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THE SPECIFICATION OF UNPROCESSED ROCKFILL FOR HIGHWAY APPLICATIONS - A CASE STUDY FROM THE COFFS HARBOUR BYPASS

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ABSTRACT

Efficient utilisation of site won materials is the key component for successful delivery of any earthworks scope. Materials and construction methods need to be fit-for-purpose, providing long term performance confidence for use in earthworks design. The Coffs Harbour Bypass project presents a unique materials management challenge with over 1M m^3 of material in cuttings requiring blasting within high strength siliceous metamorphic geology (Argillite). To meet the earthworks Specification for embankment construction this quantity would need to be crushed and processed, placing significant strain on delivery program and cost.

A project-based method specification was developed to suit the site geology and unprocessed blast condition, providing an efficient mass haul while ensuring performance requirements can be met over the design life. Laboratory testing, compaction trials and routine engineering geology assessment of the source cuts show that an unprocessed rock fill material can be produced that exhibits a well graded particle size distribution with high strength and durability properties. Analysis of these attributes show that the contract performance criteria including stiffness and post construction settlement can be met.

1 INTRODUCTION

This paper presents a case study on the use of unprocessed rockfill to construct road embankments. The paper aims to describe the material utilisation challenges faced by the hard rock geology encountered as part of the cut to fill earthworks and its implications to design, specification and construction. The case study shows the collaborative approach to use the site won rockfill and the site-specific modifications to project specification achieved resulting from research into previous rockfill use, site trials, developing testing methods, analysis and method specification development.

2 PROJECT DESCRIPTION

The Coffs Harbour Bypass is a dual carriageway highway with a total length of 14 km. The project consists of a 12 km ‘greenfield’ bypass of Coffs Harbour between Englands Road intersection in the south to Korora Hill in the north, and two-kilometre upgrade of the existing Pacific Motorway from Korora Hill to Sapphire Beach. The project comprises significant excavation within hard rock geology including three tunnels at Roberts Hill (158 m), Shephards Lane (321 m) and Gatleys Road (410 m).as well as cuttings up to 40m deep

The project is delivered within a Collaborative Design and Construct contract by the Coffs Harbour Bypass Team comprising:

- Transport for NSW (Principal)
- Ferrovial Gamuda Joint Venture (Contractor)
- Arcadis Sener Joint Venture (Designer)
- Aurecon (Independent Certifier)

3 EARTHWORKS SCOPE, SPECIFICATION AND DESIGN

Piccolo et al 2019, outlined the importance of a unified approach to earthworks design, construction and certification. This approach included aims to produce landform suitable for the proposed development, ensuring that construction is controlled to achieve the performance criteria, enable earthworks certification and ensuring this is achieved at the least cost. The rockfill method specification for the project was developed by engaging all delivery partners from initial concept to construction, working within the Collaborative Design and Construct contract.

3.1 SCOPE OF WORKS AND TECHNICAL CRITERIA

The geotechnical design for the highway embankment is defined in the contract Scope of Works and Technical Criteria (SWTC). This is developed by the Principal and details the performance criteria for the earthworks to provide support to the pavement in design life. These criteria include outlining the pavement design lifespan (40 years), the limits of post construction settlement (including differential settlement) to design for and stability criteria for embankment and cut design.

3.2 EARTHWORKS SPECIFICATION R44

Earthworks Specification R44 is provided by the Principal and is typically generic for all earthworks projects constructed as a TfNSW asset. The intent of earthworks specification R44 is to set out the requirements for earthworks for roadworks, in order to create a stable formation suitable for a pavement to be constructed upon using the materials from within the site. Site specific departure of the Specification can be developed to provide efficient earthworks to meet program requirements and site conditions.

R44 defines earth fill as material that derive their stability from compaction of the fine material around the coarser particles. This is specified as rock weight percentage being no less than 60% passing the 37.5mm sieve, with a maximum particle size two thirds of the layer thickness. Cohesive earth fills can be placed, compacted and tested using conventional means where the high fines content creates a soil matrix that supports the particles providing the fill with strength, stiffness and low permeability.

The Specification defines rockfill as hard sound durable rock with limited fine particles which when placed derives its stability from the mechanical interlock of the coarser particles rather than finer particles around the coarse particles.

Rockfill material shall meet the grading and strength requirements outlined in Table 1. The specification outlines the need for screening and / or processing to achieve this grading

Table 1- Earthworks Specification R44 Rock Fill Material Properties

Property	Requirement
Maximum particle dimension	300 mm
Percentage passing:	
100 mm AS sieve	0 – 20%
19.0 mm AS sieve	0 – 10%
1.18 mm AS sieve	0 – 5%
Percentage of +100 mm fraction with $I_{s(50)}$ < Annexure R44/A2.2	10% (max)
Wet/Dry Strength Variation	Max 35%

3.3 EARTHWORKS DESIGN

The earthworks are designed to meet the performance criteria set by SWTC and must be constructed in accordance with the Earthworks specification. The challenge of good earthworks design is to meet the contractual performance requirements, using the Earthworks Specification, while also providing a safe, efficient and workable solution that can be constructed to project timeframes and cost. In addition to this, the earthworks design and construction needs to be certified at completion. The role of certification lies with the Independent Certifier (IC), not affiliated with either the Principal, Designer or Contractor. To undertake the Earthworks Design, the Designer develops a Geotechnical Investigation Plan that informs an Geotechnical Interpretation Report, compiling all the geotechnical information to provide a geotechnical model and parameters to use in design.

