RESEARCH AND ANALYSIS OF GEOSYNTHETICS FOR A TAILINGS STORAGE APPLICATION

Marc, AMTSBERG[1], John, BUCKLEY[2], Chris LANE[3]

[1] Sector Manager Mining, Geofabrics Australasia, Gold Goast, Australia, **:** *m.amtsberg@geofabrics.com.au*
[2] Business Development Manager SFL Piletech, Gold Coast, Australia, jbuckley@sflpiletech.com.au
[3]2LMGSPL, Perth, Australia, lmgspl@bigpond.com

This paper describes the benefits of using performance based geosynthetic testing for a copper-gold tailings storage operation in South Australia. This particular location requires strict environmental controls in a sensitive environment. Consultation occurred early during the approvals process to provide geosynthetic design guidance on the tailings storage facility site and design which had been selected. The regulatory requirements had two aims. The first was to provide a primary under-drainage collection system and the second was to provide a low permeability barrier in the form of a clay liner or geomembrane.

In the preliminary design stage of this tailings storage facility, technical issues were addressed through a number of options. Refinement of the options and selection of the final option required a project specific testing regime to demonstrate its effectiveness.

The selected option comprised a double HDPE geomembrane with a tri-planar drainage geonet as a leak detection system. The over-drainage on the top liner comprised another tri-planar drainage geonet overlain by a geotextile in order to meet flow requirements. The tri-planar HDPE geonet was internally reinforced enabling in-plane flow rate to be maintained at high compressive loads. A thorough evaluation of the proposed tailings storage under-drainage and lining system was carried out in order to establish an equivalent or superior performance to the original design alternatives. The relevant evaluation analysis included:

1. Filtration testing using a modified Gradient Ratio test
2. Hydraulic analysis and performance assessment of the proposed design profile for in-plane flow at normal pressures up to 1000kPa under long-term conditions
3. Detailed performance analysis of the geonet, geotextile, and geomembrane interfaces under high normal stress

The use of geosynthetics in primary tailings drainage systems must be a design-for-function process as index specifications do not address the range of performance criteria found onsite. Geotextiles must consider clogging potential for each tailings medium as segregation risk and precipitation properties may have an unwanted influence on filter performance. Geosynthetic performance testing should be considered early in the project design stage. A robust testing regime can be a key part of the approvals process providing the client with design alternatives that consider and control engineering risk and project economics.

Keywords: Geonet, Geotextile, Geomembrane, Drainage, Filter, Tailings

1 INTRODUCTION

The site is located in the Mount Lofty Ranges, 55 kilometres southeast of Adelaide, South Australia. The mine is located within the catchment of the Murray River and is therefore located in a sensitive environment. The project is situated within the Kanmantoo Trough, which is an axial zone hosting numerous former base metal and copper-gold mines and has been the subject of sporadic mining activity of both vein and replacement style deposits since the mid 1800's. A mine previously operated at the site from 1970 to 1975 when mining ceased and the mine was placed on care and maintenance in 1976. The mine produced a total of 4.1 million tonnes of copper ore. Operations ceased due to low copper prices, a high exchange rate and increasing costs. In April 2004 another company acquired the mining lease and commenced exploration of the deposit and undertook various studies to bring the project into production.

The selected style of tailings storage facility (TSF) for the new project was an integrated waste landform (IWL), one of the options examined as part of an initial scoping study. The IWL is simply defined as a tailings storage facility (TSF) that is located inside the waste rock storage. It is formed by placing controlled, compacted, earthworks to form a containment embankment to retain the tailings. Mine waste is placed around the outer edge of this containment embankment such that a void is formed inside the storage. This void allows for further controlled, compacted, earthworks around the circumference of the void to form a perimeter containment boundary between the tailings and the mine waste.

Prefeasibility studies for a number of waste storage options and configurations had been undertaken prior to the selection of the final site. The site selected for the IWL was based on consultation between representatives of the Mining Company and representatives of Primary Industries and Resources South Australia (PIRSA). The site required a lined Tailings Storage Facility (TSF) to store both tailings and waste rock that met regulatory lining requirements and maximised water recovery.

