Klohn Crippen Berger

January 12, 2011

Resolution Copper Mining
P.O. Box 1944
Superior, Arizona
85273

Mr. Darby Stacey
Senior Metallurgical Engineer

Dear Mr. Stacey:

Resolution Project
2010 Geotechnical Testing of Tailings Samples

This letter report presents the results of the 2010 geotechnical testing program on scavenger and cleaner tailings. The results are also compared with the previous test programs in 2007 and 2009.

1. 2010 TEST PROGRAM

The testing was conducted on samples of scavenger and cleaner tailings supplied by FLSmidth's Dawson Metallurgical Laboratories. The samples, listed in Table 1, comprised dried[1] samples of tailings with samples of process water used during the locked-cycle test work for scavenger and cleaner tailings. Appendix I provides the sample transmittal letter from FLSmidth and photographs of the as-received condition of the samples and process waters.

The test work was conducted at the University of Alberta under the direction of Dr. Don Scott. The details and results of the test work are described in his report given in Appendix II. Table 1 summarizes the samples and the completed test work.

2. DISCUSSION OF RESULTS

2.1 2010 Test Program

The tailings samples were prepared from locked cycle metallurgical tests on batched samples of core representing the following periods:

[1] Samples dried at 50º C.

Klohn Crippen Berger Ltd. • 500 – 2955 Virtual Way • Vancouver BC V5M 4X6 • CANADA
604.669.3800 t • 604.669.3835 f • www.klohn.com

- Composite MC-1 representing high pyrite ore during the early years of mining in Years 1 to 15;
- Composite MC-2 representing the average ore during the middle Years 16 to 30; and
- Composite MC-3 representing average ore during the late Years 31 to 40.

Current tailings management scenarios consider separate disposal of scavenger and cleaner tailings to minimize their environmental impacts. For an in-pit disposal scenario, disposal of the combined tailings streams is being considered in the early years. Therefore, consolidation behavior of a combined scavenger and tailings was evaluated by mixing of tailings from Composite MC-1. This combined sample is also termed MC-1 in the test program in Appendix II.

Relevant observations and results from the 2010 test program include the following:

- The average specific gravity, Gs, for the scavenger tailings varied narrowly between 2.75 and 2.88, with an average of 2.81.
- Gs of the cleaner tailings varied between 3.80 and 4.33, with an average of 4.01. The highest Gs of 4.33 occurred for Cleaner–T7 reflecting the higher pyrite content of the feed ore in MC-1.
- Atterberg Limits classify the ore as a low to non-plastic silt (ML) in behavior.
- The P_{80} of the scavenger tailings ranged between 160 to 180 microns and the percent clay sized particles (less than 2 micron) ranged from 8% to 12%. The P_{80} of the cleaner tailings ranged between 40 to 41 microns and the percent clay-sized particles (less than 2 micron) ranged from 12% to 20%. It is important to note that not all clay-sized particles are active clays and may be fine rock flour. Also, the ASTM Hydrometer test method disperses the tailings particles such that the clay-sized fraction reported may over-estimate the actual fraction of the tailings streams.
- The percentage of clay-sized particles varied in both the scavenger and cleaner samples in a similar manner, with the lowest clay in Composite MC-1 and highest in Composite MC-3. As would be expected, the liquid limit and plasticity of the samples increased slightly with the increased clay content.
- The XRD analyses of the tailings samples showed that the cleaner tailings samples are rich in pyrite and muscovite when compared to the scavenger

tailings which had only minor amounts of muscovite and no pyrite. kaolonite and illite are the primary clay species. Appreciable swelling clays (smectite) were found only in Cleaner-T9 and Scavenger-T9 from Composite MC-3.

- The tailings consolidation curves (void ratio versus effective confining stress), shown in Figure 1, are separated into distinct groupings for the scavenger and cleaner tailings. The curves for Composite MC-3 (Cleaner-T9 and Scavenger-T9) are slightly higher than both Composites MC-1 and MC-2, reflecting the influence of the small proportion of swelling clays in Composite MC-3. The whole tailings sample MC-1 falls reasonably between the cleaner and scavenger groupings.

- The hydraulic conductivity of both the scavenger and cleaner tailings decreased by about two orders of magnitude as the samples were consolidated and, as expected, the scavenger tailings are more permeable than the finer-grained cleaner tailings. For both tailings streams, lower hydraulic conductivities were observed in samples with higher "clay" content, with the lowest values measured for Composite MC-3 (Cleaner-T9 and Scavenger-T9). The lower values for Composite MC-3 are also likely influenced by the presence of swelling clays as discussed above. Again, the whole tailings sample MC-1 falls reasonably between the cleaner and scavenger groupings.

2.2 Comparison to Previous Test Programs

Geotechnical index tests and slurry consolidation tests were previously coordinated by KCB at the University of Alberta in 2007 and 2009. For completeness, reports for these tailings testing programs are provided in Appendices III and IV.

Table 2 compares the index parameters for these programs with the 2010 program. Figure 2 also compares the consolidation and hydraulic conductivity data for all three test programs.

General observations between the test programs are as follows:

- The scavenger and cleaner consolidation curves measured in 2010 are slightly higher (samples less dense at a given stress) than those measured in 2007 and 2009, particularly at higher stress levels. This is attributed mainly to the higher "clay" content of the 2010 samples (Table 2).

- The hydraulic conductivity of the 2010 tailings samples are generally higher (by a factor of 2 to 5) than the tailings tested in 2007 and 2009.

This result is unexpected given the higher "clay" content of the tailings. It is suspected that the drying of the tailings samples in an oven, albeit at low temperature, could have agglomerated some of the finer silt and clay tailings particles. Insufficient dispersion of the agglomerations during preparation of the test samples would result in higher apparent hydraulic conductivity. Conservative assumptions on the hydraulic conductivity should therefore be made in selection of parameters for any consolidation analyses.

3. CLOSURE

This letter report was prepared by Klohn Crippen Berger Ltd. for the account of Resolution Copper Mining. The material in it reflects Klohn Crippen Berger's best judgment in light of the information available to it at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Klohn Crippen Berger Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

Please contact me if you have any questions or require further assistance.

Yours truly,

KLOHN CRIPPEN BERGER LTD.

Howard D. Plewes, M.Sc., P.Eng.
Project Manager

Attachments: Tables 1 and 2
Figures 1 and 2
Appendix I – 2010 Samples Transmittal Data
Appendix II – 2010 Laboratory Test Program
Appendix III – 2007 Laboratory Test Program
Appendix IV – 2009 Laboratory Test Program

Table 1 Summary of 2010 Test Program

Master Composite	Test (cycles)	University of Alberta Material/Code	Specific Gravity	Atterberg Limits	Particle Size Distribution	Slurry Consolidation Testing	Permeability Standpipe Tests	Slurry Water Chemistry Analyses	Clay Speciation by XRD Analyses
MC-1	7 (3 – 7)	Scavenger–T7	X	X	X	X	X	X	X
MC-2	8 (2 – 7)	Scavenger–T8	X	X	X	X	X	X	X
MC-3	9 (2 – 7)	Scavenger–T9	X	X	X	X	X	X	X
MC-1	7 (3 – 7)	Cleaner–T7	X	X	X	X	X	X	X
MC-2	8 (2 – 7)	Cleaner–T8	X	X	X	X	X	X	X
MC-3	9 (2 – 7)	Cleaner–T9	X	X	X	X	X	X	X
		Whole Tailings Composite MC-1 prepared at 77.1/22.9 ratio of Scavenger–T7 and Cleaner–T7 by dry weight				X	X		

Table 2 Comparison of Tailings Tested in 2007, 2009 and 2010

Test Date	Material/Code	Other Information	Specific Gravity (G_s)	Atterberg Limits (%)		Particle Size (mm)		
				Plastic Limit	Liquid Limit	P_{80}	P_{50}	% Clay <0.002 mm
2007	Scavenger SC-1	Test T-62 (Cycle 3-12)	2.75			0.150	0.055	7
	Cleaner CL-1	Test T-62 (Cycle 3-11)	4.20			0.047	0.022	9
2009	Scavenger		2.71			0.150	0.062	7
	Cleaner		3.23			0.031	0.010	14
	Whole Tailings Composite prepared at 85/15 ratio of scavenger and cleaners tailings by dry weight		2.79			0.150	0.045	7
2010	Scavenger–T7	7 (3 – 7)	2.75	19.0	19.0	0.160	0.080	8
	Scavenger–T8	8 (2 – 7)	2.80	19.6	20.0	0.160	0.060	10
	Scavenger–T9	9 (2 – 7)	2.88	19.3	20.7	0.180	0.065	12
	Cleaner–T7	7 (3 – 7)	4.33	13.1	15.2	0.041	0.017	12
	Cleaner–T8	8 (2 – 7)	3.80	15.6	19.0	0.041	0.014	16
	Cleaner–T9	9 (2 – 7)	3.91	16.3	21.0	0.040	0.013	20
	Whole Tailings Composite MC-1 prepared at 77.1/22.9 ratio of Scavenger–T7 and Cleaner–T7 by dry weight							