4 PROJECT GEOLOGY

The Coffs Harbour Bypass is in the southern region of the New England Fold-Belt. The alignment sits to the southeast of the Coffs Harbour Orocline within meta-sedimentary rocks of the Coffs Harbour Sequence.

The project route is underlain by metamorphosed sedimentary rocks deposited as turbidite sequences within a regional scale accretionary wedge structural domain (Korsch 1981). The sedimentary rocks have undergone two phases metamorphism including initial low-grade metamorphism ranging from prehnite-pumpellyite to lower greenschist facies. Secondary contact metamorphism associated with granitic plutonism has occurred affecting fine sediments (Graham and Korsch 1985). The structural orogeny and metamorphic phases have created three main lithostratigraphic units than make up the Coffs Harbour sequence (Gillian, L., Brownlow, J., Cameron, R., Henley, H. 1992):

- Brooklana beds (Ccor) – thinly bedded siliceous mudstone and siltstone with rare lithofeldspathic wacke, locally chert, magnetite bearing chert and metabasalt.
- Coramba beds (Ccoc) – lithofeldspathic wacke, minor siltstone, siliceous siltstone, mudstone meta basalt, chert and jasper.
- Moombil beds – black massive, rare lithostratigraphic wacke and granule conglomerate. This unit is not present along the alignment.

The project alignment, as shown in Figure 1, is underlain by the Brooklana beds to the south and Coramba bends to the north with the boundary between the two located toward the centre of the project. Although the lithology of the metamorphic rock ranges from siliceous mudstone to greywacke sandstone, the term Argillite has been used to describe the lithology under the whole of the alignment and it is used locally to describe both Brooklana and Coramba units.

The metamorphic processes have formed a hard-durable siliceous rock. The rock fabric has been tightly folded, forming steeply dipping cleavage and defect structure that is typically very closely to moderately spaced (60 mm to 600 mm). The defect structure limits the maximum size of the excavated rock from this geology to 400 mm to 600 mm with some rare larger occurrences.

The rock strength of the slightly weathered to fresh Argillite ranges from medium to extremely high strength, with a mean value unconfined compressive strength (UCS) of 50 MPa and seismic velocity greater than 2100 m/s. The wide range of UCS is likely attributable to the test loading relative to anisotropy and cleavage of the argillite and the varying textures within the geological unit (ie meta siltstone to greywacke)

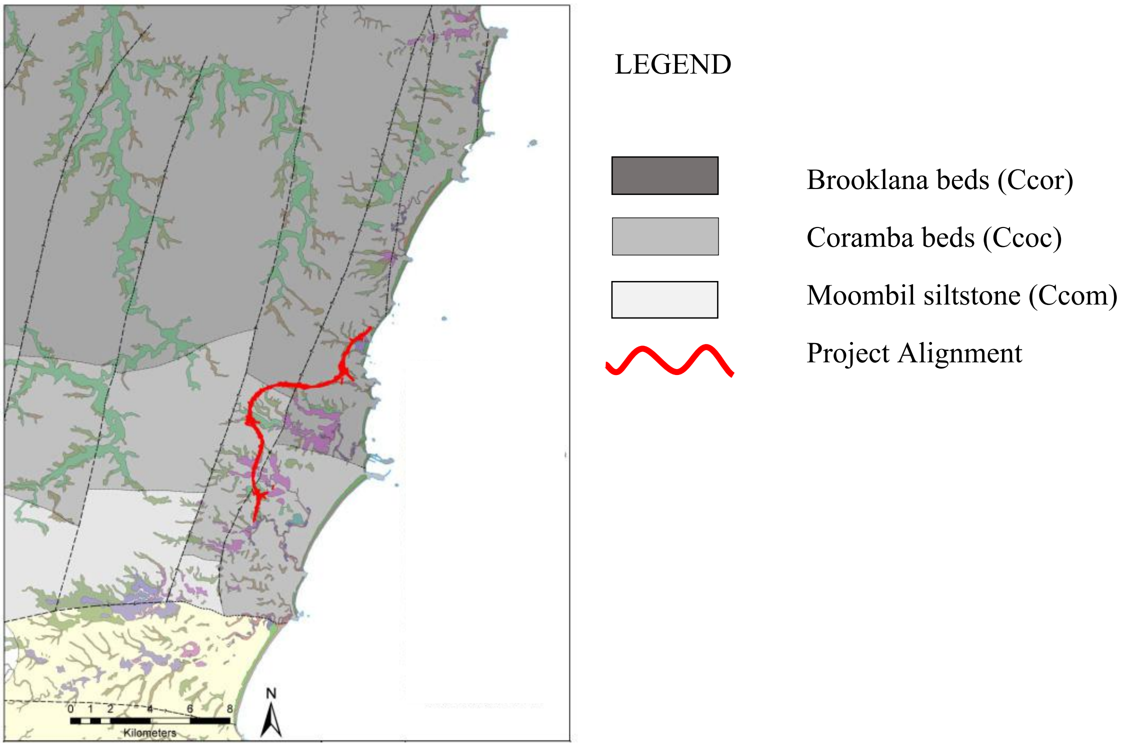


Figure 1 – Project alignment (in red) relative to regional geology (Gillian, L., Brownlow, J., Cameron, R., Henley, 1992)