Initially 1.75m thick of compacted clay and a herring bone panel pipe drainage system was considered for the base of the TSF. Containment embankments comprised compacted clay with a horizontal width of 5m. However it was determined that a geomembrane lined facility with a leak detection system would better serve to meet regulatory requirements.

Certain unknown Geosynthetic properties manifested during the design process, focussed on the impact of confining pressures up to 1000kPa on the drainage and lining system, and the impacts of fine grade tailings on the geotextile filters making up part of the drainage system. It was the design intent to establish test values of the specific Geosynthetics under as many project conditions that could be replicated in the laboratory to provide design values and Safety Factors to establish a better understanding of long term performance of the filters, drainage and lining system.

2. DESIGN OPTIONS

2.1 DESIGN OPTION 1

The initial design option presented to the regulators in October 2007, comprised compacted clay liner of 0.75m over insitu clay of 1.0m (a total thickness of 1.75m) with a primary drainage system consisting of herring bone panel drains. The construction risks for this proposal included volumes of suitable clay available for construction, economics of sourcing clay from a number of borrow sources identified around the site and construction quality control and the survivability of the clay liner during construction and operation. Design questions included the potential for blinding of the geotextile materials wrapped around the underdrainage pipe and the granular filter in which the underdrainage pipe was to be placed and ability of the proposed drainage systems to perform under the extreme loads of 55m of tailings (1000kPa).

2.2 DESIGN OPTION 2

The construction and operation risks of Option 1 for a compacted clay liner resulted in the development of the next option which comprised 1.5mm HDPE geomembrane liners in lieu of the compacted clay. The design comprised a double HDPE liner with a flownet leak detection layer over the base area likely to be flooded by the design storm event, and a single HDPE liner over base areas unlikely to be flooded by the design storm event. A primary underdrainage drainage system similar to the design for Option 1 was retained for Option 2. Further questions were raised based around mitigation of liner damage during construction of the underdrainage system. A layer of crusher dust waste was proposed as the material to enable the surface of the liner to be trafficked during construction. Sourcing of the crusher dust materials and construction risks posed challenges in terms of cost and constructability.

2.3 DESIGN OPTION 3

The construction risks associated with Option 2 resulted in the same liner profile with the primary underdrainage system replaced with a flownet and geotextile filter. Laboratory testing designed to replicate project parameters was carried out at the Geosynthetic Centre of Excellence. Testing included suitability and direct comparisons between the panel drain system and a drainage geonet for primary drainage performance. Potential geotextile damage and the impacts of the geonets in terms of strain values transferred to the geomembranes were tested under 1000kPa to ensure liner integrity under long term normal stresses. A selection of geotextiles were tested in direct contact with both full Tailings samples and segregated fine samples, to establish clogging and retention potential.

The testing led to the final design for construction of a lower specification 300mm clay layer with a 5mm triplanar geonet sandwiched between 2mm HDPE geomembranes to serve as leak detection. The primary drainage collection system consisted of a 5mm triplanar geonet with a select nonwoven needle punched polyester geotextile in intimate contact with the tailings media.

3. LABORATORY TESTS AND DISCUSSION

3.1 FILTER PERFORMANCE TESTING

3.1.1 TEST SUMMARY

Both the panel drain and geonet design would rely on filter performance of the upstream Geotextile in terms of a balance between particle retention and prevention of clogging of the drainage system. The immediate advantage of the geonet system over a pipe wrapping was increased surface area of the filter geotextile that could allow direct placement of the tailings medium. The key question was whether filter performance would be achieved with a tailings medium with full fraction under 600 microns and 15% under 75 microns, with segregation potential upon deposition that would require consideration (Palmeira et al 2010). The concern with the incorporation of a geotextile filtration layer is threefold:

a. the geotextile would clog preventing flow of liquor into the drainage system
b. the pore size of the geotextile exceeded that of tailings and a significant fraction would be carried through the geotextile into the geonet, clogging this system.
c. while passing a certain tailings fraction, piping and instability would occur in the tailings upstream.

Tailings properties tested comprised whole of tailings (sand and silt with minimal clay) and a fine tailings fraction (<63μm). Initial investigations into the compatibility of the geotextile with the tailings was carried out using a Gradient Ratio Test (ASTM D5567) however when the fine tailings fraction(<63μm) rendered this test method unsuitable. An alternative test was developed to test both the clogging potential and the fines retention capacity of the geotextile in direct contact with the tailings sample.

