Cyclic and Post-cyclic Laboratory Test Results on Undisturbed Samples of Filter Pressed Mine Tailings

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ABSTRACT
Relatively little information is available regarding the cyclic behaviour of consolidated mine tailings. A major issue is that tailings often cannot be reliably classified based on conventional empirical techniques for sands or clays. This technical paper presents results from a laboratory testing program of undisturbed in situ samples of filter pressed mine tailings that were deposited in a "dry-stack" tailings storage facility. The laboratory program included index classification tests, consolidation tests, monotonic, cyclic and post-cyclic simple shear tests. This paper will focus on the results of the cyclic and post-cyclic simple shear tests and compare them to previous tests completed on reconstituted samples of the same material.

RESUME
Relativement peu d'informations est disponible concernant le comportement cyclique de résidus miniers consolides. Un enjeu majeure est que souvent les résidus ne peu être classifiés de manière fiable a base de techniques classiques empiriques pour les sables ou argiles. Ce document technique présente les résultats d'un programme d'essais de laboratoire d'échantillons intactes in situ de résidus miniers presse au filtre qui on été déposes dans une « pile sèche » d'une installation de stockage de résidus. Le programme de laboratoire inclue des analyses de classifications index, des analyses de consolidations, et des analyses de cisaillement simple mono toniques, cycliques et post-cycliques. Ce document va accentuer les résultats des analyses cycliques de cisaillement simple et tentera de caractériser le comportement comme celui du sable ou de l'argile.

1 INTRODUCTION

Relatively little information is available regarding the behaviour of consolidated mine tailings under cyclic loading. Experience and available information indicate that this unique material cannot be reliably classified based on conventional empirical techniques for sands or clays. This paper presents the results of a laboratory testing program of undisturbed samples collected in situ from filter pressed mine tailings that were deposited in a "dry-stack" tailings disposal facility (TDF). These "dry" filter pressed tailings were hauled to the storage facility in standard haul trucks, placed in lifts and lightly compacted. The tailings sampled and tested had been in situ for up to 15 years.

The climate at the site is generally poor for fill placement. For the majority of the year the site is under persistent rainfall; and snow falls during winter months. On average the site receives approximately 1.5 m of rainfall and 2.9 m of snowfall annually. Conventional Standard Penetration Test (SPT) or Cone Penetration Test (CPT) investigation programs provided inconsistent and contradicting information regarding cyclic resistance and liquefaction susceptibility of the tailings. A laboratory testing program was undertaken to help resolve the conflicting information from in situ testing.

Mill tailings at the site can be classified into two categories: "Old" tailings which were produced prior to a prolonged mill shutdown during which the milling process was changed; and "New" tailings which were produced using the new process.

The laboratory program included index classification tests, consolidation tests, monotonic, cyclic and post-cyclic simple shear tests on undisturbed samples. Cyclic simple shear tests are compared to previous tests completed on reconstituted samples of the same material.

2 CYCLIC RESPONSE AND EMPIRICAL CLASSIFICATION OF SOILS TYPES

For this project the objective of the investigation was to assess the potential for slope failure or large deformations during cyclic loading. A key step of predicting material behaviour during cyclic loading is proper classification. Boulanger and Idriss (2004) proposed classifying cyclic behaviour of materials into three groups: sand-like, clay-like and transitional. Development of elevated porewater pressures and large shear strains during undrained cyclic loading is referred to as "liquefaction" in sand-like soils and as "cyclic failure" in clay-like soils (Boulanger and Idriss, 2004).

During liquefaction of sand-like loose granular materials can undergo significant sudden strength loss. Strength loss during cyclic failure of clay-like soils is less severe and generally builds up progressively over several load cycles. Both liquefaction and cyclic failure are capable of producing large scale deformation. Boulanger and Idriss (2004), note that the potential consequences of clay-like, cyclic failure can range from relatively severe to inconsequential, depending on the soil's sensitivity and specific site conditions. The more rapid nature of liquefaction in granular soils increases the possibility of a large scale run out failure, where the material flows as a fluid mass. The distinctions between sand-like and clay-like materials are governed, and can be classified by, basic soil index properties such as gradation and Atterberg Limits.