5 EFFICIENT UTILISATION OF SITE MATERIALS

The design alignment through the project requires up to 3 M m^3 of cut to fill earthworks to achieve the design grade within the steeply undulating topography. This requires cuttings up to 40 m deep and fills up to 25 m high to be constructed. Geotechnical modelling of the alignment identified up to 40% of the cut mass haul occurring within marginal ripping to blasting strength material. Crushing and processing this material to the Specification rock fill or earth fill was considered cost and program prohibitive based on over 1 M m^3 required to be incorporated into embankment fill.

5.1 SUITABLITIY OF PROJECT GEOLOGY FOR ROCKFILL

During design development, local quarries within the Brooklana and Coramba formations were assessed and mapped for material as R44 rockfill. Observation and testing quarry blast piles, as presented in Photo 1, showed a durable, high strength rock. Particle Size Distribution (PSD) testing of the blast piles showed a maximum particle size in the order of 400 mm to 500 mm, up to 70% passing the 100 mm sieve and 60% retained on the 37.5mm sieve. The fine end of the grading has less than 5% passing the 1.18mm sieve with no observed ‘dirty’ fines (ie clay and fine sand).

The PSD positioned the unprocessed material within a non-conforming envelope between the Earth fill and Rock fill grading envelopes as shown in Figure 2. Due to the relatively small maximum particle size and the fractured nature of the rock, screening and crushing material to meet rockfill would produce significant wastage on the fine end (ie 70% of the rock would be too fine to produce rock fill). Conversely, a significant crushing and processing campaign would be required to comply to the Earth fill requirement of 60% passing the 37.5 mm sieve.

Photograph 1 - Blast pile of SW to FR argillite from Woolgoolga quarry within Coramba formation (Ccoc)

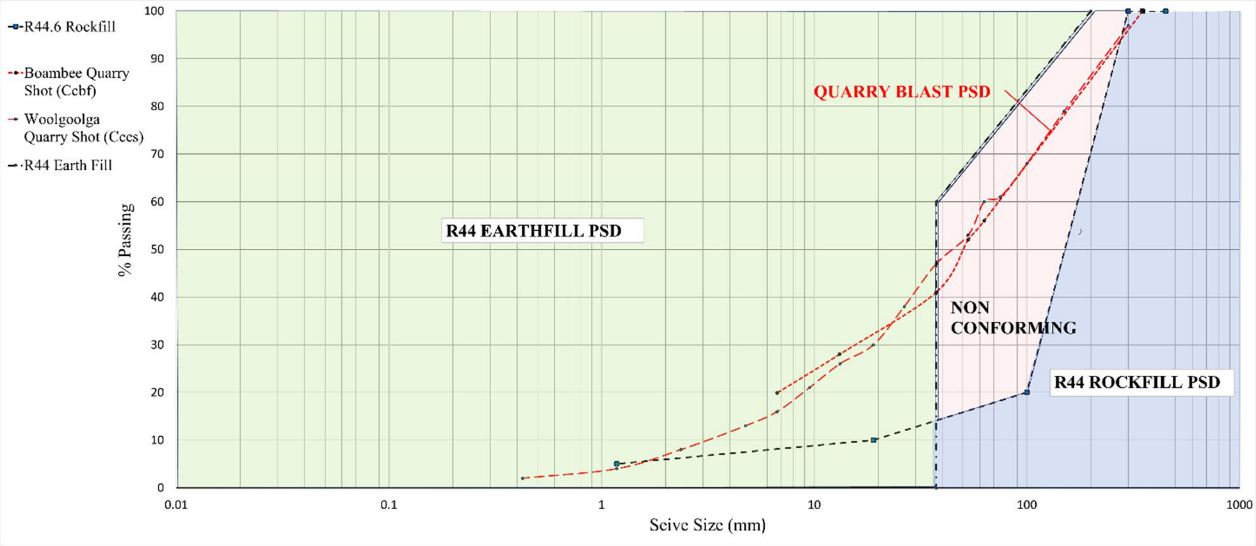


Figure 2 - Graph showing the PSD limits of R44 Earth fill and Rock fill compared to the quarry blast piles

5.2 PREVIOUS USE OF UNPROCESSED ROCKFILL

Unprocessed rock fill that has been adapted for site conditions for use in embankment construction on several sections of the Pacific Highway Upgrade. These include Alliance delivery projects at Bulahdelah, Coopernook and Kempsey. These projects included a large range of parent geology and maximum particle size.