Gradient Ratio Testing
The initial Gradient Ratio test to ASTM D5101-12 was set up using the tailings supplied to provide a ratio of the hydraulic gradient for the tailings/geotextile interface to the hydraulic gradient of the tailings alone. Once backfilling commenced there were several issues with the sealing of the apparatus, time to backfill (up to 7 days) and tailings leaving the soil column and leaks occurring because of the fine particles This was assumed to be because the fines in the tailings were consolidating too well during the loading process. The authors consulted one of the leading world experts on this test who suggested that for sub 100 micron soils, a modified test may provide more relevance. This test was useful to define initial properties of the geotextiles for further testing.

Alternate Testing
An alternative test method was adopted where the tailings samples were placed in a constant head, fixed wall permeameter where system permeability, hydraulic gradients and fines loss through the geotextile could be measured. The testing apparatus was modified to reflect the actual conditions on site with intent that the process and results would be evaluated independently.

.

3.1.2 FILTER TEST RESULTS

Initially three different tests were conducted at varying moisture contents; 0%, 40% and 60%.The first two methods of placement (0% and 40% moisture content) were considered to be in variance with actual site conditions and both applications resulted in behaviour in the tailings which raised questions regarding validity of any results. The unusual behaviour was as follows;

- the 0% moisture content test resulted in sink holes forming over the surface which formed preferential flow paths through the material
- the 40% moisture content test had noticeable air-pockets within the tailings structure

The procedure which most accurately reflected the conditions on site involved pre-hydrating the tailings to a moisture content of 60% such that material would flow into the test apparatus and settle naturally before a head was applied. During initial testing, measurements were taken with regard to permeability, hydraulic gradient and most crucially fines passing for two non-woven geotextiles. The behaviour of the tailings sample was observed and the notable observations were as follows;

- fines passing peaked during tailings placement and reduced to zero after 24-72 hours;
- at the interface between the top surface of the tailings and the water a layer of super saturated gel like material formed. This gel appeared very rapidly during settlement post disturbance of the sample, was highly bonded and confined to the upper most layer of the tailings where there was limited self-weight confinement.

After the testing was completed for fines retention the tailings sample was vacuum excavated to evaluate the permeability of the sample at different thicknesses. While doing this the sample would be disturbed, but once completed the gel layer reformed very rapidly each time. This layer appeared to comprise the finest fraction of the tailings and appeared to control the permeability of the system.

3.1.3 Fines Retention Results

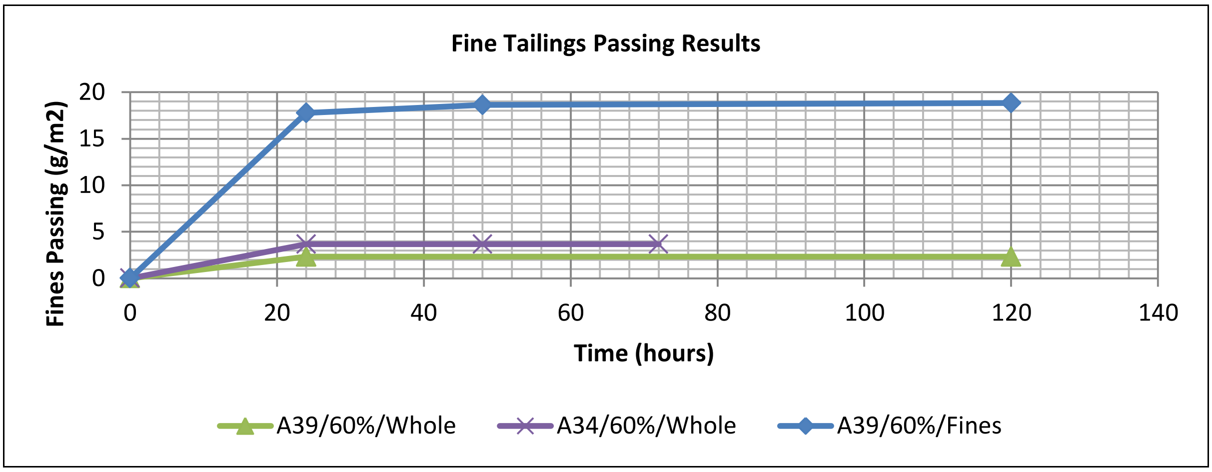
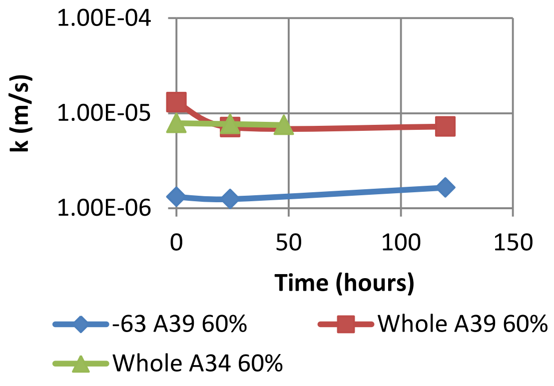