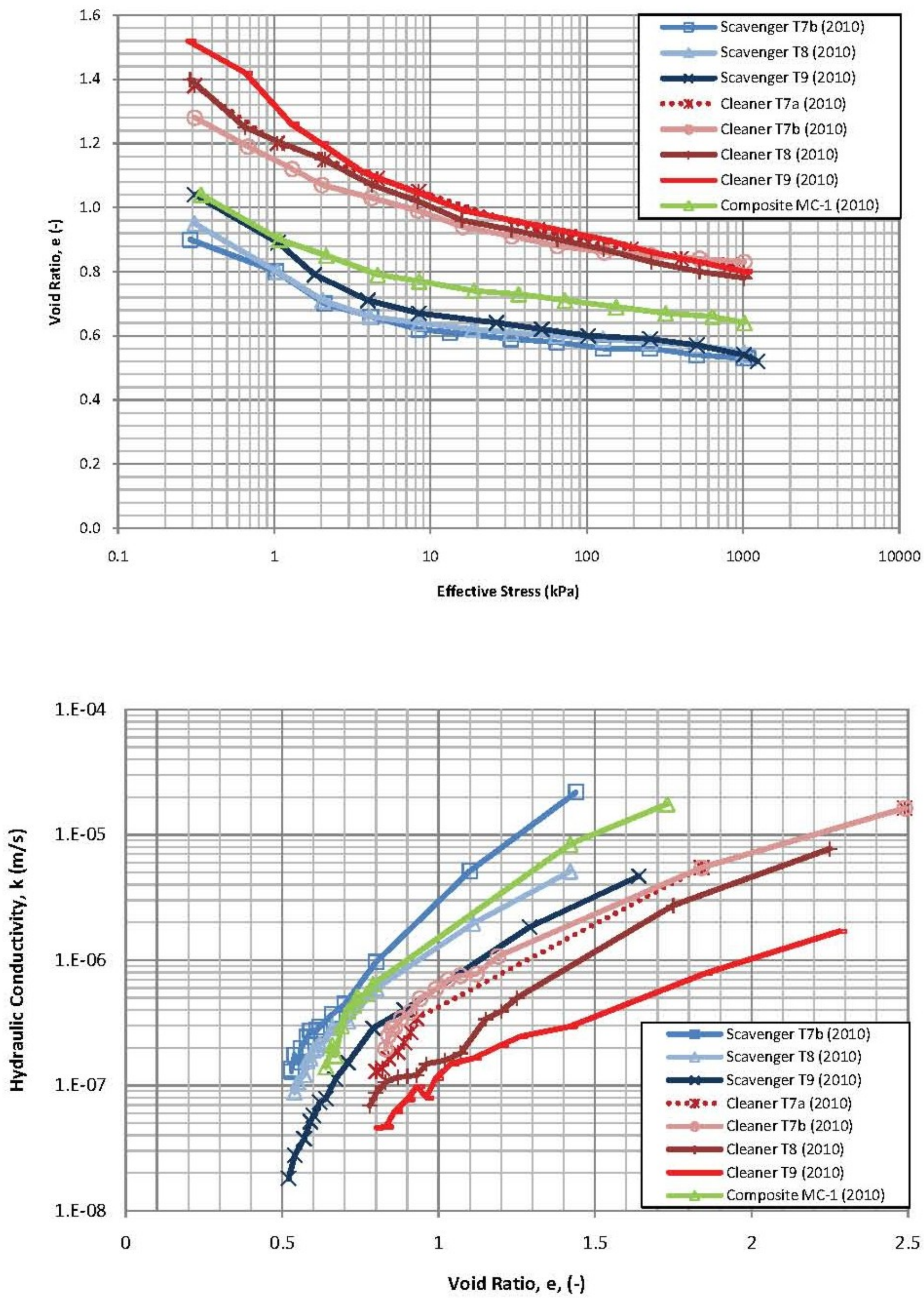


Figure 1 2010 Consolidation Test Data

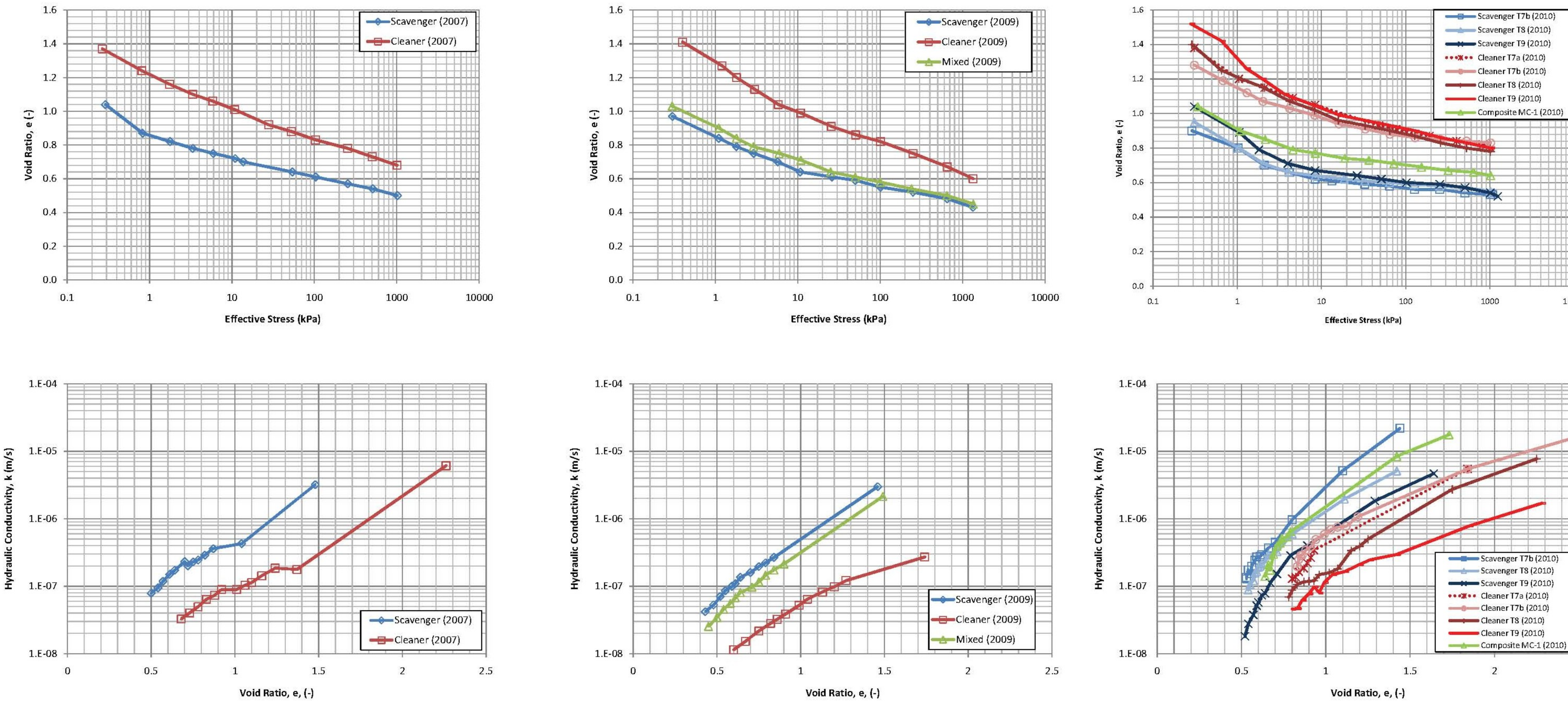


Figure 2 Comparison of All Consolidation Test Programs

APPENDIX I

2010 Samples Transmittal Data

FLSMIDTH

DAWSON METALLURGICAL LABORATORIES
2030 North Redwood Road, Suite 70
Salt Lake City, Utah 84116
Phone: (801) 596-0430
Fax: (801) 596-0425
Email: SLCDawsonLabs@FLSmidth.com

August 11, 2010

Klohn Crippen Berger
500-2955 Virtual Way
Vancouver, BC V5M 4X6
Canada

Attention: Mr. Howard Plewes

Subject: Delivery of Composite Samples from Rio Tinto's Resolution Property for Geo Tech Work. Our Project No. P-4148.

Dear Howard,

Enclosed are six (6) individual composite samples from the Resolution Property in Arizona. The composites were constructed from individual samples generated from seven cycle locked-cycle flotation tests conducted at DML on Resolution Master Composites (MC) 1, 2 and 3.

The following composite samples and weights are enclosed.

Master Composite	Test (cycles)	Composite Samples	Wgt, gm
MC-1	7 (3-7)	Cl scav tail	2800
		Scav tail	5000
MC-2	8 (2-7)	Cl scav tail	780
		Scav tail	5000
MC-3	9 (2-7)	Cl scav tail	480
		Scav tail	5000

The weight percent of Cl scav tails and scav tails to generate "whole tails" is presented below. The percentages are based on the locked-cycle work at DML.

Master Composite	Test (cycles)	Composite Samples	Wgt %,
MC-1	7 (3-7)	Cl scav tail	22.9
		Scav tail	77.1
		Total	100.0
MC-2	8 (2-7)	Cl scav tail	10.3
		Scav tail	89.7
		Total	100.0
MC-3	9 (2-7)	Cl scav tail	9.5
		Scav tail	90.5
		Total	100.0

Also included are 6, 5 gallon buckets (each approximately 1/2 full) of two different process waters used during the locked-cycle test work. Three buckets are identified as "Ro/scav water" and three as "Cl water" for each respective MC tests. The Ro/scav water was used during the rougher flotation stages. The Cl water was used during the cleaner flotation work.

If you have any questions, please contact me.

Sincerely,
FLSmidth Salt Lake City

Paul G. Bennett

Paul Bennett
Operations Manager
U:\My Documents\Rio Tinto\4148\Geo tech letter.doc

MATERIAL SAFETY DATA SHEET

Kennecott Utah Copper Corporation

DUCT INFORMATION — COPPER ORE

YNONYMS: Copper Ore	PRODUCT CODE: N/A	HIERARCHY: N/A
:HEMICAL FAMILY: Metal Sulfide and Silicate Minerals	FORMULA: N/A	MOLECULAR WEIGHT: N/A
1ANUFACTURER: Kennecott Utah Copper Corporation, P.O. Box 6001, Magna, UT 84044 (801) 569-6000	REVISION DATE: September 12, 2006	REPLACES SHEET DATED: September 24, 2002

FOR CHEMICAL EMERGENCIES CONTACT CHEMTREC (800) 424-9300

GREDIENTS / HEALTH HAZARD INFORMATION

COMPONENT	C.A.S. #	%	EXPOSURE LIMITS:
Silica	14808-60-7	Approx. 30%	0.1 mg/m³ OSHA/MSHA PEL for respirable quartz.
Alumina Silicates	1344-28-1	Approx. 50%	5.0 mg/m³ OSHA PEL for respirable dust.
Amphiboles & Pyroxenes (non-asbestiform)	N/A	Approx. 10%	
Metal Sulfides	N/A	Approx. 5%	5.0 mg/m³ OSHA PEL for respirable dust.
Other Minerals	N/A	Approx. 5%	5.0 mg/m³ OSHA PEL for respirable dust.

:emaining components not determined hazardous and/or hazardous components present at less than 1.0% (0.1% for carcinogens). NOTE: The International ،gency for Research on Cancer (IARC) has determined that respirable crystalline quartz is a Group I human carcinogen.

IYSICAL PROPERTIES

BOILING POINT: Not determined	SPECIFIC GRAVITY: Not determined	MELTING POINT: Not determined	EVAPORATION RATE (BUTYL ACETATE = 1): Not applicable
VAPOR PRESSURE: Not applicable	% VOLATILE: Not applicable	VAPOR DENSITY (AIR = 1): Not applicable	VISCOSITY, SUS: Not applicable
% SOLUBILITY IN WATER: Insoluble	POUR POINT: Not applicable	pH: Not applicable	APPEARANCE/ODOR: Broken rock; gray to greenish gray color with slight metallic odor.

ιᴗDUCT HEALTH HAZARD INFORMATION

NGESTION: Not a normal route of exposure. If powdered material is ingested, symptoms may include metallic taste, thirst, and abdominal pain.
KIN: Abrasive action may cause reddening, itching and inflammation. May cause allergic reactions in some individuals.
YE: Contact with powdered material may cause irritation. Abrasive action may cause damage to the outer surface of the eye.
NHALATION: Exposure to dust may cause respiratory tract irritation. Prolonged exposure to elevated levels of airborne dust may cause silicosis.
PECIAL TOXIC EFFECTS: None known.

RST AID

NGESTION:	Not a normal route of exposure. If large amounts have been swallowed, give 1-3 glasses of water or milk and induce vomiting. Do not make an unconscious person vomit. Keep affected person warm and at rest. Get immediate medical attention.
KIN CONTACT:	Wash area of contact thoroughly with soap and water. Get immediate medical attention if irritation persists.
YE CONTACT:	Flush immediately with large amounts of water. Eyelids should be held away from the eyeball to ensure thorough rinsing. Get immediate medical attention if irritation persists.
NHALATION:	Remove affected person from source of dust exposure. If not breathing, institute cardiopulmonary resuscitation (CPR). If breathing is difficult, give oxygen. Get immediate medical attention.

:RSONAL PROTECTION INFORMATION

YE PROTECTION:	SKIN PROTECTION:	RESPIRATORY PROTECTION:
/hen generating particles or dusts, wear ıfety glasses or chemical goggles to revent eye contact. Do not wear contact :nses when working with this substance. ave eye baths readily available where ye contact can occur.	Wear adequate gloves and protective clothing to prevent skin contact.	Use NIOSH approved respirator when airborne exposure limits are exceeded. NIOSH approved breathing equipment may be required for non-routine and emergency use. Ventilation may be used to control or reduce airborne concentrations.

RE AND EXPLOSION DATA

.ASH POINT: Not Applicable	AUTOIGNITION TEMPERATURE: Not Applicable	FLAMMABILITY LIMITS IN AIR (% BY VOL): Lower: NA Upper: NA
NUSUAL FIRE AND EXPLOSION HAZARDS: ıis material dose not give a flash point by conventional -' methods.	BASIC FIRE FIGHTING PROCEDURES: Use extinguishing agent suitable for type of surrounding fire. Fire fighters should wear NIOSH approved SCBA respirators with full-face mask and full protective equipment.	

