment was unacceptable for a project of this size.

Figure 9: Pad foot wheel trench backfill compactor.

Figure 10: Pad foot wheel roller.

The contractor then modified a towed pad foot roller to enable it to be attached to the boom of an excavator (Figures 11 and 12). A welded coupling strong enough to survive the operation of the roller took some time to achieve but eventually a workable system was produced. Trials were carried out to assess the efficiency of this plant and a method specification of 20 passes of the roller was established.

Figure 11: Modified towed roller attached to excavator.

Figure 12: Modified towed pad foot roller.

The roller/excavator combination was used for the lower levels of a relatively small section of the north pit wall. Productivity was a concern, given the total length of the north pit wall subject to an exclusion zone. The earthworks contractor resolved this issue by mobilising a remotely controlled CAT815 pad foot compactor (Figure 13).

Figure 13: Remote controlled CAT815.

This machine is versatile in that it can be operated from the cab or remotely by radio control. The contractor reports productivity in remote control mode of about 40% of that which can be achieved when an operator mans the cab. In remote control mode the machine cannot spread fill and a 30 tonne excavator is required to place and spread each layer up to the pit wall. The authors recommend such plant where possible consequences of slope instability may include injury or even death.

## 7 LANDSLIDE REMEDIATION

A major design issue for filling works was what to do with the existing landslide and buttressing fill. If the landslide material was left in place, a relatively large area of the infilled pit would be unsuitable for residential development and there would be an ongoing risk of instability and settlement of fill placed over the landslide. Therefore, removal of the landslide material and fill buttress was considered essential if the objectives of engineered backfilling to the pit were to be achieved.

To achieve the removal of the landslide material without remobilising the landslide and causing it to regress into privately owned properties uphill of the site, the existing buttress would have to be augmented to increase the factor of safety and then, under controlled conditions, progressively removed and replaced with engineered support – such as rock anchors and drains, augmented with safety measures such as batter mesh and rock bolts.

The following three options were considered:

- Option 1 - Removal of the landslide material and buttressing fill, and installation of anchors and drains for the full height of the back scarp behind the landslide.
- Option 2 - Removal of the landslide material and buttressing fill and installation of anchors and drains to RL82m and sequenced excavation and replacement of the remaining landslide and buttressing fill without installing drains or anchors.
- Option 3 - Partial removal of the landslide and buttressing fill, leaving some material at lower elevations.

Options 1 and 2 would have reduced the size of the exclusion zone for residential development but incurred greater cost and involved higher risk of instability due to the greater amount of material that would be removed. Option 3 was lower cost, but the remaining landslide material and uncompacted buttressing may result in an increased area where residential development would be restricted. A flexible approach was adopted removing the landslide to RL82 m and then assessing the remaining landslide material and uncompacted fill.

Reliance was placed on the buttressing effect of the existing slide material for those sections below the level of rock reinforcement.

The design that was implemented required:

- The diversion of surface drainage above the slide area before commencement of work.
- Fill placed over the existing slide materials to provide access to the top of the landslide. The design allowed for placement of an enveloping fill placed in layers not exceeding 750 mm thickness, working from the base of the pit climbing up and around the slide material and trafficking with heavy plant to achieve compaction. A slope of about 1V:1.4H is indicated to provide a soil slope with sufficient level of stability for access by bulldozer and excavator.

- Removal of the slide material from the top down; achieved by using the existing slide material to gain access to the top of the slope.
- Scaling followed by installation of batter mesh and rock reinforcement measures such as drainage holes and stressed strand anchors progressively as the excavation proceeds.

Rock anchors were 19 m to 22 m long strand anchors with a 4 m bonded length, 330 kN to 600 kN design load. Although the anchors were to be temporary their required service life was a minimum of several years and could potentially have been many years if the project was delayed. Therefore, greased sheathing was specified for the free length of all anchors although the free length was not cement grouted as would be the case for a permanent anchor. As the fill has been brought up to the level of the anchors they have been de-stressed by knocking off the anchor blocks with an excavator bucket.

Figures 14 to 17 show schematics of the stages of support and excavation of the landslide mass.

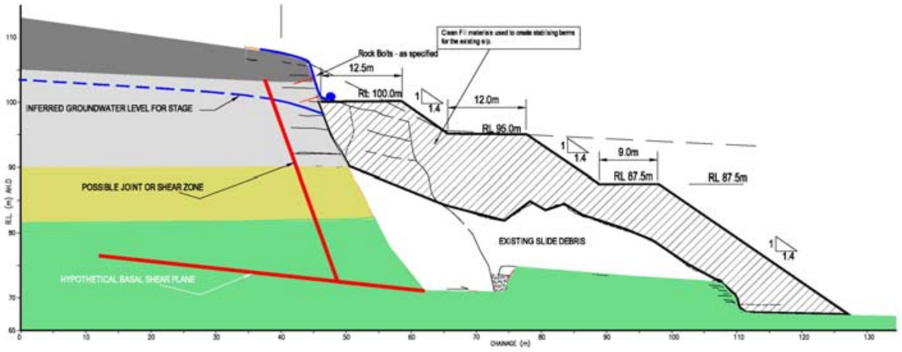

Figure 14: Stage 1- Construct access ramp and shape buttress.