Figure 3.1 Results for whole tailings sample and fines(<63 µm) placed at 60% moisture Content for A34 and A39 geotextiles;

3.1.4 System Permeability Result

The permeability of the system was recorded and results indicate that the permeability for each sample was established very rapidly after hydration and remained stable throughout the test. The permeability of the system was also taken for various sample lengths of tailings cover, when the length was less than 50mm, system permeability was increased by an order of magnitude, indicative of a coarser fraction formation within this zone above the geotextile.



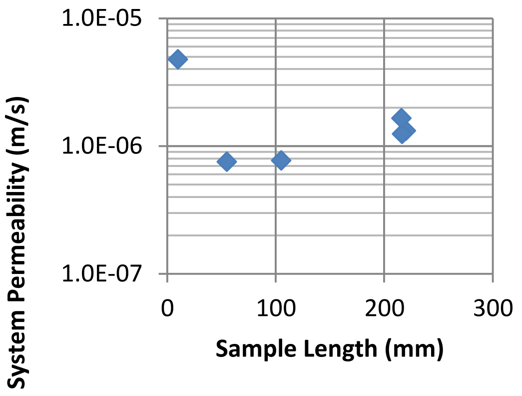


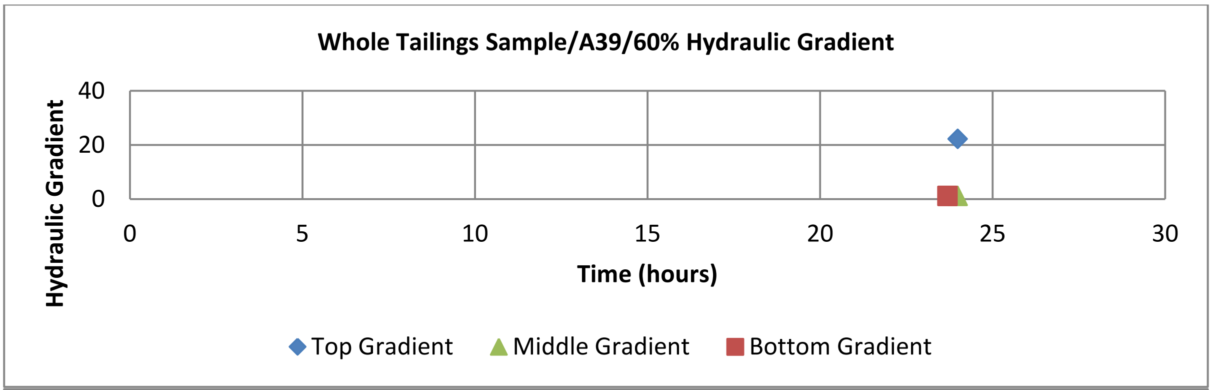
Figure 3.2 – System permeability A34/A39

Figure 3.3 Permeability vs Sample Length for A39/<63 micron samples

This exercise was only carried out on the <63µm tailings material due to time restraints. Note that permeability is normalised to the sample length above and a more clear observation is the flow rate of the sample. Observations noted when the thickness of tailings was reduced to a fine level covering the geotextile it could no longer effectively form the gel state, and allowed the water to flow through much more rapidly.