In practical situations an improved understanding of the controlling mechanism and expected response, in this case liquefaction or cyclic failure, allows for fit for purpose designs and a clearer understanding of the associated risks.

For sand-like and clay-like materials industry standard procedures, primarily empirical, have been developed to assess how susceptible the material is to liquefaction or cyclic failure (Youd et al., 2001; Idriss and Boulanger, 2006; Bray and Sancio, 2006) based on critical indicators such as relative density and penetration resistance (SPT, CPT) for sand-like soils and Atterberg Limits and moisture content for clay-like soils.

The third category of cyclic behaviour proposed by Boulanger and Idriss (2004), transitional, refers to soils that do not fit uniquely into either the sand-like or clay-like classifications and can have distinguishing traits from either group. The mine tailings discussed in this paper fit into the transitional category.

Boulanger and Idriss (2004) suggest that fine grained soils transition from sand-like to clay-like between the Plasticity Index (PI) range 3 to 8. However, they recommend characterising fine grained soils as sand-like if PI $<$ 7 and as clay-like if PI $\geq$ 7.

Transitional materials are far less understood than the others groups and there are currently no industry standard empirical correlations (e.g. density, Atterberg Limits, etc.) that uniquely relate the material to expected cyclic behaviour. The industry standard for assessment of cyclic behaviour of soil is in situ techniques such as SPT or CPT. These tests work well in granular (sandy) soil. However for transitional soil types, in situ techniques can be difficult to interpret and give inconclusive results. The authors have commonly found this to be the case with metal mine tailings which have a very limited number of case histories available in the public domain relative to other soil types.

To further the understanding of the mine tailings a sampling and lab testing program was undertaken.

3 SAMPLING PROGRAM

As part of an expansion project, a section of the TDF was excavated. The cutslope of the excavation exposed tailings that had been buried for up to 15 years. This presented an opportunity to collect undisturbed samples of the in situ tailings for laboratory testing at a significantly lower cost than conventional down-hole sampling methods.

The samples were collected by pushing a modified 3-inch diameter stainless steel Shelby tube into the ground using a uniaxial hydraulic jack. The modified Shelby tubes were approximately 200 mm in length and the leading edge was sharpened at an angle approximately 30 degrees from vertical. The inner “bulge” near the leading tip of the original Shelby tube was removed. After the modifications the roundness of each tube was checked. The tubes were accepted for use in sampling if the shape of the tube had not been misshapen by the machining process and the roundness of both ends of the tube were similar.

During sampling, weight was added onto the sampling apparatus to counteract uplift forces from the jack and force the tube into the ground. The sampling tubes were supported by a purpose built jig and held upright throughout the sampling and were retrieved from the ground by careful hand excavation. After the sample tube was extracted, the top and bottom were sealed to prevent moisture loss with a layer of Paraffin wax, a smooth faced tube plug and another layer of Paraffin wax. Prior to placing the seal on the tube bottom, approximately 25 mm of sample was removed from the tube with clay molding hand tools. Once the seals were in place the sample tubes were kept upright. Other details such as weight, sample length and initial moisture content were documented immediately after sampling and checked just prior to sample extrusion in the lab.

Observations of the material during the sampling program found the buried tailings to be very stiff and significant counterweight (up to 450 kg) was required to prevent the sampling apparatus from lifting during pushing of the sample tube.

In total 20 samples were collected from 5 test areas (TA), of these 18 samples were later determined to be suitable for testing. A bulk sample of tailings was collected from each of the test locations for general index testing.

To reduce disturbance during transport, the samples were stored in specialized shipping containers. The shipping containers were constructed out of a plywood shell which was lined with a layer of “hard” foam and multiple layers of “soft” polyurethane foam. Each sample tube was wrapped in soft foam and placed upright inside a 125 mm diameter PVC pipe, 300 mm long with polyurethane foam on the top and bottom. The PVC pipes were glued and strapped together to prevent them from rattling against one another.

The shipping containers were loaded onto a truck that was driven by project staff, to maintain chain of custody, from the site to the testing laboratory at the University of California Berkeley (UC Berkeley).