EACTIVITY DATA

\BILITY/INCOMPATIBILITY: .ble under normal conditions of use.	HAZARDOUS REACTIONS / DECOMPOSITIONS PRODUCTS: Hydrogen sulfide may be released if ore is in contact with strong acid.

NVIRONMENTAL INFORMATION

SPILL OR RELEASE TO THE ENVIRONMENT: No special procedures are required for cleanup of spills or leaks of this material. Avoid methods that result in airborne dispersal or water pollution. Caution should be exercised regarding personnel safety.

WASTE DISPOSAL: This substance, when discarder or disposed of, is not specifically listed as a hazardous waste in Federal regulations. It could be designated as hazardous waste according to state regulations. This substance could also become a hazardous waste if it is mixed with or comes in contact with a hazardous waste. If such contact or mixing may have occurred, check 40 CFR 261, 262, 263 and 264 to determine what if any, hazardous waste regulations apply. The transportation, storage, treatment, and disposal of hazardous waste materials must be conducted in compliance with all applicable federal, state and local regulations.

ADDITIONAL ENVIRONMENTAL REGULATORY INFORMATION: Copper, total; arsenic, total; and lead, total are listed as a toxic pollutants (in water) pursuant to 40 CFR 122.21, Appendix D, Table III. Notification levels are describe in 40 CFR 122.42 (a) (1) and (2). Due to the low solubility of copper ore, this product is unlikely to exceed notification levels. Specific local, regional or state regulations must be complied with.

EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW (EPCRA) SECTION 313 SUPPLIER NOTIFICATION:
This product, "COPPER ORE", contains the following chemicals subject to the reporting requirements of section 313 of EPCRA:

CAS #	CHEMICAL NAME	PERCENT BY WEIGHT
7440-50-8	Copper & Compounds	<1.0 (as copper)
7439-92-1	Lead & Compounds	<0.1 (as lead)
7440-38-2	Arsenic & Compounds	<0.01 (as arsenic)

PECIAL PRECAUTIONS/SUPPLEMENTARY INFORMATION

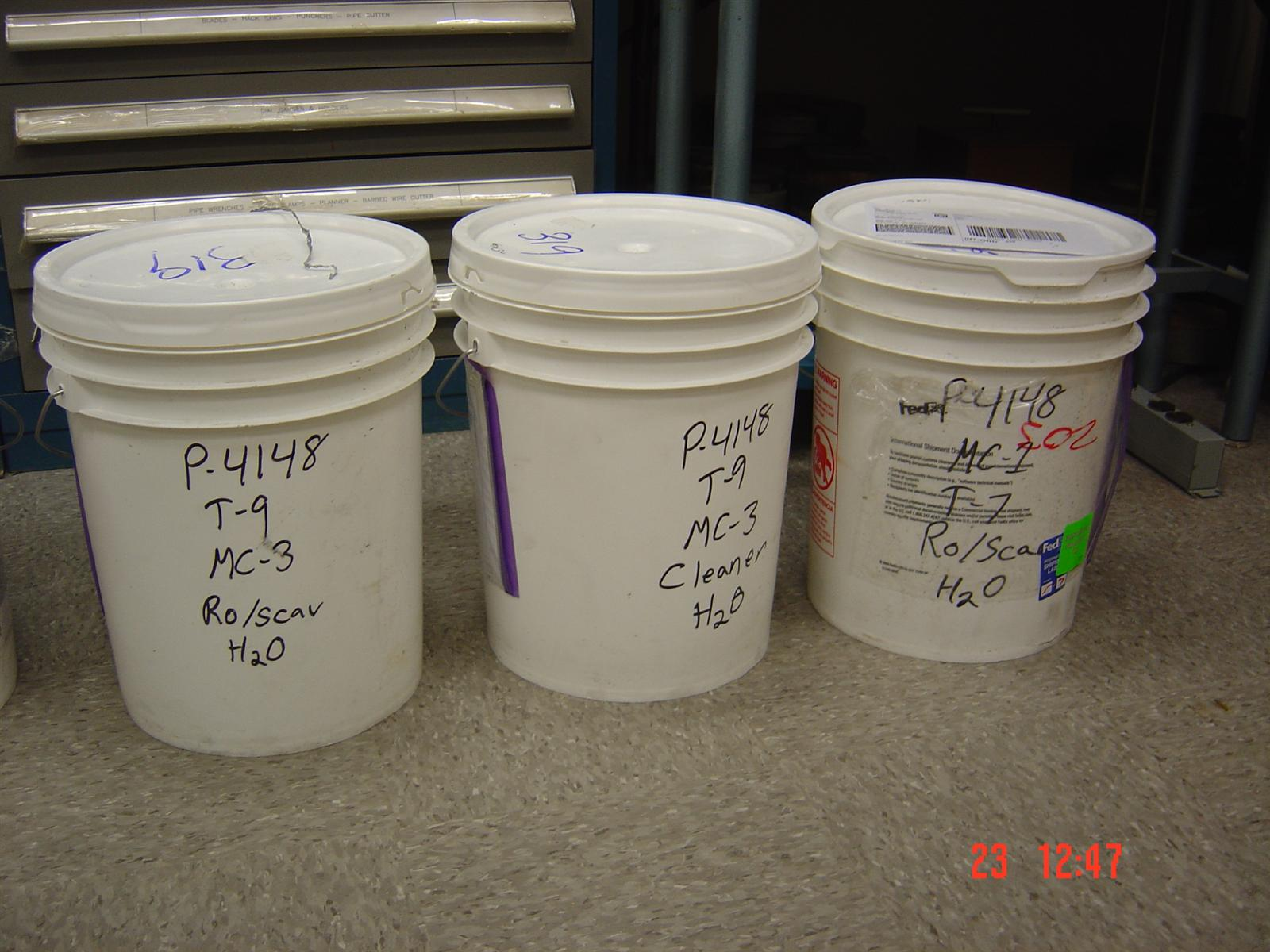
HANDLING/STORAGE: Avoid inhalation of dust from the material during processing.
MARITIME TRANSPORT: The bulk maritime shipment of copper ore should comply with all Coast Guard/DOT rules under 46 CFR 148.01 including the International Maritime Organization (IMO) Code of Safe Practice for Solid Bulk Cargoes. The cargo moisture content must be less than the Transportable Moisture Limitation.

'RANSPORTATION REQUIREMENTS

.O.T. HAZARD CLASS (49 CFR 172.101): N.A.	D.O.T. PROPER SHIPPING NAME (49 CFR 172.101): N.A.	D.O.T. PLACARDS REQUIRED: N.A.
D.O.T. LABELS REQUIRED (49 CFR 172.101): N.A.	BILL OF LADING DESCRIPTION: Unprocessed COPPER ORE	UN / NA CODE: CODE: N.A.


P.4148 RESOLUTION
T.7 MC.1
SCAV TAIL
COMPOSITE
5.0 kg
P.4148
RESOLUTION
T.8 MC-2
SCAV TAIL
COMPOSITE
5.0 kg
RESOLUTION
T.9 MC-3
5.0 kg
P.4148
RESOLUTION
2.8 kg
P.4148
RESOLUTION
T.8 MC-2
CL SCAV TAIL
COMPOSITE
RESOLUTION
T.9 MC-3
CL SCAV TAIL
COMPOSITE
23 12:36


MEMBRANE STRETCHERS
P-4148
MC-1
T-7
Cleaner
H2O
P-4148
MC-2
T-8
CL H2O
P-4148
T-8 MC-2
RO/Scav H2O
23 12:47


P-4148
T-9
MC-3
Ro/scav
H2O
P-4148
T-9
MC-3
Cleaner
H2O
P-4148
502
MC-1
T-7
Ro/Scav
H2O
23 12:47

APPENDIX II

2010 Laboratory Test Program

Final Report
on
Consolidation Testing of Resolution Project Tailings

November 30, 2010

To:

Howard D. Plewes, M.Sc, P.Eng.
Principal

Klohn Crippen Berger Ltd.
Suite 500, 2955 Virtual Way
Vancouver, British Columbia
V5M 4X6

From:

J. Don Scott

Department of Civil and Environmental Engineering, University of Alberta
3-133 Natural Resource Engineering Facility
Edmonton, Alberta
T6G 2W2

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Appendix A

Appendix B

1 Introduction

A testing program has been performed on seven tailings samples from the Resolution Copper Mining Project: three Scavenger Tailings, three Cleaner Tailings and one Composite Tailings. The testing program included the determination of the specific gravity, particle size distribution, mineralogy, Atterberg limits and consolidation properties. The consolidation testing included permeability standpipe tests to determine the void ratio - hydraulic conductivity relationships at large void ratios or low solids contents. At lower void ratios or higher solids contents these relationships are determined during the large strain consolidation tests. The Test Procedures and Test Apparatus are outlined in Appendix B attached to this report.

All of the above testing has been completed. Test results for the tests are given in the following tables and figures with a short discussion of the test results.

2 Resolution Tailings Material Received

Table 1 is a list of the samples as received. For identification, the table contains the geotechnical test numbers which have been used for all the tests. For testing purposes the relevant process water was mixed with the dry powder to make the fluid tailings samples. The consolidation test samples were mixed to approximately 65% solids content for the large strain consolidation tests. The relevant process water was also used for the permeability tests in the large strain consolidation cells and in the permeability standpipe tests to maintain the water chemistry in the samples.

3 Specific Gravity Test Results

Table 2 shows the specific gravity test results for the six tailings powders received. The samples were saturated with their respective tailings waters and deaired by boiling and applying a vacuum to the specific gravity flask. As specific gravity values are required for the analysis of the test results the specific gravity of the Composite MC-1, composed of 22.9% Cleaner-T7 and 77.1% Scavenger–T7, was calculated using the weighted percentages of the specific gravities of these two materials.

4 Tailings Water Chemistry Analyses

To prevent changes to the clay mineral bonding and structure in the tailings samples which may affect settlement, compressibility and hydraulic conductivity during the tests, all water added to a particular tailings must have the same water chemistry. In order to evaluate whether the water chemistry of the different tailings was having a significant effect on the different tailings geotechnical properties, the water chemistry was determined in the Department of Civil and Environmental Engineering laboratories.

The six water samples received were analyzed to obtain pH, electrical conductivity (EC), major anions and cations and trace metals (Table 3). Major anions and cations were determined using an Ion Chromatograph (IC) while trace metals were determined using a Inductively Coupled Plasma Mass Spectrometer (ICPMS). The alkalinity of the tailings water was determined by titrating the samples with 0.02N H_2SO_4. In order to prepare the sample for IC analysis, as received tailings water was filtered using a 0.2mm Nylon filter and diluted 10 times. For the ICPMS analysis, as received tailings were diluted 50 times with 1% HNO_3 solution to ensure that all the metals were in dissolved phase.
Although the Cleaner tailings contain significant amounts of pyrite and all the tailings are derived from a copper mine site, the ICPMS analysis of the tailings water did not reveal notable iron or copper. However, the IC analysis showed that all the tailings water is very rich in Ca^{2+} and SO_4^{-2} with minor amounts of Na^+, K^+, Mg^{2+} and Cl^- but NH_4^+ was not detected in all the samples. The ionic strength of all the tailings is quite high because of all the ions in solution (Table 3).

EC is an important parameter in water chemistry analysis. It can also be approximated by the equation, EC (mS/cm) = 100x(Sum of eq/L of Cations or Anions). The results of the equation calculation were in close agreement with the IC analysis for all the samples.