A local example of unprocessed rockfill filling was identified as part of for Karangi Dam, located approximately 15km due west of the site (Dept of Public Works and Services 1996). The site based local quarry for the works won rock from the Coramba Formation (Ccoc). Construction reports show up to 67 000 m^3 unprocessed rock fill placed with an apparent grading less than 350 mm from observation of site photos, Photo 2 for example. Inspection of the dam site confirm this, with an observed maximum dimension of 300 mm, no apparent breakdown or significant weathering of the rock material and a good mechanical interlock of particles forming a 1.5H to 1V batter grade.

Based on the previous experience with rockfill on Pacific Highway projects and previous use of the local argillite rockfill in dam embankment construction, it was concluded that the slightly weathered to fresh argillite material could be used for embankment fill application adapting a site-specific specification for grading, strength and placement.

Photograph 2 Unprocessed rockfill dam embankment under construction at Karangi circa 1995

6 UNPROCESSED ROCKFILL TRIALS

A total of five rockfill trials were conducted on the project to develop the method specification of unprocessed rockfill for the project. The trial(s) provided research and development to support a project method specification that would meet the SWTC criteria. The initial trial (Trial #1), as shown in Photo 3, was conducted off the alignment, with subsequent trials incorporated into the project works. Two cut source locations were nominated to provide material for the trials;

- Cut 4 within the Brooklana formation (Ccor)
- Cut 16 within the Coramba formation (Ccoc)

Progressive mapping of each cut during excavation was compared to the project geotechnical model and core logs to confirm the presence of material suitable for rockfill. Where this was identified, the relevant blast bench was nominated as source material and incorporated into the trial.

The placement trials were conducted using site plant including bulldozers (Caterpillar D8) and flat drum rollers (Cat CS78B 18 tonnes) equipped with survey telemetry and intelligent compaction sensors. Each trial layer was modelled by survey and loaded into the onboard telemetry as a ‘design’ to control layer thickness.

A survey grid area of 5 m by 5 m was marked out at each trial site, with layer thickness measured after two roller passes. The survey was conducted by placing a control survey plate over the irregular surface to obtain a uniform surface for pick up for each successive survey.

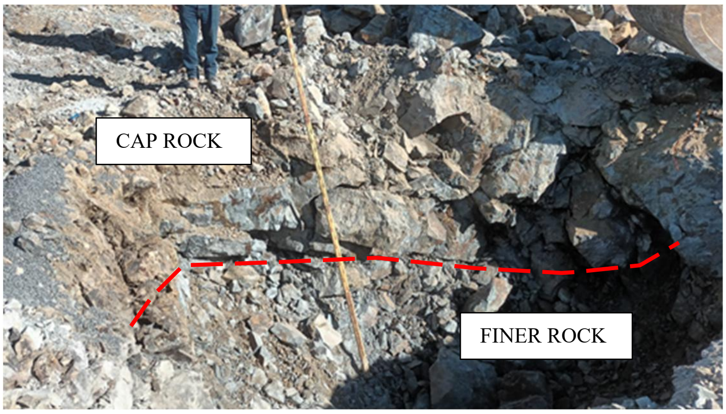
Table 2 – Summary of Unprocessed Rockfill Trials

Trial Number	Geological Formation	Cut Source	Fill Area	Aims	Results	Specification Development
1	Ccoc	Cut 16	TRIAL PAD	Develop pass count vs settlement correlation Assess the effect of water conditioning Assess the particle size distribution of the blasted rockfill Assess mechanical interlock and compacted condition of the fill Assess stiffness, internal settlement and durability Layer thickness performance between 500 mm to 600 mm (Compacted)	Material shows suitable attributes for earthworks construction that are likely to meet SWTC requirements 4 to 6 passes are suitable for compaction, no significant settlement of the layer between pass 4 to 6 Reduce compacted layer thickness to 500 mm in Trial 2 Cut source management needs attention, oversize reaching the fill site and having to be dealt with during placement Particle Size Distribution testing methodology needs to be reviewed, taking entire sample back to the lab is not feasible from a technical and OHS practicality perspective Full layer moisture conditioning required	PSD does not meet Specification requirements However, trial shows material can be placed under a method specification likely to meet SWTC requirements
2	Ccoc	Cut 16	Fill 17	Reduce layer thickness to 500 mm (compacted) Site specific PSD testing methodology Cut source Management Procedure Assess the developing trend of cut source PSD Assess stiffness of the rockfill in the dry and inundated condition	PSD showing a well graded trend Results of inundation testing show settlement estimates due to stiffness contrast can be accommodated within SWTC criterial Developing QA process to manage cut source production and fill placement	Trial confirms SWTC requirements can be met Need to develop QA process
3	Ccor	Cut 4	Fill 3C	Compare rockfill performance of Trials 1 and 2 within separate geology	Material from moderately weathered to slightly weathered zone of cut Significant breakdown noted in the fill placement Variability in the cut source between medium to high strength rock, difficult to manage at the source.	**Trial failed – abandoned**. Material from moderately weathered horizon is too variable in strength and placement breakdown
4	Cccs	Cut 16	Fill 17	Refine QA process Additional inundation stiffness testing conducted	Results of ongoing PSD testing used to develop a revised specification PSD envelope Develop Quality Assurance ITP and associated documentation for cut source and fill placement	QA process developed, Method Specification drafted
5	Ccor	Cut 4	Fill 4	Repeat trial for separate geology – slightly weathered to fresh argillite Repeat trial steps from #2 and #4 to compare, can both geological sources be incorporated into one method specification?	Less variability in cut source material PSD shows good comparison to the Cccs source Placement trials show that 8 passes limit layer settlement to less than 5mm Stiffness testing in line with Cccs trials	Slightly weathered to fresh Ccor material source can be used as rockfill to meet SWTC criterial. Project Wide Method Specification Finalised incorporating both geological units.