4 LABORATORY TESTING PROGRAM

A technical team which included Dr. M. Riemer (UC Berkeley) and the Technical Reviewers: Dr. R.W. Boulanger and I.M. Idriss was assembled to assist the authors in design of the laboratory testing program. Frequent discussions were held prior to and during the testing to assess results and determine the order and number of further testing required to meet the project objectives.

A summary of the complete program that was completed is presented in Table 1.

Table 1 Laboratory Testing Program

TEST	Number
Atterberg Limits	8
Gradation	5
Specific Gravity	3
Standard Proctor	4
Consolidation - Constant Rate of Strain	6
Monotonic Simple Shear (MSS) - Undrained	6
Cyclic Simple Shear (CSS) - Undrained	8
Post-cyclic Simple Shear – Undrained	6

5 LABORATORY RESULTS AND DISCUSSION

5.1 Sample Quality

The objective of the sampling program was to collect samples of the tailings, and transport them to the testing laboratory, with as little disturbance as possible. It is not possible with even the most advanced sampling technique to eliminate all disturbance.

In classic theory "undisturbed" clay samples should show a sharp transition in the laboratory consolidation curve, from a relatively flat gradient, below the past pressure, to a much steeper curve at stresses greater than the past pressure (i.e. transitions from overconsolidated to normally consolidated). The less disturbance that is present in the clay soil the more abrupt that change in slope. Fine grained, low or non-cohesive soils often show a curving over in the consolidation plot that is not directly linked to maximum past pressure as is commonly associated with clay soils. Constant rate of strain (CRS) consolidation tests were chosen to better define the shape of the consolidation curve as a measure of sample disturbance. A testing rate of 0.015 mm/min was selected for the consolidation tests.

The change in slope of the consolidation curves for our samples was gradual as expected for a non-cohesive soil and could have been influenced by slight-cementation in the samples which is discussed in Section 5.4. However, this could also indicate that there was some disturbance of the samples.

A comparison of consolidation curves completed on an undisturbed and reconstituted sample from the same TA shows that they are not parallel, even after the past pressure of the undisturbed sample is exceeded (Figure 1). This observation suggests that the samples collected for this test program, had retained important aspects of the in situ soil fabric.

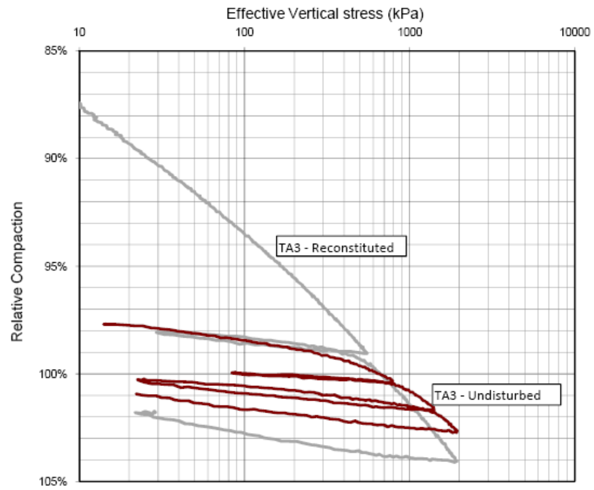


Figure 1. Comparison of Consolidation Curves from Reconstituted and Undisturbed Samples

It was the conclusion of the authors and the technical team that the samples were of sufficient quality that their responses in the laboratory test could be used to estimate in situ behaviour (Boulanger and Idriss, 2009).

Disturbance that may have been present in the samples is believed to have resulted from internal shear within the sample while the tube was pushed into the tailings. It is unlikely this element of disturbance could be avoided using this sample method. Other sampling methods such as self boring samplers could possibly overcome this issue.

5.2 In-situ Density

In situ-density and standard Proctor test results are presented in Table 2. The in-situ density values measured in the field were in general higher than expected with the exception of TA2. Field records indicate that the tailings were generally placed at 90% to 95% relative compaction (RC). RC is defined as the ratio of in situ dry density to the maximum Standard Proctor dry density and is expressed as a percent. The field testing indicated that tailings at depth >6 m have an in-situ RC greater than 100%. The RC of the Old tailings is shown to increase with depth based on the results from TA2, TA3 and TA4. The New tailings (TA6) had a very high RC of 113%.