Cation distribution on the clay surface is an important parameter as it influences the clay structure formation. As equilibrium exists in all clay water systems, analysis of pore water ion distribution can be used to approximate the ionic distribution on the clay surfaces. A higher proportion of adsorbed divalent cations on the clay surfaces indicate formation of a card house structure and a non-dispersive nature of clay suspension which tends to release water faster. A higher amount of monovalent cations on solid surfaces, however, indicates a dispersive nature of the suspension and a slower rate of water release. In a clay rich sediment, the effect is notable. Further analyses of the IC results indicate that 92 to 94% of the clay sites for the Scavenger tailings would be occupied with the divalent cation (Ca^{2+}) while 96 to 99% of the clay sites for Cleaner tailings would be occupied with the Ca^{2+} ion. Therefore the tailings waters would not disperse the clays in the solids and the tailings slurries would have a high rate of water release. The lack of dispersion was noted when mixing the slurries as the released water during settlement was clear and no colloids where discernable.

Mineral precipitation (especially divalent carbonate salts such as Calcite, Aragonite, and Dolomite) can be of concern as it can cause clogging of pores in a soil system which will reduce the hydraulic conductivity. As all six tailings water samples are rich in Ca^{2+} and SO_4^{-2} which can cause Gypsum ($CaSO_4.2H_2O$) to precipitate. However, PHREEQC analyses (a geochemical software) of the water samples showed that saturation indices (SI) for these carbonate salts and for Gypsum are either negative or very close to zero. A positive SI for a particular mineral indicates precipitation and vice versa. Hence, Carbonate salts and Gypsum precipitation is not likely to be of concern for these tailings materials.

5 Particle Size Distribution Test Results

Figure 1 shows the particle size distribution by sieve and hydrometer testing for the six samples received. The particle size distribution for Composite MC-1, also shown on Figure 1, was calculated by taking a weighted average of those for Cleaner-T7 and Scavenger-T7. The coarser grain size distributions obtained in the sieve tests were determined by washing 100g to 150g of the tailings on a 75 micron sieve to remove all the finer material and then sieving that retained. The hydrometer test was performed on 25g of material passing the 75 micron sieve. The full particle size distributions were then calculated using the weighted averages of the two test procedures.

6 Summary of XRD Analyses

The six tailings powders were analyzed by AGAT Laboratories Ltd. for bulk and clay XRD mineralogy. Table 4 is a summary of the XRD analysis. The conclusion of the analysis was that these results show that the Cleaner Tailings samples Cleaner-T7 to Cleaner-T9 are rich in pyrite (heavy mineral) and muscovite when compared to the Scavenger Tailings samples Scavenger-T7 to Scavenger-T9, which only has minor amounts of muscovite in Scavenger-T9 only and has no pyrite heavy mineral. In addition, sample Scavenger-T9 has significantly higher amounts of smectite and moderately more chlorite when compared to sample Cleaner-T9. Smectite clays swell in presence of freshwater.

The full AGAT report is attached as Appendix A.

7 Atterberg Limits

The Atterberg Limits: the Liquid Limit, the Plastic Limit and the Shrinkage Limit were determined on the three Scavenger Tailings and on the three Cleaner Tailings. The results are given in Table 5. A Plasticity Chart which shows the engineering classification of soils is provided in Figure 2. All six tailings fall in the category of silts or clayey silts with slight plasticity.

8 Consolidation Test Procedures

The design initial solids content for the consolidation testing was 65%. As the specific gravities of the seven materials are different, the initial void ratios are different. The initial void ratios for all the consolidation tests are shown in Table 5.

As self-weight settlement in the consolidation cells resulted in a significant increase of solids content to about 75% before any test measurements could be taken, the initial permeability properties were determined by the permeability standpipe tests. To achieve reasonable data from these permeability standpipe tests, two solids contents, one at a solids content of 65% and one at a solids content of about 70% were chosen for testing.

The results of the large strain consolidation tests will be presented first followed by the permeability standpipe test results. The effective stress – void ratio measurements from the large strain consolidation tests will be presented first followed by the void ratio

– hydraulic conductivity measurements. The void ratio – hydraulic conductivity relationships determined by combining all of the above permeability results then will be shown with an analysis of the test results.

9 Large Strain Consolidation Tests

Table 5 lists the large strain consolidation tests performed and their initial and final properties. The table also shows the consolidation cells dimensions. Our typical cell is 152.6 mm in diameter and the typical sample height is between 80 mm and 90 mm.

The initial height of the sample is chosen so that the diameter-height ratio is approximately 2.5, to minimize wall friction, when effective stresses become significant above 10 kPa applied vertical stress. For a sample with an initial water content of about 75% (void ratio of 2.0) (solids content of about 60% depending on the specific gravity), it is estimated that an initial height of 80 mm to 90 mm would result in a height of about 50 mm at effective stresses over 10 kPa, based on consolidation tests previously performed in our laboratory. The height should be as large as possible, keeping in mind the diameter-height ratio, to obtain accuracy in the permeability test. An initial height of 80 mm to 90 mm appears to satisfy both requirements. The diameter-height ratio under these conditions has been found to be approximately 2.6 at a vertical effective stress of 10 kPa and over 3.0 at a vertical effective stress of 250 kPa. For samples with initial water contents greater than 75% or a solids content less than 60% a greater initial height is used.

As the amount of two of the three cleaner materials, T8 and T9, was not enough to fill a cell 152.6 mm in diameter to a sufficient height for accurate hydraulic conductivity measurements, cells 63.48 mm in diameter and about 63 mm in height were used. To evaluate whether side friction was affecting the volume decrease in these cells, consolidation tests on Cleaner-T7 were performed in both the 63.48 mm diameter and 152.6 mm diameter cells. As no evidence of cell friction was seen in these comparison tests, consolidation tests on Cleaner-T8 and Cleaner-T9 was performed in the 63.48 mm diameter cells.

The first test performed was on Scavenger-T7. When the tailings were tremied into the cell, it appeared that the tailings were channeling, that is, several small one mm diameter quick channels were formed with water and fine material flowing to the surface. This action stopped fairly quickly as the sample settled. Subsequent hydraulic conductivity tests on this sample, however, did not perform properly and the test was abandoned. As initial results on this test appear to be relevant, the test was called Scavenger-T7a and the data is presented in Table 6. To prevent channeling in subsequent tests, the drainage conditions were changed during filling from single upward drainage to double upward and downward drainage. This test procedure appeared to work well and a second test, Scavenger-T7b, was performed. The data is presented in Table 7.

For submerged samples about 80 mm to 90 mm high the effective stress at mid-height of the sample is approximately 0.3 kPa, depending on the specific gravity, and this effective stress is used for the self-weight effective stress.

The first applied load in the consolidation cells is about 0.7 kPa from the submerged mass of the top plate which results in an effective stress of about 1.0 kPa including self-weight. For the small diameter cells it is about 0.7 kPa. The load is approximately doubled for each load step up to a maximum effective stress of about 1000 kPa resulting in 12 or 13 load steps including self-weight. Each load is applied for usually two days for this tailings material until all settlement has basically ceased and then an upwards flow hydraulic conductivity test is performed. The samples are then unloaded in 3 load steps and the rebound measured.

Tables 6 to 14 show the change in height and change in void ratio from each load step. Hydraulic conductivity tests are conducted after consolidation from each load step is complete. The results from these tests are also shown on Tables 6 to 14.

After self-weight has completed consolidation, the void ratio varies from a high void ratio at the surface of the sample to a much lower void ratio at the bottom. The void ratio values in the tables for self-weight are the average values. Hydraulic conductivity tests are not performed after self-weight consolidation as it is not known what void ratio controls the hydraulic conductivity.

Hydraulic conductivities at the initial void ratios can also be determined in the consolidation tests from the initial settlement velocities if drainage is single upwards. As this drainage mechanism appeared to cause channeling in the samples it was not used except for Scavenger-T7a and no other initial hydraulic conductivity values were obtained in these tests. Hydraulic conductivity at the initial solids content of about 65%, however, was determined in the permeability standpipe tests.

10 Compressibility from Consolidation Tests

Compressibility from the large strain consolidation tests in terms of void ratio versus effective stress is shown in Figures 2 to 7.

Figure 2 shows the compressibility of the three Scavenger tailings. The results are quite similar. Scavenger-T9 shows less consolidation below an effective stress of 100 kPa which might be an effect of it starting at a larger void ratio. The three tailings have similar void ratios at the largest effective stress of about 1,000 kPa. Figure 3 is the same data but the initial void ratios have been plotted at an effective stress of 0.1 kPa. Previous compressibility standpipe tests on resolution tailings indicated that at an initial solids content of 65% the effective stress was about 0.1 kPa. However, Figure 3 was plotted this way mainly to show the total volume change from the initial void ratio to that at 1,000 kPa confining stress. This figure shows that about one-half of the total consolidation occurred under self-weight and about 85% occurred under a 10 kPa confining stress.

Figure 4 shows the compressibility of the three Cleaner tailings. The results are quite similar. Figure 5 is the same data with the initial void ratio plotted at 0.1 kPa. Over half of the total consolidation occurred under self-weight and over 85% occurred under a 10 kPa confining stress. The Cleaner tailings consolidate less than the Scavenger tailings which is probably the result of their finer grain size.

Figure 6 compares the compressibility of sample Cleaner-T7a in the large 152.6 mm diameter cell with the compressibility of sample Cleaner-T7b in the small 63.48 mm diameter cell. Self-weight consolidations and total consolidations of the two samples are very similar. If wall friction was preventing consolidation in the small cell which had an initial diameter-height ratio of about one, it would be manifest in the low stress range. By about 20 kPa confining stress the consolidation was enough that the diameter-height ratio had increased to about two and the effects of wall friction would be small.

Figure 7 shows the compressibility of sample Composite MC-1. For comparison, the two tailings which were combined to make Composite MC-1, tailings Scavenger-T7 and Cleaner-T7, are also plotted on Figure 7. The three compressibility plots reflect the percentages used of the two T7 tailings, their different particle size distribution and their different specific gravities.

11 Permeability Standpipe Test Results

The permeability standpipe tests have to be performed at a low enough solids content that hindered sedimentation can be measured before consolidation dominates the settling process. The tests also have to be performed at a high enough solids content that segregation, which is the larger particles preferably settling faster than the smaller particles, does not occur. After mixing, the Cleaner tailings at 65% solids had some large heavy pyrite particles settle out quickly but this small amount was not considered to be a problem.

In the permeability standpipe tests the drainage is single upwards drainage and the possibility of channeling as in the Scavenger-T7a consolidation test was recognized. The permeability standpipe tests at 70% solids did not show any signs of channeling. The tests at 65% solids also did not show any channeling in the first 10 to 20 minutes of the test which allowed enough data to be collected to determine the hydraulic conductivity at this solids content.

The hydraulic conductivity is calculated from the initial settling velocity by the following equation:

$$v_s = -\left(\frac{\gamma_s}{\gamma_w} - 1\right)\frac{k}{1+e} \qquad [1]$$

Where v_s is initial settling velocity, γ_s is unit weight of solids, γ_w is unit weight of water, k is hydraulic conductivity and e is the initial void ratio.

Table 15 shows the tests performed, the initial hindered settling velocities and the calculated hydraulic conductivities.

12 Combined Hydraulic Conductivity Measurements

The hydraulic conductivities measured in the consolidation tests and in the permeability standpipe tests are combined and plotted in Figures 8 to 10 versus void ratio.