Photograph 3 – Trial 1 site showing marked up survey grid

6.1 CUT SOURCE

The blast bench in Cut 16 for the Trial 1 source comprised a drill spacing of 2.4 m x 2.4 m drilled to an average depth of 6m. The total volume of the blast for the trial was approximately 1300 m^3. Test pits excavated within the blasted material, as shown in Photo 4 for example, revealed an upper 1 m to 1.5 m horizon of larger cap rock with maximum dimension in the order of 600 mm to 800 mm. Below this level, the particle size fined to an approximate maximum dimension of 500 mm, with an apparent distribution of particle size between 50 mm to 400 mm.



Photograph 4 – Test pit into blast material

Managing the cut source was identified as a significant aspect to the method specification. Based on the initial blasts for the trials and observation of the quality of rockfill arriving to the trial fill site, it became apparent that:

- Sorting of oversize cap rock at the source is integral to the quality of rockfill. This was reinforced on site by instructing excavator operators on the size of material to load out and oversize to put aside. It is also important that there be operator continuity at each cut source; and
- Clearly identifying the extent of the acceptable material. The engineering geologist delineates the blast bench and informs the excavator operator and leading hands on the acceptable appearance of slightly weathered to fresh material to load out.

Documentation and daily inspection of the load out face was conducted by the engineering geologist and loaded into the QA lot. This comprises a daily mapping record of the excavation face identifying suitable material and delineating material unsuitable for unprocessed rockfill material.

Photo 5 shows a typical stockpile of unprocessed rockfill ready for use.

Photograph 5 - Material to be used for unprocessed rockfill trial

6.2 LAYER THICKNESS AND COMPACTION

Survey of the layer settlement between each pass showed a total of 40 mm to 60 mm of settlement after eight vibratory passes of the 18 tone flat drum roller. Up to 75% of this settlement occurred after the first 2 passes with less than 5mm of settlement occurring between Pass 6 and 8. Survey showed that the modelled loose layer thickness provided a 90% confidence on compacted layer thickness after the 8 passes of the flat drum roller. Test pits were excavated into the trial after placement to assess the condition of the rock fill. The test pits, as shown in Photo 6 for trial 1 pad, revealed:

- Good correlation with surveyed layer thickness.
- An upward fining of particle size attributed to the compactive effort and attrition of the bulldozer and roller during placement.
- Trench sides showing good definition with no slumping of the rockfill. Moisture conditioned trench side were measured at 65° to 70°.
- A homogenous mixture of rockfill with no zones of segregation, voiding or accumulation of fine material.
- Rockfill material that comprised an angular coarse gravel to cobble sized material (ie 40 mm to 200 mm) with some larger particles (500 mm) and a trace of very large particles (500 to 700).

Photograph 6 - Trial 1 test pit showing good trench side definition

6.3 PARTICLE SIZE DISTRIBUTION

Particle size distribution (PSD) testing in the large rock fill required modification to TfNSW T201 method to provide tester safety and efficiency due to the large sub sample mass required to representatively test the material.

The site-based methodology comprised:

- Sampling the face of the rock fill source with the loadout excavator equipped with a load cell. A minimum 3 tonne sub-sample is weighed and recorded by the tester and loaded into a dump truck.

- The truck dumps the sample at a purpose-built testing site comprising concrete bays with a steel base adjacent to the cut source. The load cell equipped excavator 'sieves' the sample through a custom built 100 mm slotted bucket
- The retained rock mass is measured by the excavator and material passing is representatively sub sampled to continue the PSD test in the soils laboratory.

Figure 3 presents the results of 69 PSD tests conducted as part of the trial(s), with Photo 7 showing the good mechanical interlock rock fill. Results of particle size distribution conducted from both the cut source and fill placement confirmed non-conformance to the grading requirements in R44 Specification.