Increasing density of the tailings is expected as the material consolidates under the increasing load. However, consolidation tests results on reconstituted

Table 2 Summary of Test Areas, Index and In-situ Testing Results

Test Area	Depth (m)	Est. In-situ Stress	Avg. In-situ Dry Density	Avg. In-situ m/c	% Silt/ Clay	Liquid Limit	Plasticity Index	Max. Dry Density	Opt. m/c
TA2	6.2	130 kPa	2.01 t/m^3	19.4%	91.3%	18% to 19%	4% to 6%	2.21 t/m^3	13.9%
TA3	8.0	166 kPa	2.13 t/m^3	19.8%	94.0%	19.0%	5.0%	2.07 t/m^3	16.1%
TA4	13.6	283 kPa	2.07 t/m^3	14.2%	94.8%	23% to 26.8%	5.7% to 9%	1.97 t/m^3	15.0%
TA5	11.4	226 kPa	2.00 t/m^3	14.2%	96.5%	22.0%	9.0%	-	-
TA6	7.4	139 kPa	2.39 t/m^3	12.5%	85.2%	16.3% to 17%	2% to 3%	2.12 t/m^3	15.0%

m/c = moisture content

and in situ samples indicate that consolidation alone cannot account for the high in situ density and other processes must contribute to the measured in situ density. Processes that may be influencing the in situ density of the tailings are discussed in Section 5.4.

5.3 Index Testing

Historical testing had indicated that, on average, the Old tailings have higher liquid limits and a higher plasticity index when compared to New tailings. This trend continued in these test results. It was further observed that the liquid limit and plasticity index values of Old tailings tended to increase with the burial depth which could loosely be linked to age (i.e. deepest samples TA4 and TA5 had higher liquid limit and plasticity index values than the shallower TA2 and TA3).

Particle gradation tests also fell within the expected range based on historical testing: Old tailings >90% passing 75 µm; and New tailings ~85% passing 75 µm. Consistent with previous assumptions, the New tailings was a coarser grind than the Old tailings for particles sizes less than 0.01 mm.

Atterberg limits and particle gradation results for each TA are summarised in Table 2.

Specific gravity test results for the Old tailings ranged from 3.2 to 3.4, while the New tailings was slightly higher at 3.5.

5.4 Consolidation

The compressibility of the samples was variable and could be linked to RC (Figure 2). The New tailings sample from TA6 had the lowest compressibility and highest RC of all tailings samples tested and the reconstituted sample had the lowest RC and highest compressibility. Based on the incremental load consolidation data for MSS and CSS test samples there is also an overall decrease in secondary compression with increasing RC. These observations

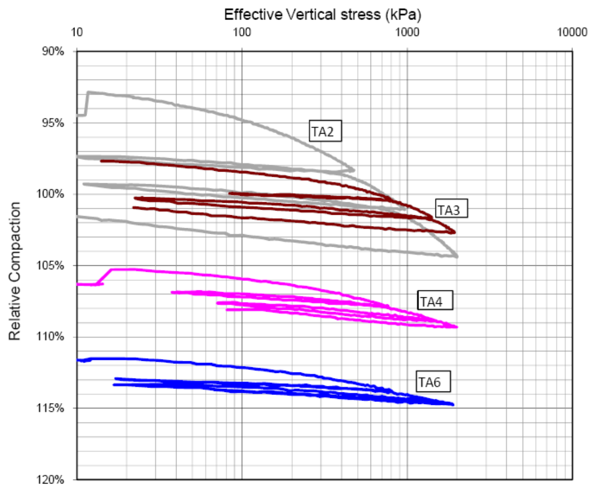


Figure 2. Undisturbed Sample Consolidation Curves Plotted Versus Relative Compaction.

are consistent with the logic that as a material becomes more dense it is less compressible.

Past pressures estimated from the consolidation tests on the in situ samples showed the presence of some degree of overconsolidation in the tailings with overconsolidation ratios (OCR) approximately 1.3 to 1.9. This is an important observation, as prior to this program, the in situ tailings were believed to be normally consolidated or possibly still consolidating under the load of the rising TDF. There are various processes that could have resulted in this overconsolidation, the most likely being: compaction during placement; matrix suction; secondary compression; aging; and/or geochemical/biological processes. The Technical Reviewers identified compaction and matrix suction as the most likely contributors. Matrix suction develops negative suction pressures in unsaturated soils which increases the stress acting on the soil.