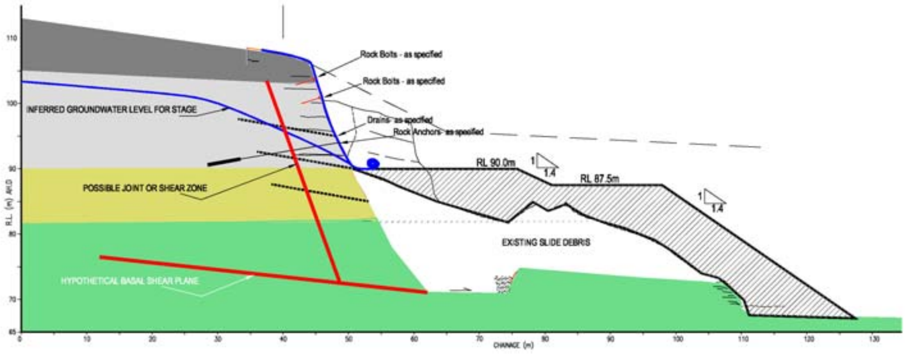

Figure 15: Stage 2 - Excavate landslide and install mesh, drains and 1 row of rock anchors.

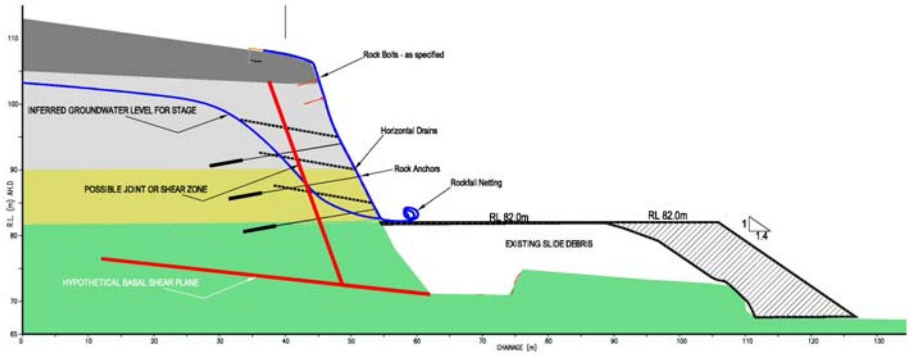

Figure 16: Stage 3 - Excavate landslide and install mesh, drains and 2 rows of rock anchors.

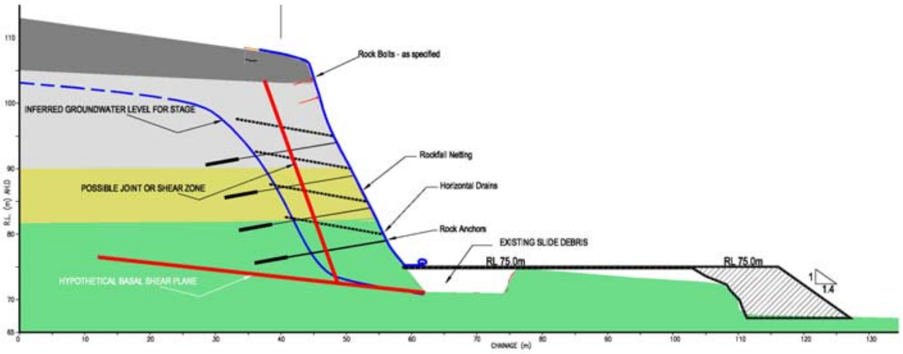

Figure 17: Stage 4 - Leave landslide debris where possible and buttress with engineered fill.

The fill and landslide materials were progressively removed down to RL82 m level. At this level the exposed slide material comprised relatively fresh shale that had moved as a block into the drainage ditch during the 1999 landslide. The edge of the slide material was assessed to lie far enough north so as not to encroach on residential lots. Therefore, a combination of Option 2 and Option 3 was adopted. Buttressing fill and landslide material was removed progressively, but a large block of fresh shale slide material was left *in situ* to avoid installation of anchors and drains below RL82 m.

Figure 18 shows the remediated landslide area with three rows of anchors and with some landslide material left in place and buttressed by fill.

Figure 18: Remediated landslide with remaining slip material left at base.

## 8 CONCLUSIONS

The Eastwood Brickworks Project illustrates rockface stabilisation and earthworks design and work methods that can be successfully employed to place and compact fill within old quarry pits where significant slope stability issues exist. Geological mapping, slope stability risk assessments and design of integrated stabilisation works and earthworks are required to meet project objectives without significant risk to site workers. The design for this project featured:

- A combination of scaling and batter mesh was used to reduce the occurrences and impacts of rock falls.
- Horizontal drains in areas assessed to be of critical stability.

- Pattern rock bolting was not used due to factors such as safety cost, practicality of installation and potential ineffectiveness due to the fractured and undercut nature of the pit walls.
- Exclusion zones were used to overcome the shortcoming of stabilisation works.
- Innovative remote controlled compaction plant was used to achieve compaction within the exclusion zones.

A major feature of the project, requiring design of slope stabilisation works within the framework of an earthworks program, was the remediation of a large landslide. Earthworks were used together with stabilisation measures such as temporary rock anchors, horizontal drains and batter mesh to remediate the landslide and loose buttressing fill. A flexible design allowed assessment of the extent of removal of landslide material to achieve economies.

## 9 REFERENCE

AS3798 (1996) “Australian Standard: Guidelines on earthworks for commercial and residential developments”, Standards Australia.