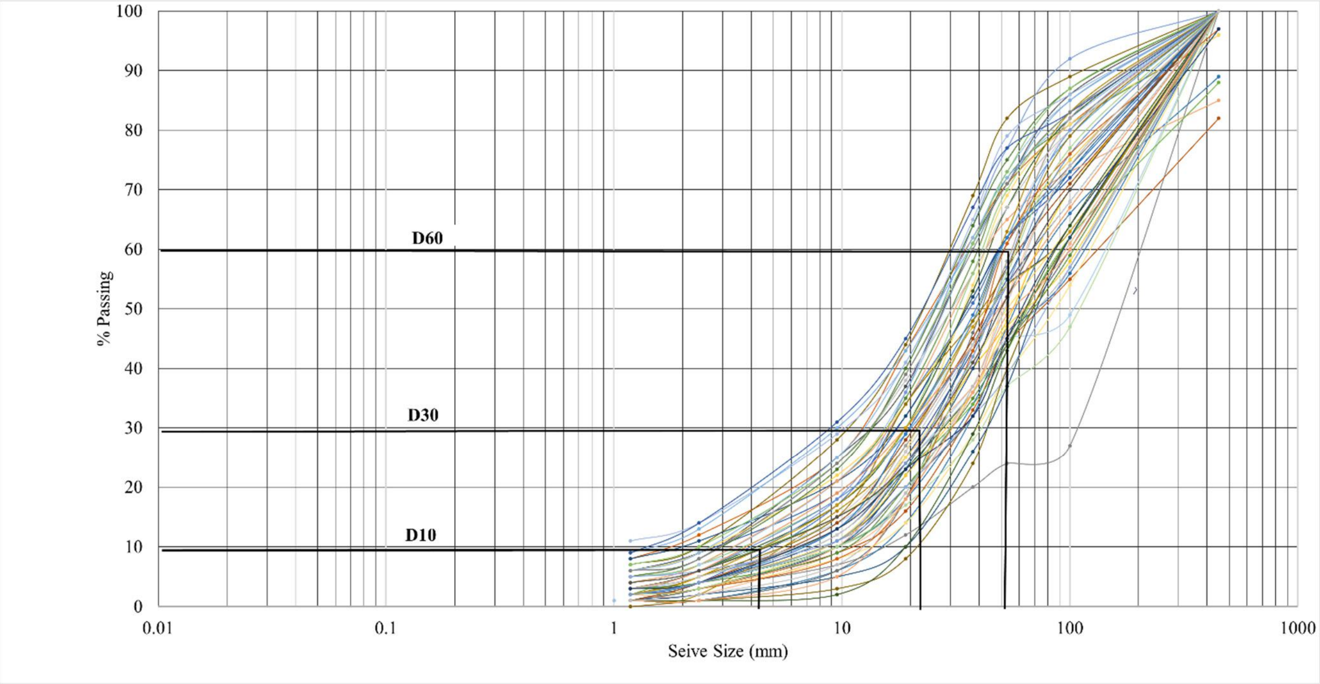


Figure 3 - Particle size distribution testing conducted during the trials

Photograph 7 – Particle size distribution and mechanical interlock exposed in Trial 1 test pit.

7 ANALYSIS

7.1 PARTICLE SIZE DISTRIBUTION COEFFICIENT

Risk associated with coarse fills is that a poorly graded PSD is developed within the compacted material. This may lead to internal erosion within the compacted mass where finer material migrates downward within the fill profile, causing voiding and potential collapse settlement. The observed condition of the compacted layers show both an interlock and point to point particle contact of the intermediate grain sizes. The packing of finer particles between this interlock of larger particles is observed in Photo 7. Uniformity coefficient (Cu) and coefficient of curvature (Cc) were used to assess the grading and potential for tight packing. Results show a well graded material with Cc between 1 and 5 and Cu greater than 4. The finer material (less than 1.18mm) is a minor component of the grading and is granular in composition. No significant cohesive fines (less than trace < 5%) were observed supporting the rock particles under compactive effort. PSD as shown in Figure 4 and strength testing was undertaken from the fill placement and compared to the corresponding source material testing for both geological sources. This comparison shows no significant breakdown post compaction for both geological sources and loss in material strength.