Compaction of the tailings during placement would raise the density beyond the expected normally consolidated value from consolidation for low stress levels. It is logical to believe that as the overall stress on the tailings increases (i.e. the tailings pile rises) the influence from compaction would decrease and the material density would tend toward a normally consolidated state. However, there is no strong correlation in the data between overconsolidation ratio (OCR) and depth. Suggesting that compaction is not the dominant factor in the overconsolidation.

During the consolidation of the CSS samples a significant amount of secondary compression was observed in the samples, particularly at stresses higher than their in situ value.

In laboratory and field studies fine-grained soils have shown a tendency to increase strength and stiffness with time in process referred to as aging which can also contribute to some overconsolidation (Mitchell and Soga, 2005). This can be linked to secondary consolidation.

There is evidence of process salts in the tailings and this could produce a slight cementation, which mimics over-consolidation. Slight cementation can also produce a rounded curve on the typical consolidation testing e-log p plot, as observed in this test program, as bonds of variable strength break down over a range of pressures. In this case even completely undisturbed samples exhibit a rounded consolidation curve.

The relative influence of the above factors on the apparent overconsolidation of the tailings has not been determined and has been identified as an area of future study.

5.5 Monotonic Simple Shear Testing

The samples were prepared in the MSS testing apparatus and sheared at a constant deformation rate of 0.10 mm/min. This rate was shown to be sufficiently slow to keep pore pressure equilibrated during shear.

No defined peak strength was achieved during the MSS tests. Shear stress continued to rise throughout the test with increasing strain. This is believed to be the result of shearing the dense, angular tailings under undrained conditions (i.e. no volume change), which restricts dilation of the material during the test.

A value for the internal angle of friction (ϕ') cannot be calculated from MSS test data because the precise orientation of the shear plane is unknown. However, if it is assumed that the applied load is the maximum shear stress which is believed to be a reasonable assumption for this material. The ϕ' (assuming no cohesion) for the New tailings was estimated to be slightly above 40° and estimated values for the Old tailings were: 31° (TA2); 37° (TA3); and 38° (TA4). These are relatively high values for natural materials that are predominately silt and clay sized. The authors believe this to mainly be the result of the angular particle shape of the tailings. The results for the Old tailings appear to be influenced by the RC of the tailings.

To assess the influence of the apparent overconsolidation on the static shear strength, two sets of MSS tests were completed on samples from the same sample tube and sheared under the same vertical stress but with different OCR values, 1.0 and 1.5. The OCR values were simulated by loading the samples beyond the past pressure stress. The normalized shear strength of the samples with an OCR of 1.5 was observed to have increased by an average of 13% to 20% over the samples with an OCR of 1.0.

5.6 Cyclic Testing

The main purpose of previous testing in this program was to characterise the soils and assess the sample quality therefore giving some indication of how well the cyclic resistance observed in the laboratory tests can be relied upon to reflect the in situ behaviour of the transitional material.