Figure 8 shows the hydraulic conductivities for the three Scavenger tailings. Although the three tailings materials had similar particle size distributions and similar compressibilities, there are enough differences to result in different hydraulic conductivity relationships with void ratio. The two high hydraulic conductivities for each tailings are from the permeability standpipe tests. As well, the initial hydraulic conductivity measured in the consolidation test on Scavenger-T7a at its initial solids content of 65% is also plotted and agrees well with the permeability standpipe test on Scavenger-T7.

Figure 9 shows the hydraulic conductivities for the three Cleaner tailings. These tailings also had different hydraulic conductivity relationships with void ratio. Their hydraulic conductivities are lower that those of the Scavenger tailings which reflects their finer particle size distribution.

Figure 10 shows the hydraulic conductivity for the Composite MC-1 tailings. For comparison, the two tailings which were combined to make Composite MC-1, tailings Scavenger-T7 and Cleaner-T7, are also plotted on Figure 10. The three hydraulic conductivity plots reflect the percentages used of the two T7 tailings, their different particle size distributions and their different specific gravities.

A power law relationship for hydraulic conductivity expressed as Equation 2 is suggested for each tailings material and plotted in Figures 8, 9 and 10. The C and D values are shown in Table 16.

$$k = Ce^{D} \qquad [2]$$

13 Summary

A testing program has been performed on seven tailings samples from the Resolution Copper Mining Project: three Scavenger Tailings, three Cleaner Tailings and one Composite Tailings. The testing program included the determination of their classification properties and their consolidation properties. The classification testing included specific gravity, particle size distribution, mineralogy and Atterberg limits. The consolidation tests included large strain consolidation to determine their effective stress – void ratio relationships and their void ratio – hydraulic conductivity relationships. Permeability standpipe tests were also performed as part of the hydraulic conductivity investigation. In addition, the tailings water chemistry was analyzed to determine its influence on the geotechnical properties.

The three Scavenger tailings were similar in their properties as were the three Cleaner tailings. The Composite Tailings properties were a weighted average of the Scavenger tailings and Cleaner tailings that composed the Composite Tailings.

The XRD analysis showed that the Cleaner Tailings samples Cleaner-T7 to Cleaner-T9 are rich in pyrite (heavy mineral) and muscovite when compared to the Scavenger Tailings samples Scavenger-T7 to Scavenger-T9. There are minor amounts of muscovite only in Scavenger-T9 but no pyrite heavy mineral. In addition, sample Scavenger-T9 has significantly higher amounts of smectite and moderately more chlorite when compared to sample Cleaner-T9.

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Table 1: Resolution Tailings Materials Received

Master composite	Name	Geotechnical Test Number	Material	Mass (gm)
MC-1	Cl scav tail	Cleaner-T7	Dry powder	2800
MC-1	Scav tail	Scavenger-T7	Dry powder	5000
MC-2	Cl scav tail	Cleaner-T8	Dry powder	780
MC-2	Scav tail	Scavenger-T8	Dry powder	5000
MC-3	Cl scav tail	Cleaner-T9	Dry powder	480
MC-3	Scav tail	Scavenger-T9	Dry powder	5000
MC-1	Cleaner	Cleaner-T7	Water	12000
MC-1	Ro/Scav	Scavenger-T7	Water	14500
MC-2	Cleaner	Cleaner-T8	Water	10600
MC-2	Ro/Scav	Scavenger-T8	Water	12000
MC-3	Cleaner	Cleaner-T9	Water	9500
MC-3	Ro/Scav	Scavenger-T9	Water	13100

Table 2: Specific Gravity Tests

Test number	Test method	Sample used (gm)	Specific gravity
Scavenger-T7	boiling and vacuum	75	2.75
Scavenger-T8	boiling and vacuum	75	2.8
Scavenger-T9	boiling and vacuum	75	2.88
Cleaner-T7	boiling and vacuum	75	4.33
Cleaner-T8	boiling and vacuum	75	3.80
Cleaner-T9	boiling and vacuum	50	3.91
Composite MC-1	Calculated	-	3.11

Table 3: Water Chemistry Analyses

Sample ID	pH	EC (mS/cm)	mg/L							I (M)
			Na	K	Mg	Ca	Cl	SO4	Alkalinity (as HCO_3)	
Scavenger-T7	7.46	0.824	27.8	41.7	4.7	95.5	24.0	275.6	57.9	0.011
Scavenger-T8	7.64	1.774	42.2	78.0	9.8	296.2	30.3	915.7	64.6	0.028
Scavenger-T9	7.5	2.52	65.4	52.8	11.3	508.2	26.1	1698.9	59.7	0.045
Cleaner-T7	6.56	0.87	14.5	6.2	0.9	155.8	17.5	341.9	20.1	0.013
Cleaner-T8	6.75	0.835	15.0	8.2	4.1	139.0	20.0	318.0	22.9	0.012
Cleaner-T9	4.73	1.167	17.6	11.1	2.9	218.9	19.7	549.2	1.2	0.018

Sample ID	Equivalent fraction on clay surface				Saturation Index (SI)				
	β_{Na}	β_{K}	β_{Mg}	β_{Ca}	Anhydrite	Aragonite	Calcite	Gypsum	Dolomite
Scavenger-T7	0.01	0.02	0.05	0.92	-1.3	-0.6	-0.4	-1.1	-1.8
Scavenger-T8	0.00	0.03	0.03	0.94	-0.6	-0.02	0.12	-0.4	-0.9
Scavenger-T9	0.01	0.01	0.02	0.96	-0.3	-0.07	0.07	-0.04	-1.2
Cleaner-T7	0.00	0.00	0.01	0.99	-1.1	-1.7	-1.6	-0.9	-5.1
Cleaner-T8	0.00	0.00	0.03	0.96	-1.2	-1.5	-1.4	-0.9	-4.0
Cleaner-T9	0.00	0.00	0.01	0.98	-0.8	-4.3	-4.2	-0.6	-10.0

Table 4: Summary of XRD Analysis

SAMPLE ID.	TYPE OF ANALYSIS	WEIGHT %											CLAYS					Total
			Qtz	Plag	K-Feld	Cal	Dol	Anhy	Pyr	Musc	Bar	Sider	Kaol	Chl	Ill	ML	Smec	Clay
Scavenger-T7	BULK FRACTION:	93.38	63	0	1	0	0	0	0	0	0	0	19	0	17	0	0	36
	CLAY FRACTION:	6.62	1	0	0	0	0	0	0	0	0	0	43	0	56	0	0	99
	BULK & CLAY	100	59	0	1	0	0	0	0	0	0	0	21	0	19	0	0	40
Scavenger-T8	BULK FRACTION:	92.24	67	0	2	0	0	0	0	0	0	0	10	0	21	0	0	31
	CLAY FRACTION:	7.76	1	0	0	0	0	0	0	0	0	0	28	0	71	0	0	99
	BULK & CLAY	100	62	0	2	0	0	0	0	0	0	0	11	0	25	0	0	36
Scavenger-T9	BULK FRACTION:	90.26	65	0	3	0	0	0	0	6	0	0	6	0	14	0	6	26
	CLAY FRACTION:	9.74	1	0	0	0	0	0	0	0	0	0	15	5	53	0	26	99
	BULK & CLAY	100	60	0	3	0	0	0	0	5	0	0	7	TR	17	0	8	32
Cleaner-T7	BULK FRACTION:	96.49	12	0	3	0	0	0	65	3	0	0	12	0	5	0	0	17
	CLAY FRACTION:	3.51	5	0	0	0	0	0	9	0	0	0	33	0	53	0	0	86
	BULK & CLAY	100	11	0	3	0	0	0	63	3	0	0	13	0	7	0	0	20
Cleaner-T8	BULK FRACTION:	96.13	14	0	1	1	0	0	49	23	0	0	5	0	6	0	0	11
	CLAY FRACTION:	3.87	3	0	0	0	0	0	5	17	0	0	33	0	42	0	0	75
	BULK & CLAY	100	14	0	1	1	0	0	47	23	0	0	6	0	8	0	0	14
Cleaner-T9	BULK FRACTION:	95.56	8	0	1	0	0	0	56	20	0	0	6	0	9	0	0	15
	CLAY FRACTION:	4.44	7	0	0	0	0	0	16	0	0	0	3	3	65	0	6	77
	BULK & CLAY	100	8	0	1	0	0	0	54	19	0	0	6	TR	11	0	TR	18

ABBREVIATIONS

Amp – Amphiboles
Ana – Analcime
Anhy – Anhydrite
Ank – Ankerite
Apa – Apatite
Bar – Barite
Cal – Calcite
Chl – Chlorite
Phos – Phosphate

Dol – Dolomite
Gyp – Gypsum
Hal – Halite
Hem – Hematite
Ill – Illite
Kaol – Kaolinite
K-feld - Potassic Feldspar
Mack – Mackinawite
Musc – Muscovite

Marc – Marcasite
ML* - Illite-Smectite
ML** - Corrensite (chlorite-smectite)
Plag - Plagioclase Feldspar
Pyr – Pyrite
Qtz – Quartz
Sider – Siderite
Smec - Smectite (montmorillonite)
Wues – Wuestite

Pr - Pure (95 – 100%)
NPr - Near Pure (90 – 95%)
Abnt - Abundant (60 – 90%)
Com - Common (30 – 60%)
Mnr - Minor (10 – 30%)
Rre - Rare (1 – 10%)
Tr - Trace; detectable but not measurable (0 – 1%)

Unk - Unknown

Table 5: Atterberg Limits

Sample	Liquid limit	Plastic Limit	Plasticity Index	Shrinkage Limit
Scavenger T7	19.0	19.0	0.0	19.0
Scavenger T8	20.0	19.6	0.4	19.0
Scavenger T9	20.7	19.3	1.4	17.3
Cleaner T7	15.2	13.1	2.1	12.9
Cleaner T8	19.0	15.6	3.4	15.3
Cleaner T9	21.0	16.3	4.7	13.1

Table 6: Large Strain Consolidation Tests

Test number	Cell diameter (mm)	Initial properties			Final properties		
		Solids content %	Void ratio	Height (mm)	Solids content %	Void ratio	Height (mm)
Scavenger-T7a	152.6	65.0	1.48	81.0	-	-	-
Scavenger-T7b	152.6	65.0	1.48	86.4	83.4	0.54	53.7
Scavenger-T8	152.6	66.4	1.42	84.0	83.4	0.55	54.0
Scavenger-T9	152.6	64.6	1.58	86.0	84.4	0.53	51.1
Cleaner-T7a	152.6	63.5	2.49	65.8	84.0	0.83	34.4
Cleaner-T7b	63.48	63.5	2.49	65.7	83.9	0.83	34.5
Cleaner-T8	63.48	62.8	2.25	67.5	82.7	0.79	37.2
Cleaner-T9	63.48	63.2	2.28	64.5	82.7	0.81	35.7
Composite MC-1	152.6	66.5	1.57	84.7	84.0	0.65	54.4

Table 7: Large Strain Consolidation Test for Scavenger-T7a

Effective Stress (kPa)	Height (mm)	ΔH (mm)	Solids content %	Void ratio	Hydraulic Conductivity (cm/s)
0	81.00	0.00	65.0	1.48	1.97E-03
0.28	63.00	18.00	74.9	0.92	-
0.92	59.60	3.40	77.1	0.82	3.36E-06
2.08	57.33	2.27	78.6	0.75	2.62E-05