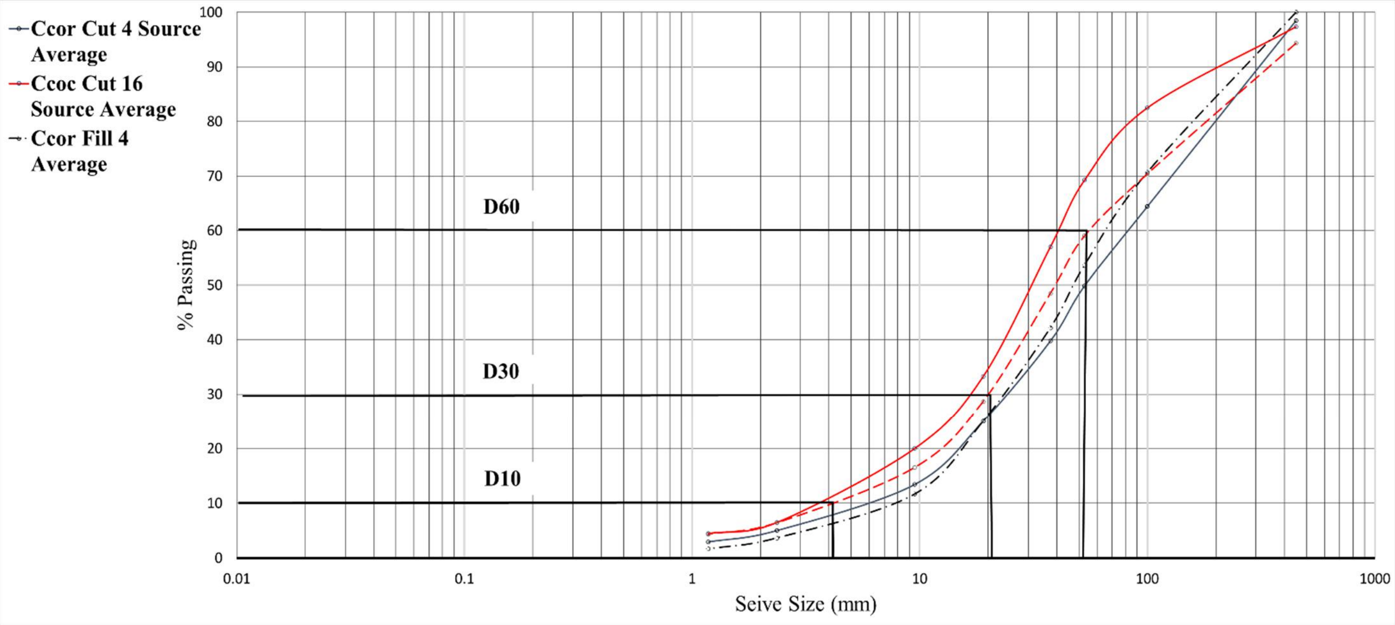


Figure 4 - Blast Source compared to Fill Placement Average Particle Size Distribution

7.2 STRENGTH AND MECHANICAL INTERLOCK

Material testing of both the Coramba and Brooklana sources show an average point load strength between 1 MPa to 6 MPa (Is50), wet dry variation that is typically below 35% and a wet strength between 200 kN to 250 kN. Both sources show very low slake durability breakdown (> 95% retained on 2nd cycle), and a high peak angle of internal friction of 43° to 48° tested on material passing the 37.5mm sieve. Strength testing shows that the parent rock is a hard durable material that is not susceptible to breakdown in both the wet and dry condition. The rock does originate from an argillaceous sedimentary source, however successive periods of deformation and burial have metamorphosed the original fabric to create a rock mass dominated by an indurated siliceous matrix and stress cleavage. .

7.3 INTERNAL SETTLEMENT

Twenty-five plate load tests were conducted on the trial fill placement. Results for Youngs modulus show a 90% confidence of E 50MPa which is in line with design assumptions for high strength rockfill.

Hunter et al 2002 provides a comprehensive review of rockfill dam deformation from over 40 concrete face rockfill dams worldwide. Results of this review show a summary of creep strain rate of compacted rockfill for medium strength to very high strength sources for embankment heights greater than 20 m. When extrapolated to an embankment height of 10 m to 15 m in line with project design, the long-term rate of settlement is estimated to be less than 0.05% of the embankment height per log cycle of time for high strength rock fill. This is shown in Figure 5. Waddell (2005) show between 0.05% to 0.16% creep strain for compacted medium strength sandstone fill.

Based on this and the high strength of the trial rockfill, a conservative creep strain rate of less than 0.1% per log cycle of the embankment thickness is considered reasonable is less than the SWTC criteria.

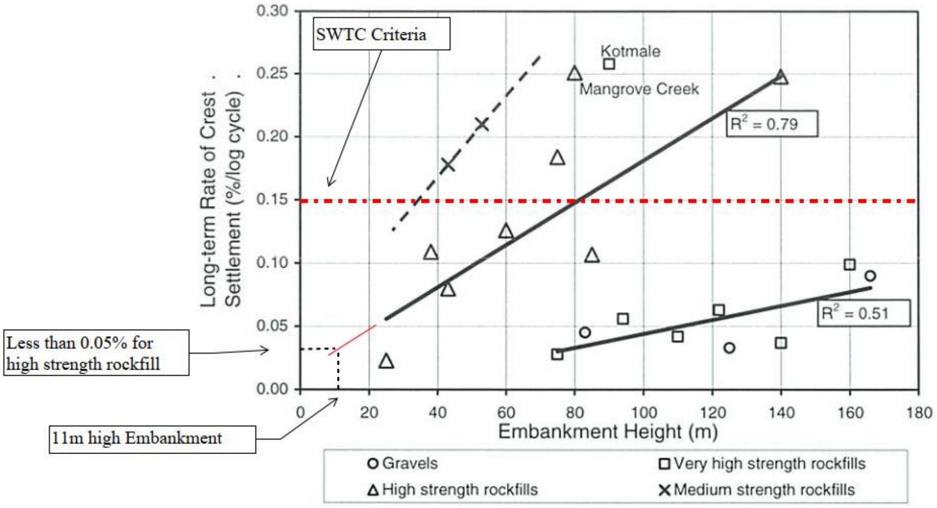


Figure 5 – Estimated long term rate of embankment settlement after Hunter and Fell 2002

7.4 HYDROCONSOLIDATION

Hydroconsolidation is a collapse compression occurring when uncompacted or partially saturated fills are inundated, causing increased, rapid settlement. In rockfill or large granular fills where the stiffness of the fill relies on the point-to-point contact between particles, the properties of the rock fragments and susceptibility to softening of the highly stressed point contacts controls the magnitude of hydroconsolidation settlement. Controlling this effect relies on controlling the strength, compaction and moisture conditioning during placement of the fill. The potential hydro consolidation effects of the rockfill after inundation were tested in Trials 2, 4 and 5. The test included conducting a plate load test in the dry condition on top of placed rockfill, then constructing a bunded area around the test site and inundating the site with water for 3 days. Measurements of settlement and an additional plate load test was conducted after the period of inundation.