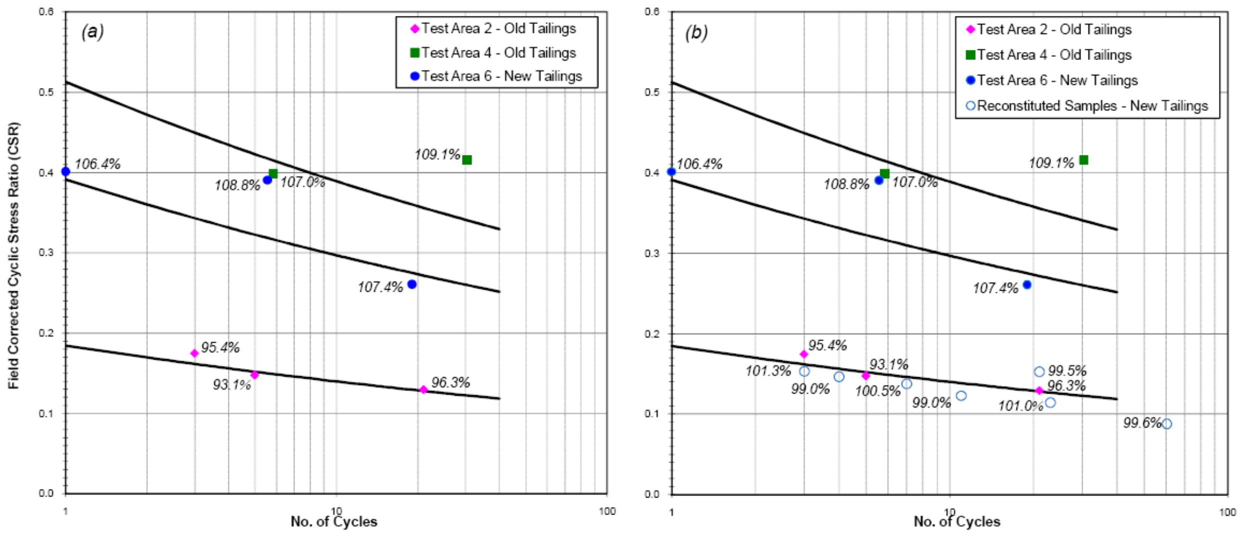
The cyclic resistance of the undisturbed samples were tested using the cyclic simple shear (CSS) testing apparatus. During the CSS tests the shear load was applied as a sinusoidal cycle with a frequency of 0.2 Hz. For this program liquefaction was defined as 5% double amplitude shear strain during a single cycle.

The observed cyclic resistance of the tailings during the CSS tests have been plotted on Figure 3 as cyclic stress ratio (CSR) versus the number of cycles to reach liquefaction. This presentation format was selected as design earthquake loadings can be plotted in this form and compared to soil strengths. The test results are plotted based on equivalent numbers of uniform loading cycles, which were computed using the following power relationship and the procedures adopted by Seed et al. (1975) and illustrated in Idriss and Boulanger (2008):

$$\text{CSR} = \text{A}^*(\text{NO. OF CYCLES})^{-\text{B}}$$

A value of 0.12 was selected for (B) based on the trends in the data set and typical values for fine-grained soils (Boulanger, Idriss 2007). The value of (A), which is equal to the y-intercept of Figure 3(a), was selected based on the best-fit value for the data set. To account for multi-directional shaking in the field CSR, values measured in the lab were reduced by 10% to convert them to an equivalent field CSR value which is believed to be conservative for this material *(*Boulanger, Idriss 2007 and 2009*)*. Each data point on Figure 3 is labelled with the post-consolidation RC of the sample tested.

Results plotted on Figure 3(a) suggest a correlation between the cyclic resistance and density as represented by RC. Old tailings samples tested from TA2 had the lowest cyclic resistance and the lowest RC values (93% to 96%). In contrast TA4 samples, also



1. Number of cycles required to reach double amplitude shear strain of 5% during a single load cycle defined as liquefaction.
2. Relative compaction of each tested sample listed in italics next to data point.

Figure 3. Plots of Cyclic Loading Test Results

Old tailings, had higher values of RC (107% to 109%) and significantly greater cyclic resistance. Samples from TA4 also had slightly higher plasticity index values, range of 6 to 9, than TA2 index values which ranged from 4 to 6. Higher plasticity index values are normally associated with an increase in cyclic resistance. The New tailings samples from TA6 also had high RC values (106% to 109%) relative to TA2 and significantly greater cyclic resistance.

The cyclic resistance of Old tailings samples from TA4 are about 30% greater than the TA6 New tailings samples despite having similar RC values. This difference is likely the result of the Old tailings having a higher plasticity index and greater age, both of which are generally expected to increase cyclic resistance.

Figure 3(b) includes the cyclic testing results from previous testing programs completed on reconstituted samples. Some of the previous tests were completed using a cyclic triaxial apparatus; these results were multiplied by 0.65 to make them equivalent to the CSR values from CSS tests (Boulanger, Idriss 2009). Figure 3(b) shows that previous results on reconstituted samples are similar to results from TA2.

The reconstituted samples of New tailings were tested at a higher RC than the Old tailings tests yet have a similar cyclic resistance. Supporting the earlier observation that at similar RC the Old tailings have a higher cyclic resistance than the New tailings.