Table 8: Large Strain Consolidation Test for Scavenger-T7b

Effective Stress (kPa)	Height (mm)	ΔH (mm)	Solids content %	Void ratio	Hydraulic Conductivity (cm/s)
0	86.40	0.00	65.0	1.48	
0.29	66.00	20.40	75.4	0.90	
1.03	62.60	3.40	77.5	0.80	9.68E-05
2.11	59.34	3.26	79.6	0.70	4.46E-05
4.15	57.65	1.69	80.8	0.66	3.69E-05
8.41	56.53	1.12	81.5	0.62	2.93E-05
13.3	56.07	0.46	81.8	0.61	2.75E-05
32.7	55.24	0.83	82.4	0.59	2.73E-05
64.3	54.86	0.38	82.7	0.58	2.43E-05
127	54.48	0.38	83.0	0.56	1.97E-05
254	54.20	0.28	83.2	0.56	1.53E-05
506	53.79	0.41	83.5	0.54	1.75E-05
1012	53.28	0.51	83.8	0.53	1.35E-05
1075	53.13	0.15	84.0	0.53	1.29E-05
506	53.18	-0.06	83.9	0.53	
254	53.25	-0.07	83.9	0.53	
1.03	53.72	-0.47	83.5	0.54	

Table 9: Large Strain Consolidation Test for Scavenger-T8

Effective Stress (kPa)	Height (mm)	ΔH (mm)	Solids content %	Void ratio	Hydraulic Conductivity (cm/s)
0	84.00	0.00	66.4	1.42	
0.31	68.00	16.00	74.6	0.95	
1.05	62.47	5.53	77.8	0.80	5.94E-05
2.04	59.39	3.08	79.8	0.71	3.26E-05
4.08	57.81	1.58	80.8	0.66	2.90E-05
8.42	56.90	0.91	81.5	0.64	2.25E-05
18.6	56.41	0.49	81.8	0.62	2.13E-05
32.7	55.99	0.42	82.1	0.61	1.99E-05
64.3	55.63	0.36	82.3	0.60	1.92E-05
127	55.31	0.32	82.6	0.59	1.65E-05
254	54.99	0.32	82.8	0.58	1.57E-05
506	54.62	0.37	83.0	0.57	1.22E-05
1012	53.96	0.66	83.5	0.55	1.06E-05
1069	53.56	0.41	83.8	0.54	8.76E-06
506	53.62	-0.06	83.8	0.54	
254	53.66	-0.04	83.7	0.54	
1.05	54.02	-0.36	83.5	0.55	

Table 10: Large Strain Consolidation Test for Scavenger-T9

Effective Stress (kPa)	Height (mm)	ΔH (mm)	Solids content %	Void ratio	Hydraulic Conductivity (cm/s)
0	86.00	0.00	64.6	1.58	
0.31	68.00	18.00	73.5	1.04	
1.06	62.98	5.02	76.5	0.89	3.99E-05
1.81	59.90	3.07	78.4	0.79	2.85E-05
3.96	57.23	2.67	80.1	0.71	1.52E-05
8.43	55.69	1.54	81.2	0.67	1.12E-05
26.4	54.72	0.97	81.8	0.64	7.84E-06
51.6	54.11	0.61	82.3	0.62	7.36E-06
102	53.54	0.57	82.7	0.60	5.75E-06
254	53.07	0.47	83.0	0.59	5.13E-06
506	52.44	0.64	83.5	0.57	3.75E-06
1012	51.52	0.92	84.1	0.54	2.77E-06
1239	50.58	0.94	84.8	0.52	1.81E-06
1012	50.61	-0.03	84.8	0.52	
506	50.68	-0.07	84.8	0.52	
254	50.76	-0.08	84.7	0.52	
1.06	51.10	-0.34	84.4	0.53	

Table 11: Large Strain Consolidation Test for Cleaner-T7a

Effective Stress (kPa)	Height (mm)	ΔH (mm)	Solids content %	Void ratio	Hydraulic Conductivity (cm/s)
0	65.78	0.00	63.5	2.49	
0.31	44.80	20.98	75.9	1.38	
1.05	41.58	3.22	78.2	1.20	4.53E-05
2.12	40.59	0.99	79.0	1.15	3.09E-05
4.56	39.50	1.09	79.8	1.09	2.33E-05
8.42	38.73	0.78	80.4	1.05	4.33E-05
48.0	36.42	2.31	82.3	0.93	3.42E-05
77.3	35.95	0.46	82.7	0.91	2.65E-05
103	35.63	0.32	83.0	0.89	2.20E-05
192	35.20	0.43	83.3	0.87	1.84E-05
401	34.78	0.43	83.7	0.84	1.64E-05
827	34.26	0.52	84.1	0.82	1.36E-05
1017	33.87	0.38	84.4	0.80	1.29E-05
763	33.91	-0.04	84.4	0.80	
382	33.98	-0.07	84.3	0.81	
1.05	34.43	-0.44	83.9	0.83	

Table 12: Large Strain Consolidation Test for Cleaner-T7b

Effective Stress (kPa)	Height (mm)	ΔH (mm)	Solids content %	Void ratio	Hydraulic Conductivity (cm/s)
0	65.70	0.00	63.5	2.49	
0.31	42.94	22.76	77.2	1.28	
0.68	41.27	1.67	78.4	1.19	1.07E-04
1.30	39.88	1.39	79.5	1.12	7.71E-05
2.02	38.97	0.90	80.2	1.07	7.50E-05
4.19	38.14	0.83	80.9	1.03	6.92E-05
8.30	37.41	0.73	81.4	0.99	5.84E-05
16.1	36.49	0.92	82.2	0.94	4.91E-05
33.2	36.05	0.44	82.6	0.91	3.82E-05
65.0	35.41	0.64	83.1	0.88	3.42E-05
129	35.06	0.35	83.4	0.86	2.90E-05
258	34.84	0.22	83.6	0.85	2.85E-05
527	34.61	0.23	83.8	0.84	2.49E-05
1017	34.37	0.24	84.0	0.83	1.95E-05
491	34.44	-0.07	83.9	0.83	
258	34.45	0.00	83.9	0.83	
0.68	34.50	-0.06	83.9	0.83	

Table 13: Large Strain Consolidation Test for Cleaner-T8

Effective Stress (kPa)	Height (mm)	ΔH (mm)	Solids content %	Void ratio	Hydraulic Conductivity (cm/s)
0	67.53	0.00	62.8	2.25	
0.29	49.81	17.72	73.1	1.40	
0.65	46.70	3.11	75.3	1.25	4.97E-05
1.12	45.71	0.99	76.0	1.20	3.90E-05
2.03	44.66	1.05	76.8	1.15	3.38E-05
4.20	42.99	1.67	78.0	1.07	1.81E-05
8.27	41.92	1.07	78.9	1.02	1.58E-05
15.9	40.80	1.12	79.8	0.96	1.48E-05
33.0	40.14	0.66	80.3	0.93	1.20E-05
64.8	39.45	0.68	80.9	0.90	1.18E-05
128	38.80	0.65	81.4	0.87	1.16E-05
258	38.09	0.71	82.0	0.83	1.06E-05
527	37.42	0.67	82.6	0.80	8.71E-06
1016	37.00	0.43	82.9	0.78	6.89E-06
490	37.05	-0.06	82.9	0.78	
30.6	37.12	-0.07	82.8	0.79	
0.65	37.23	-0.11	82.7	0.79	

Table 14: Large Strain Consolidation Test for Cleaner-T9

Effective Stress (kPa)	Height (mm)	ΔH (mm)	Solids content %	Void ratio	Hydraulic Conductivity (cm/s)
0	64.50	0.00	63.2	2.28	
0.28	49.62	14.88	72.0	1.52	
0.65	47.58	2.04	73.4	1.42	2.95E-05
1.29	44.49	3.10	75.6	1.26	2.45E-05
1.98	43.25	1.23	76.6	1.20	2.09E-05
3.69	41.46	1.80	77.9	1.11	1.64E-05
8.95	40.06	1.39	79.1	1.04	1.49E-05
16.1	39.12	0.95	79.8	0.99	1.13E-05
33.2	38.50	0.61	80.4	0.96	7.96E-06
65.0	37.92	0.58	80.8	0.93	9.80E-06
129	37.31	0.61	81.4	0.90	7.72E-06
258	36.71	0.60	81.9	0.86	6.20E-06
527	36.08	0.63	82.4	0.83	4.66E-06
1017	35.50	0.58	83.0	0.80	4.59E-06
491	35.50	0.00	83.0	0.80	
30.7	35.52	-0.02	82.9	0.80	
0.65	35.72	-0.21	82.8	0.81	

Table 15: Large Strain Consolidation Test for Composite MC-1

Effective Stress (kPa)	Height (mm)	ΔH (mm)	Solids content %	Void ratio	Hydraulic Conductivity (cm/s)
0	84.70	0.00	66.5	1.57	
0.34	67.30	17.40	75.0	1.04	
1.08	62.64	4.66	77.6	0.90	3.70E-05
2.15	61.00	1.65	78.6	0.85	3.96E-05
4.59	59.19	1.81	79.7	0.79	6.41E-05
8.45	58.38	0.81	80.2	0.77	5.35E-05
18.9	57.59	0.79	80.7	0.74	5.13E-05
36.7	57.13	0.46	81.0	0.73	4.37E-05
72.3	56.39	0.74	81.4	0.71	3.91E-05
154	55.78	0.60	81.8	0.69	2.99E-05
319	55.25	0.53	82.2	0.67	1.73E-05
636	54.83	0.42	82.5	0.66	2.08E-05
1017	54.08	0.75	83.0	0.64	1.40E-05
636	54.11	-0.03	82.9	0.64	
64.7	54.27	-0.16	82.8	0.64	
1.08	54.44	-0.16	82.7	0.65	

Table 16: Hydraulic Conductivity from Permeability Standpipe Tests

Tailings	Solids content %	Void ratio	Initial Velocity (cm/s)	Hydraulic Conductivity (cm/s)
Scavenger-T7	65.6	1.44	1.57E-03	2.19E-03
	71.4	1.10	4.29E-04	5.16E-04
Scavenger-T8	66.4	1.42	3.78E-04	5.08E-04
	71.7	1.11	1.67E-04	1.95E-04
Scavenger-T9	63.7	1.64	3.33E-04	4.68E-04
	69.1	1.29	1.50E-04	1.83E-04
Cleaner-T7	63.5	2.49	1.55E-03	1.63E-03
	70.2	1.84	6.40E-04	5.46E-04
Cleaner-T8	62.8	2.25	6.67E-04	7.74E-04
	68.5	1.75	2.78E-04	2.73E-04
Cleaner-T9	63.2	2.28	1.50E-04	1.69E-04
	67.9	1.85	7.98E-05	7.81E-05
Composite MC-1	64.3	1.73	1.35E-03	1.75E-03
	68.6	1.42	7.30E-04	8.38E-04

Table 17: Hydraulic Conductivity Power Law Relationships

Test number	Hydraulic Conductivity Functions	
	C (cm/s)	D
Scavenger-T7	3.22E-04	4.9664
Scavenger-T8	1.34E-04	4.0473
Scavenger-T9	5.99E-05	4.6716
Cleaner-T7	5.38E-05	3.8174
Cleaner-T8	1.87E-05	4.4920
Cleaner-T9	1.07E-05	3.3612
Composite MC-1	1.54E-04	4.6159