3.1.5 Hydraulic Gradient Results

The hydraulic head pressure could be read off the manometer tubes installed onto the apparatus; this could then be converted to a hydraulic gradient knowing the length of sample between each pressure tapping. The hydraulic gradient was calculated for three sections, the top gradient is between the top surface of the sample to 30mm below the surface; the middle gradient between the top and middle pressure tappings and the bottom gradient is the bottom 50mm of the sample including the geotextile. A higher hydraulic gradient between two points indicates a greater degree off restriction between these two points. The following show the various gradients for the tests for A39 geotextile;


Whole Tailings Sample/A39/60% Hydraulic Gradient

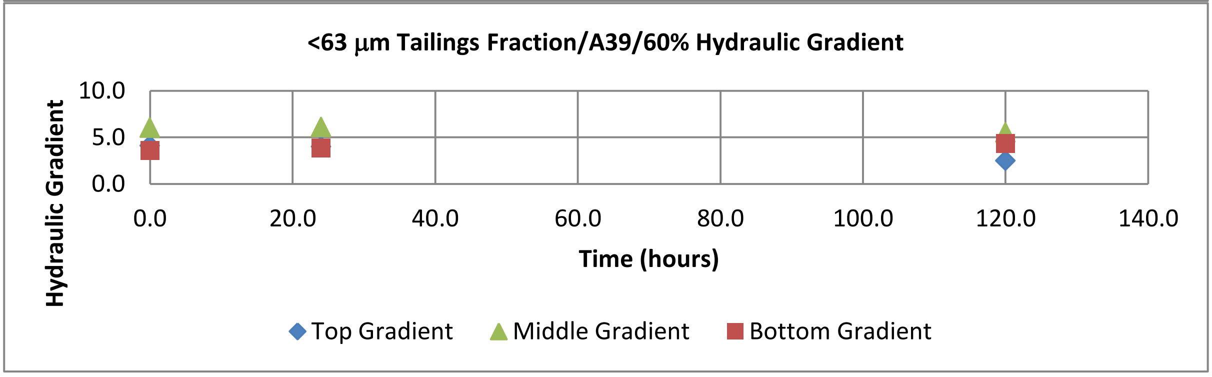

<63 µm Tailings Fraction/A39/60% Hydraulic Gradient

Figure 3.4 Hydraulic Gradient Comparisons – A39 Geotextile with Whole Tailings Sample and <63µm Sample

The two whole of tailings examples show a distinct restriction through the top layer compared with the <63µm material, which is less clear. This could be explained by a greater seperation of material during hydration which lead to the fines taking longer to settle than the coarser material in the whole of tailings, where as the <63µm material settled much more uniformly.

3.2 FILTER TESTING DISCUSSION

Results from testing indicated that fines passed through the geotextile during the initial contact with both geotextiles sampled and were reduced to zero fines passing with 48-72 hours. This initial erosion of fine material left a coarser fraction of the tailings in intimate contact with the geotextile, effectively creating a primary granular filter at this layer. This behaviour was more pronounced and rapid forming in the whole of tailings test due to increased variance in tailings particle size. This was also aided by the lack of head pressure present at this layer, seen in the results of the hydraulic gradient tests. Within the hydraulic gradient testing, particularly in the whole of tailings material, it was calculated that there was a dominant restriction through the top portion of the tailings sample with comparatively lower restriction in the middle and lower portions. This was later attributed to gel formation of the <10 micron tailings fraction which constituted around 6% of the whole tailings which would be disturbed during dam life with ongoing tailings deposition. This was confirmed by the inability of gel formation within the coarser material in the 50mm upstream of the geotextile.

Permeability of the different tailings samples was stable throughout all tests. Once the test was completed the tailings were excavated to determine the permeability and flow rate at various tailing thicknesses. What this showed was that the flow rate remained relatively constant with reducing thickness and consequently permeability slowly increased. This behaviour continued until only a fine layer of tailings covered the geotextile, after which the flow rate increased dramatically. These observations tend to indicate that there is a thin layer in the system that is governing permeability rather than the thickness as a whole.