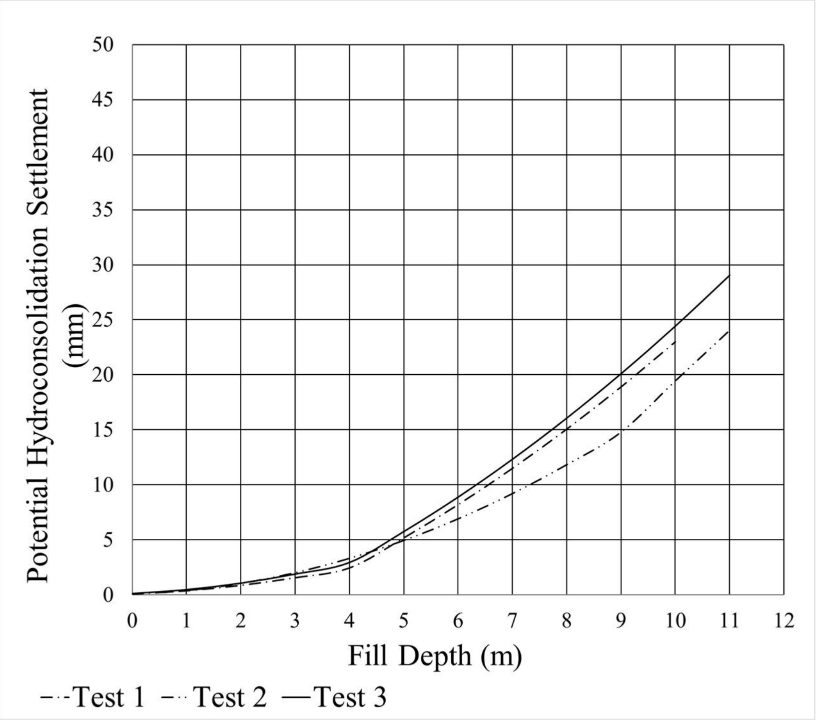


Figure 6 - Plot of Estimated Hydro Consolidation Settlement

The settlement for each 1 m layer was calculated for both the dry and inundated Youngs modulus taken from the plate load testing. The difference in settlement for each layer is plotted in Figure 5. Results of the analysis show an additional 25 mm to 30 mm of settlement may occur over a fully inundated 11m fill height (Trial Site Fill 17) due to hydroconsolidation. This would require an extreme weather event to flood the full height of the embankment and is considered unlikely. Events that flood the lower 2 m to 3 m of the embankment are more likely in flooding conditions. Based on such an event, hydroconsolidation settlement in the order 5 mm to 10 mm may occur. If the worst-case scenario of the full height of fill becoming inundated, the predicted settlement of up to 30 mm would still be acceptable from a pavement serviceability perspective noting that SWTC criteria for flexible pavements allow up to 200 mm of total residual settlement.

8 METHOD SPECIFICATION AND PROCESS CONTROL

Using the results of the trial, a method specification was developed to control the process of sourcing and placing the unprocessed rockfill. This included

- A revised PSD envelope in line with the results of testing conducted.
- Incorporating coefficient of uniformity and curvature requirements to ensure a well graded material was being placed in the fill.
- Daily cut source mapping by the engineering geologist and sorting of oversize by construction at the source.
- Regular blast and fill source strength and durability testing, including point load testing, wet / dry variation and slake durability.
- Pre modelled loose layer thickness to provide a compacted layer thickness of 500 mm.
- Minimum pass count and roller weight (18 tonne flat drum) during compaction. Each roller on the rock fill was equipped with intelligent compaction to measure pass count and coverage as well as guide on layer strength gain (CMV value).
- Test pit inspection and logging of the placed layer by the geotechnical CPS team to confirm full layer moisture conditioning and material interlock.
- Plate load testing during filling to confirm design stiffness requirements are met.

9 CONCLUSIONS

The proposed alternative of using unprocessed rock fill presented issues of conformance and certification in line with the project earthworks Specification. The identification of the issue due to geological assessment at concept stage, provided a departure to the Specification that could demonstrate adequacy to the landform requirements, be constructed in a methodical manner with the process tested, documented and certified. The modified Specification also enabled economic construction of the bulk earthworks by using the unprocessed rockfill won directly from cuts. The case study shows how a unified approach by all stakeholders can provide a best for project outcome under the Collaborative Design and Construct delivery contract.

10 AKNOWLEDGEMENTS

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