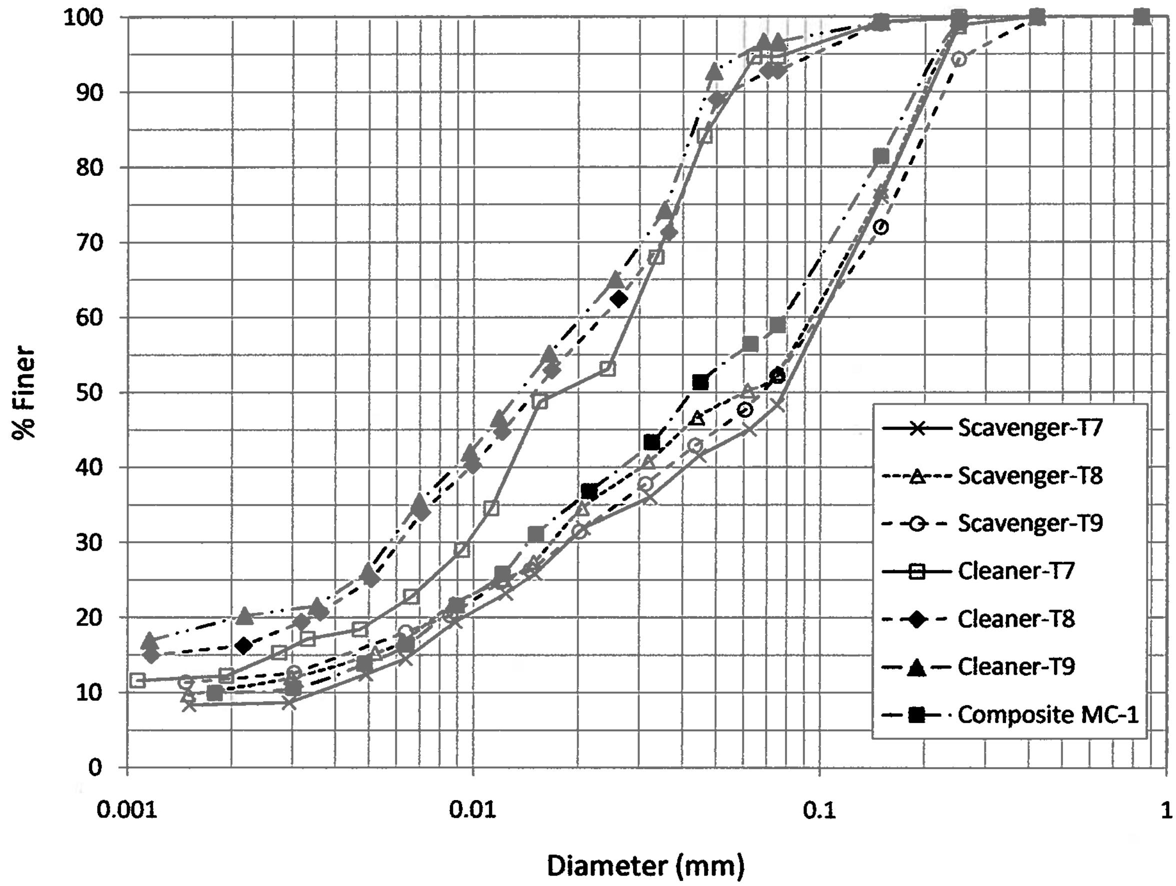

Figure 1: Particle Size Distributions.

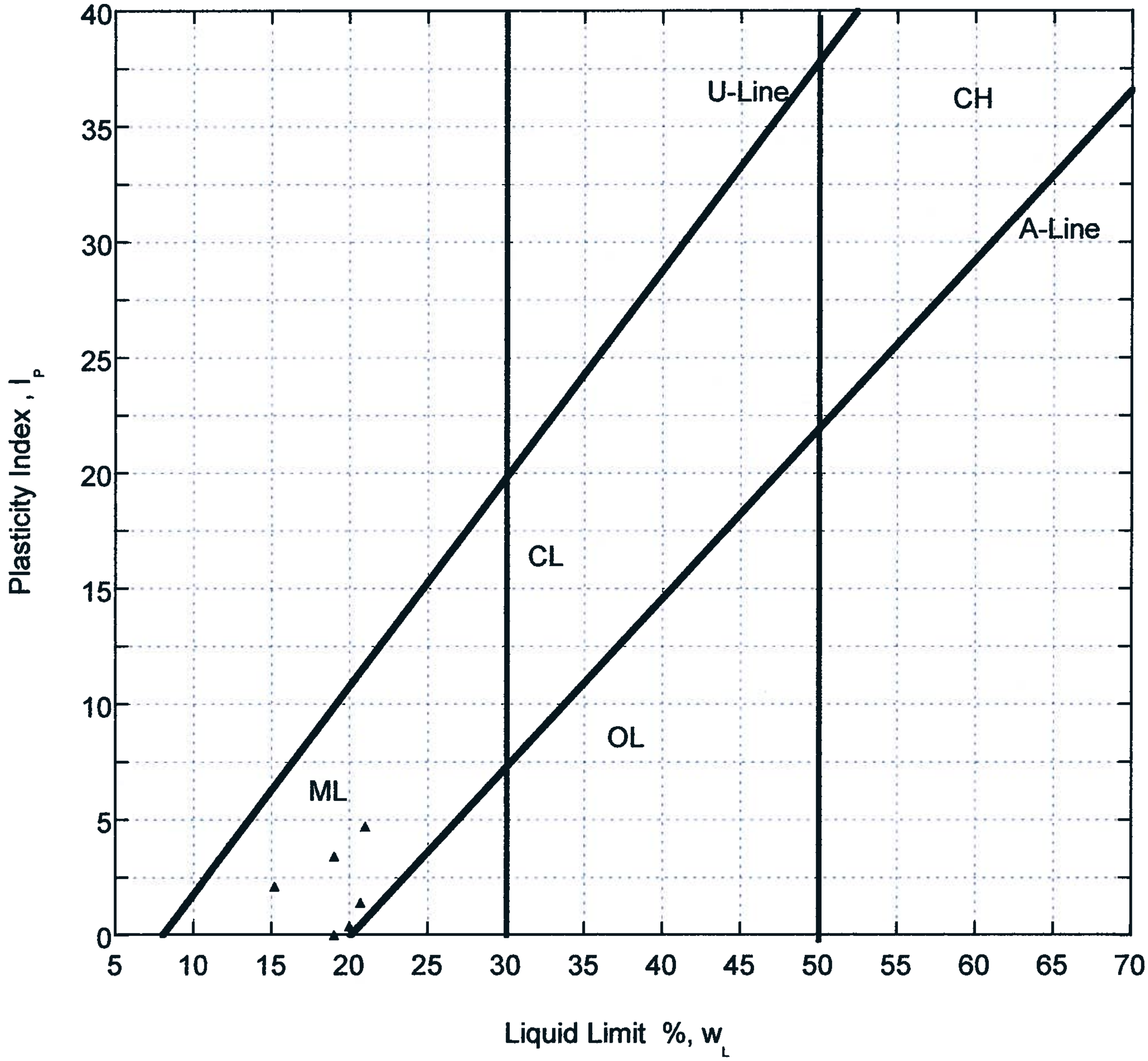

Figure 2: Plasticity Chart

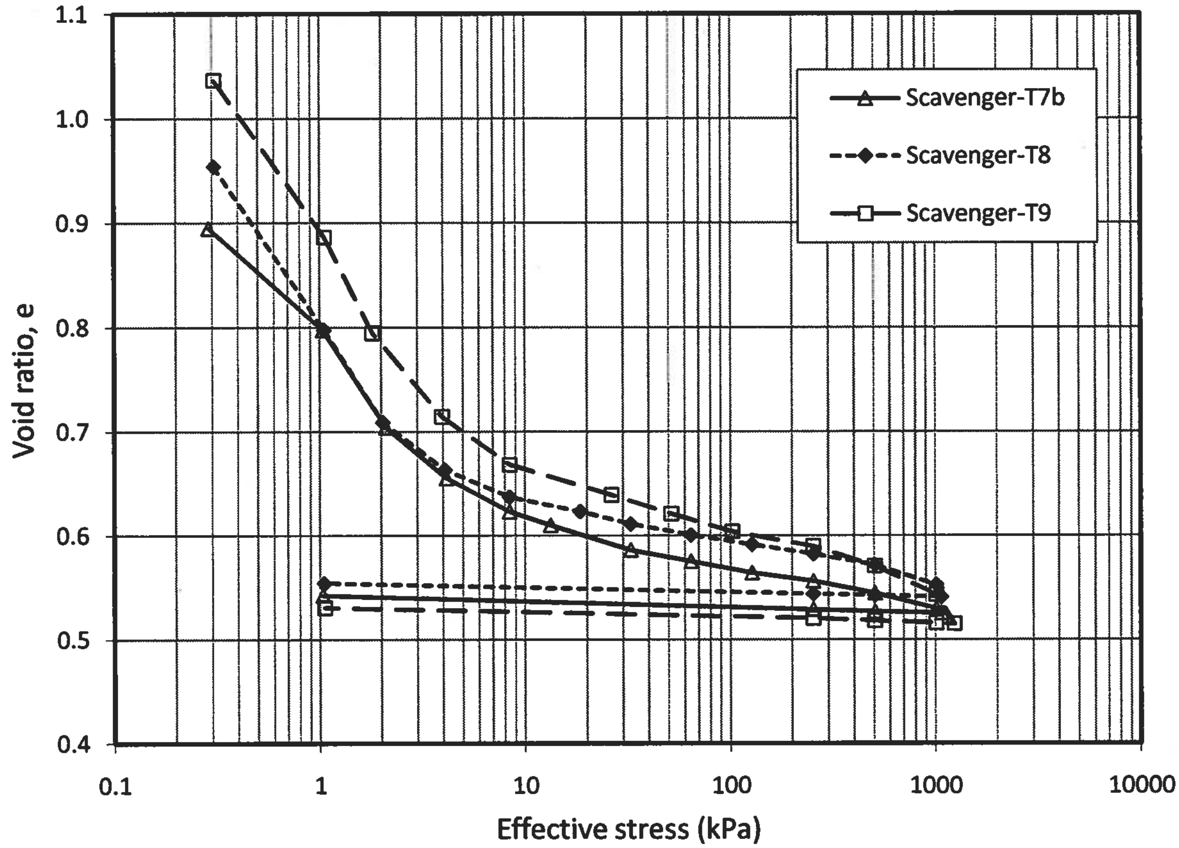

Figure 3: Compressibility of Scavenger Tailings.

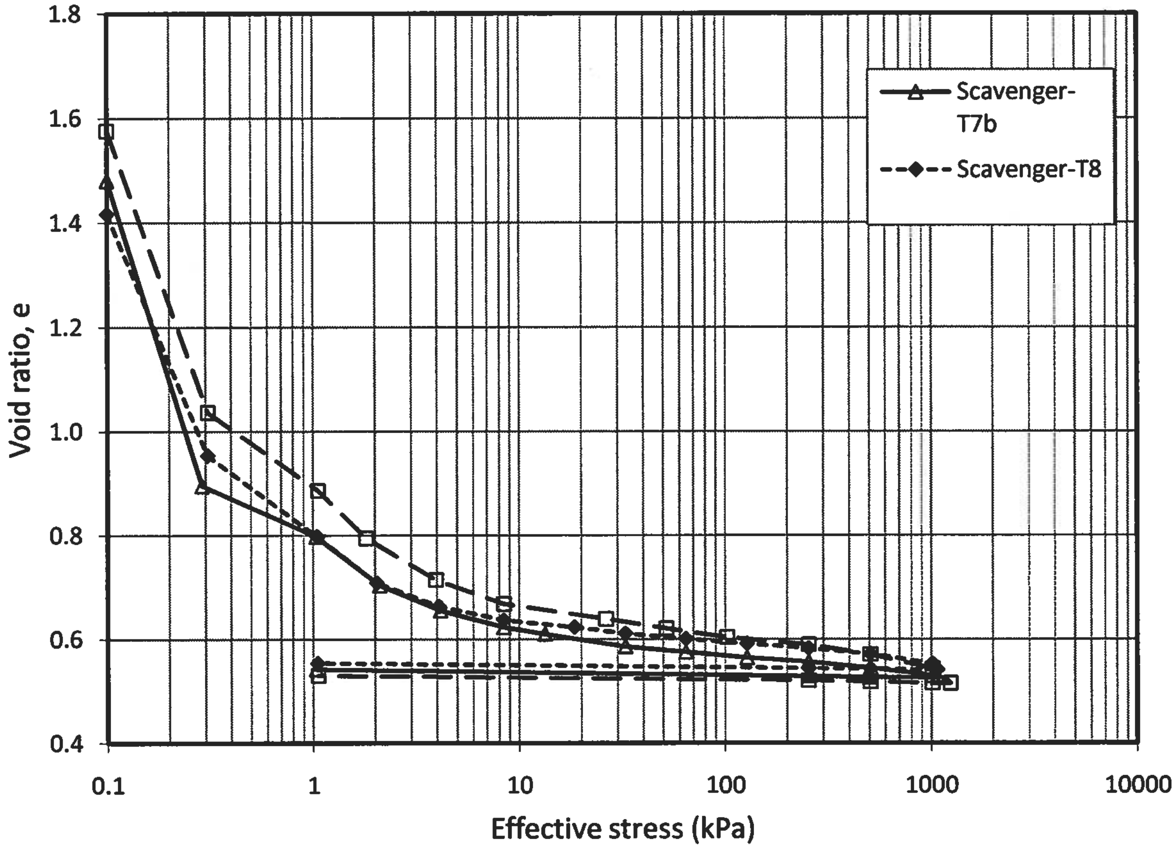

Figure 4: Compressibility of Scavenger Tailings with Initial Void Ratio at 0.1 kPa.