These observations concluded that two key things are happening within this system. Firstly the boundary at the geotextile surface is eroding initially to release fine material, leaving a coarser fraction at this interface; this is classic natural filter formation which is expected with the incorporation of a geotextile at the interface between traditional soils and a drainage layer. This behaviour is establishing a filter such that any subsequent fines are prevented from passing through the geotextile. The initial erosion of fines determined that the A39 geotextile with reduced pore size would reduce volumes of material initially passed. From this testing it was concluded that both geotextiles would provide effective filters for this tailings medium and no clogging was observed. This data was presented to Emeritus Professor Robin Fell at The University of NSW who concluded that the A39 will be an effective filter for both whole and segregated tailings in this application (Fell (2010).

3.3 LINER AND GEOTEXTILE SURVIVABILITY TESTING

3.3.1 TEST SUMMARY

As the Geosynthetic profile was under significant overburden stress up to 1000kPa, it was critical to establish survivability performance for each layer of the system. Geosynthetic damage could possibly occur in the primary filter geotextile as it bridged the geonet, could occur within the geonet itself and through strain impacts imprinted onto each geomembrane from the geonets. In order to assess the damage potential the net configuration was replicated and tested using a method similar to the DIN EN 13719 cylinder compression test method using an Aluminium plate to record deformation transferred to the geomembrane (Hornsey, Wishaw 2012) . Ideally deformation to HDPE liners should be restricted to less than 0.25% local strain in order to restrict long term stress cracking of the geomembrane. A test profile was set up to mimic the actual site conditions and to induce the greatest damage i.e. pinching of the membrane between the hard base and the geonet. The test profile was as follows (from top to bottom), tested for 137 hours and measured using laser accuracy to 0.01mm;

- Rigid plate
- Geotextile A39
- Triplanar 5mm Geonet
- Aluminium plate 0.5mm sheet

- 1.5mm HDPE Geomembrane
- Rigid plate

3.3.2 RESULTS AND DISCUSSION

The analysis program is used to group areas with similar amounts of strain and summarise these areas as a percentage of the total area, the geomembrane analysis showed that 100% of the Total Area was maintained under 0.25% strain, meeting the most stringent German landfill criteria.
For geotextile survivability, the maximum deflection observed was 3.5 mm or 3.5kN/m per grid aperture. When applied with relevant Factors of Safety for Creep = 1.4 (Polyester geotextile), Installation Damage = 1.1 (Fine grained tailings), Chemical & Biological = 1.0, Design Life = 1.1 (60 years) Structure Class = 1.1 Factored Maximum Load = 6.5 kN/m
Geotextile Wide Width Tensile Strength = 21.0 kN/m (A39 MARV Value=97.5% confidence level)
The overall SAFETY FACTOR for A39 geotextile = 3.2, was deemed appropriate for this application.

3.4 LABORATORY TESTS TO ANALYSE DRAINAGE PERFORMANCE

3.4.1 DRAINAGE TESTING

In plane flow rate testing was carried out on biplanar and triplanar geonets to ASTM D4716-08 which can be both an index test and a performance based test to site stresses, hydraulic gradients and include observation of multi-layer systems. The intent was to test both biplanar and triplanar geonets of varying mm thickness and;

1) Establish first a direct laboratory comparison for planar flow from the MQA testing carried out in Europe to the Australian laboratory. This was confirmed for data up to 500kPa.
2) Ensure that the planar flow values would meet volume requirements of the Tailings Facility.
3) Test the impact of each Geosynthetic under the same normal stress and hydraulic gradient. By introducing each layer and testing each component both separately and with the full project profile under 1000kPa, a planar flow Reduction Factor for each component could be established and linked to factors applied in desktop design.

As this testing was conducted in conjunction with initial strain testing outlined, the test focus was narrowed to a triplanar Geonet. Initial testing was carried out under normal pressure of 800kPa and 1000kPa to establish the “linear” relationship at varying stresses assumed during an index design. This data confirmed survivability and provided indication as to short term creep that may occur in the system. Testing between rigid plates was then directly correlated to testing between 1.5mm geomembranes that indicated a 5mm triplanar net would perform adequately as a “leak detection” drainage system compared to the design flow requirements of 1000m³/day.