The tailings exhibited clay-like behaviour as shear strains developed progressively over a series of load cycles. Typical stress-strain behaviour observed during cyclic loading is shown in Figure 4. Also, typical of clay-like samples, the tailings exhibited broader hysteresis loops during loading and did not develop intervals of nearly zero stiffness which is a defining characteristic of sand-like behaviour.

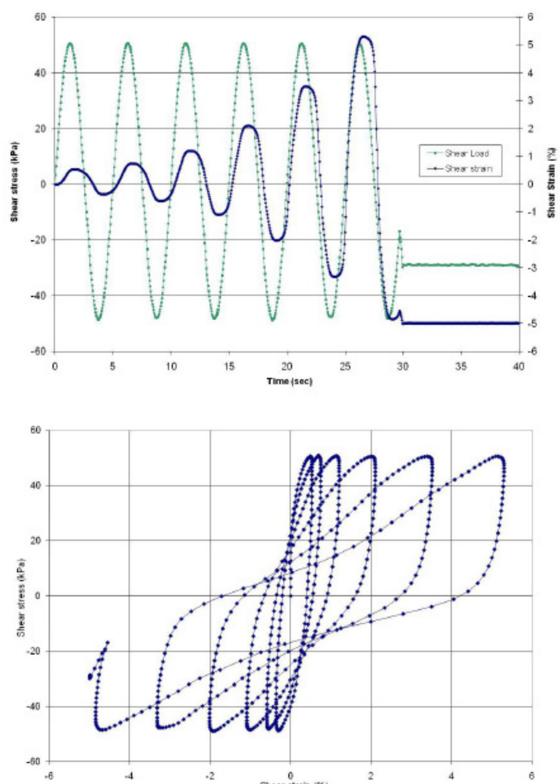


Figure 4. Typical Stress-Strain Behaviour During Cyclic Loading (Riemer 2009)

The peak excess porewater pressure value that developed in the samples was less than the vertical load (i.e. porewater pressures was less than 100% of vertical stress). The maximum porewater pressures that developed during the tests as a percentage of the vertical stress during shear were 83% for TA2 samples, 63% for TA4 samples and 75% for TA6 samples. This mimics the patterns visible in Figure 3(a) where samples with the lowest RC values (TA2) developed the greatest porewater pressure ratios. At similar RC the New tailings (TA6) developed higher porewater pressures than the Old tailings (TA4).

Based on the observed clay-like behaviour and the inability of the material to develop porewater pressures equal to the overburden stress, the New and Old tailings are expected to retain a significant amount of shear strength under cyclic loading.

5.7 Post-cyclic Testing

Stress-strain behaviour during the post-cyclic tests was observed to be quite variable. A comparison of normalised shear stress for pre and post-cyclic MSS test is provided in Table 3 and Figure 5. Normalised shear stress is defined as shear stress divided by vertical stress during shear. Some of the tests showed very little difference between the MSS and post-cyclic results while other post-cyclic samples were much softer (i.e. larger shear strains are required to develop shear stress) than the MSS tests. As a general observation, the post-cyclic strengths appear to be approximately two thirds of the monotonic shear strength under undrained conditions. However more shear strain is required relative to the pre-cyclic condition to develop that level of shear strength.

Table 3 Comparison of Normalized Shear Stress During Pre and Post-cyclic MSS Testing

Test Area	Test	Normalised Shear Stress @ 1% Strain	2% Strain	5% Strain	10% Strain
TA2	Pre-cyclic	0.152	0.175	0.234	0.296
	Post-cyclic	-	0.063	0.137	0.277
TA4	Pre-cyclic	0.230	0.309	0.398	0.521
	Post-cyclic	0.221	0.314	0.414	0.404
	Post-cyclic	0.129	0.229	0.479	0.500
TA6	Pre-cyclic	0.238	0.331	0.450	0.632
	Post-cyclic	0.200	0.288	0.425	0.575
	Post-cyclic	0.05	0.075	0.138	0.313

6 CONCLUSIONS

Proper characterisation of material behaviour is the key to the success of any earthfill structure. There are generally accepted methodologies to characterise the cyclic behaviour of sands and clays. However, there are no widely accepted methods to characterise transitional materials (i.e. between a sand and a clay) such as mine tailings. This paper presents the results from a lab testing program of undisturbed in-situ samples of tailings which had been placed into a dry-stack TDF and left in-situ for up to 15 years. The objective of this study was to attempt to determine the behaviour of the mine tailings under cyclic loading.