Further testing was designed to replicate the project profile, and provide insight as to the reduction factors that should be applied to the overall design. The full project profile was set up between rigid plates. Due to the problems associated with placing actual tailings in the rig, soft and hard rubber boundaries were used to mimic the tailings medium in the profile. These were underlain by the non-laminated non-woven needle punched A39 geotextile above the 5mm triplanar net and rigid plate. The composition of the tailings meant that chemical and biological clogging would not expect to occur and overall Creep of the geonet and geomembranes, and creep and intrusion of the geotextile would provide the primary factors for flow reduction. Using a non-laminated geotextile meant that maximum geotextile intrusion would occur, providing an element of conservatism to the results. Conservative reduction factors for both intrusion and creep were then applied in desktop analysis to tested results.

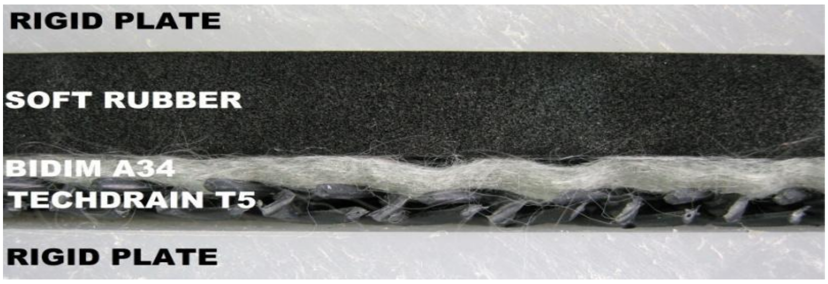


Figure 3.5 – Primary Drainage Profile with "Soft Rubber"Tailings"

3.4.2 DRAINAGE DISCUSSION AND RESULTS

The entire TSF area was split into 6 sub-catchment areas based on the location of ridge lines and the extremities of the TSF. Planar flows were established for each sub-catchment at the required hydraulic gradient and added up to establish total flow capacity for the TSF. Based on the design layout of the central collector pipes the drainage net capacities were expected to be in the range of 1,473/day to 2,147m^3/day so the use of 5mm triplanar geonets was deemed a feasible drainage option based on the following assumptions:

a. Design Normal Pressure – 1,000 kPa
b. Design Flow Volume – 1,000 m^3/day
c. Megaflo under-drainage and Megaflo pipes replaced by triplanar 5mm Geonet
d. Central Collector Pipes retained in design
e. An additional collector pipe within sub-catchment A1, to maintain Factors of Safety due to the very flat gradient of this sub-catchment
f. Long-term Reduction Factors for Chemical & Biological Clogging = 1.00 – from assumption of saturated conditions provided and the presence of a downstream airlock to prevent air entry into the underdrainage system
g. The Long-term Reduction Factors for Intrusion & Creep are as follows:
    a. Max. Drainage Net Capacity, RFin = 1.5 & RFcr = 1.4; (RFcc and RFbc = 1)
    b. Min. Drainage Net Capacity, RFin = 1.8 & RFcr = 1.7;
    c. Above from Koerner, Koerner (2005).

A key benefit of testing the non-laminated geotextile in this case developed during construction review considerations in that the laboratory had real-time data on the long-term UV stability of the geotextile beyond 6 months, allowing for certain freedoms to expose the geotextile during construction.

4.1 CONCLUSION

Geosynthetics are being used in tailings dam applications that require extreme performance criteria often not documented in typical design procedures. These include challenging chemistry, very fine materials and extreme load scenarios. This can present significant design risk to the client, designer and regulatory body. This project outlines that if a design for function approach is adopted, it allows both established and modified testing regimes to demonstrate performance criteria under site conditions. This can lead to better design practice and overall cost savings for the client.

ACKNOWLEDGEMENTS

The contribution of the following must be acknowledged by the authors;

Professor Jonathan Fannin PhD, P.Eng – *University of British Columbia*
Emeritus Professor Robin Fell – *University of NSW*
Ian Peggs – PHD, P Eng – *Icorp International*

REFERENCES

Hornsey WP, Wishaw DM 2012. Development of a methodology for the evaluation of geomembrane strain and relative performance of cushion geotextiles – Geotextiles and Geomembranes 35 (2012) 87-99

Koerner RM 2005, Designing With Geosynthetics, 5th Edition. Prentice Hall USA

Palmeira EM, Beirigo EA, Gardoni MG, 2010.Tailings non-woven geotextile filter compatibility in mining applications – Geotextiles and Geomembranes 28 (2010) 136-148