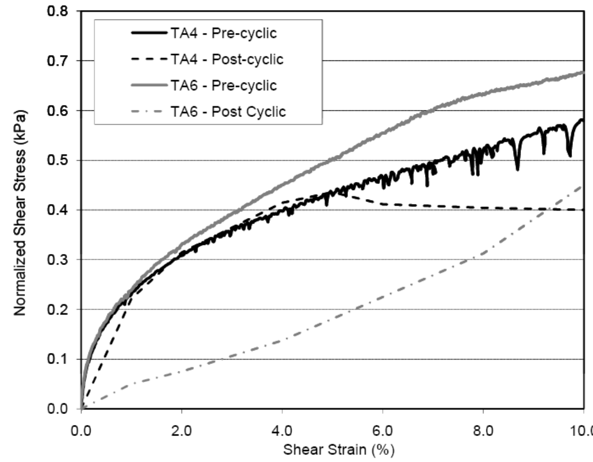


Figure 5. Comparison of typical stress-strain behaviour pre and post-cyclic MSS tests

The tailings samples were of sufficient quality to be classified as undisturbed, based on observations during sampling and testing, in particular the clay-like behaviour of the samples. Samples of sand-like materials have been shown to be very prone to disturbance and lab results cannot be directly relied upon for estimation of in situ strengths and behaviours. However, the laboratory testing program provided sufficient information regarding the soil behaviour of the tailings to have confidence that the results could be inferred as in situ behaviour and relied upon for use in design.

Observations made from the test results indicate that some important aspects of the in-situ soil fabric that are not visible during testing of reconstituted samples had been maintained in the samples. Of importance for this study, the observed cyclic behaviour of the undisturbed samples differed from that of the reconstituted samples.

The in-situ density values measured in the field were significantly greater than the average placement RC of 90% to 95%, with the exception of the shallowest samples at TA2. The samples appear to have some degree of overconsolidation. This was not expected and the mechanism(s) behind this is not known at this time but it is believed to be the result of several contributing factors.

The lab test results from this data set support the observation that the tailings have a clay-like behaviour under cyclic loading. During loading the stress-strain behaviour exhibited broader hysteresis loops during loading and did not have intervals of nearly zero stiffness. Also typical of a clay-like response, shear strains developed progressively over several cycles and the pore pressures generated during loading did not reach the vertical load.

The PI values for the tailings range from 2% to 9% which is similar to the range suggested by Boulanger and Idriss (2004) that fine grained soils transition from sand-like to clay-like. Based PI of the samples and the criteria recommended Boulanger and Idriss (2004), sand-like < PI = 7 ≤ clay-like, the majority of the tailings samples would have been classified as sand-like. However, during lab testing all of the tailings sampled showed clay-like behaviour.

The tailings appear to have relatively high cyclic resistance and some preliminary relationships between cyclic resistance and RC for these tailings were developed. At similar values of RC the Old tailings appear to have a greater cyclic resistance than the New tailings. The Old tailings have greater plasticity values and age, both of these are generally believed to increase cyclic resistance. Compared to previous tests completed on reconstituted samples the cyclic resistance observed from the in-situ samples was significantly greater.

In general the pre-cyclic shear strength of the tailings is relatively high when compared to other natural materials of similar grainsize. This is believed to be result from the angular nature of the tailings particles and lack of clay minerals. Similar to the cyclic test results, RC was observed to have a significant influence on the pre-cyclic shear strength.

A comparison of results on samples tested with an OCR of 1.0 and 1.5 showed that the elevated OCR value increased the static shear strength by 13% to 20%.

The post-cyclic shear strength was shown to be variable for the samples but in general a significant portion of the pre-cyclic shear strength was retained but the shear strain required to develop that strength was greater than the pre-cyclic case.

The next focus of study will be to develop a methodology to characterise the cyclic behaviour of the TDF using a form of in-situ testing (SPT, CPT, field vane, etc.) and this data set.

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