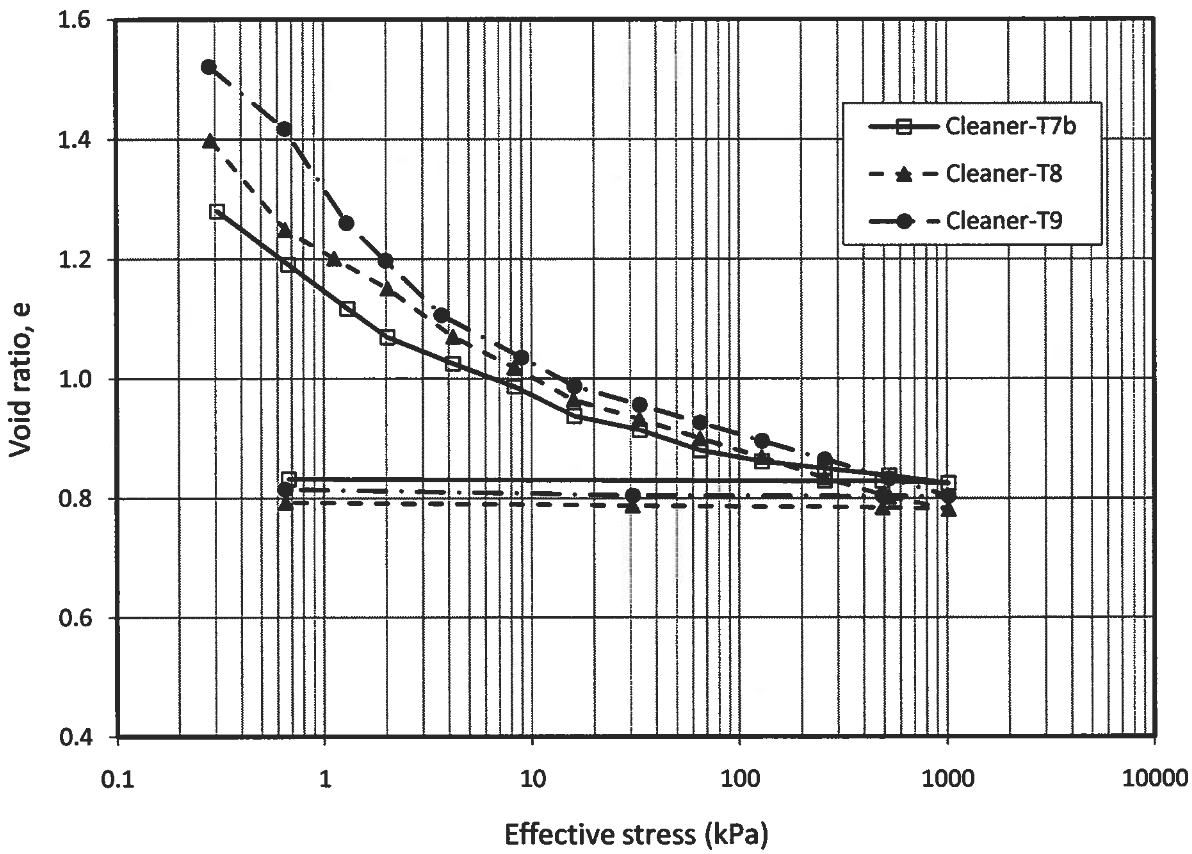

Figure 5: Compressibility of Cleaner Tailings.

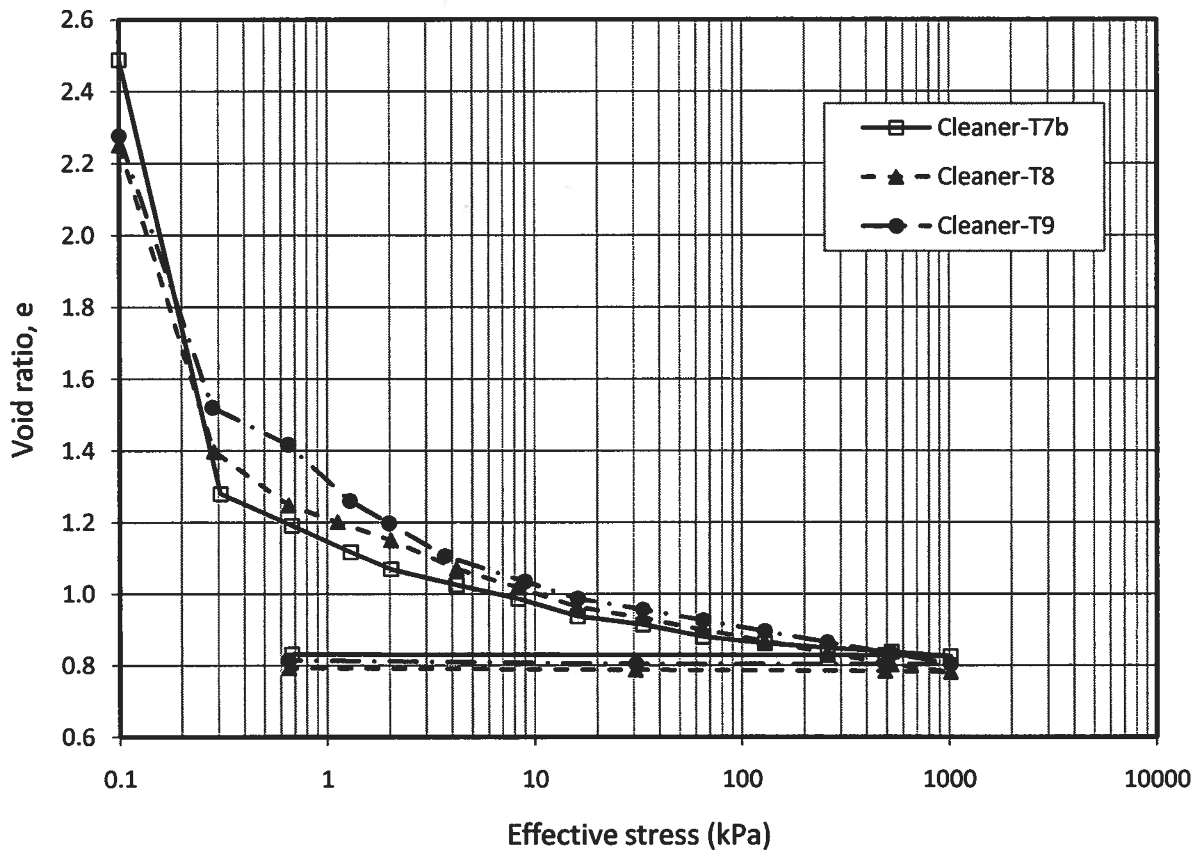

Figure 6: Compressibility of Cleaner Tailings with Initial Void Ratio at 0.1 kPa.

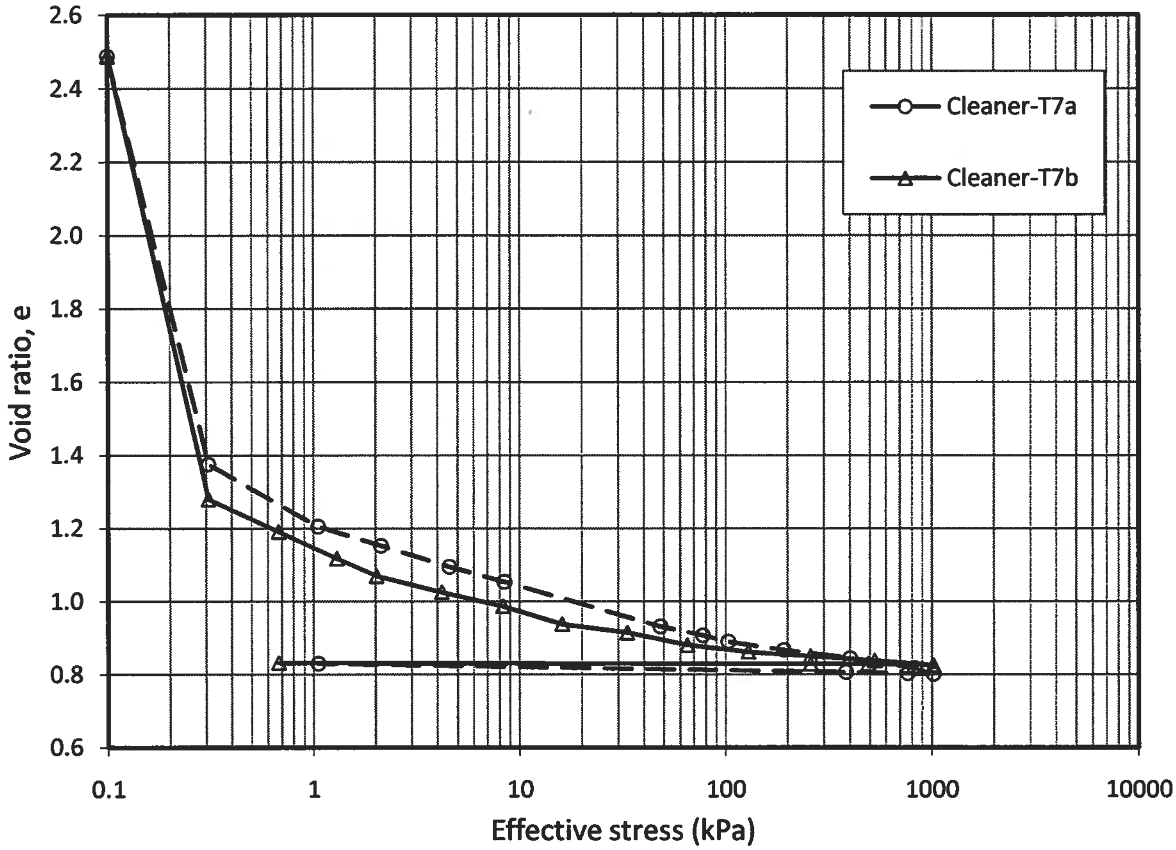

Figure 7: Comparison of Compressibility of Cleaner-T7a and Cleaner-T7b

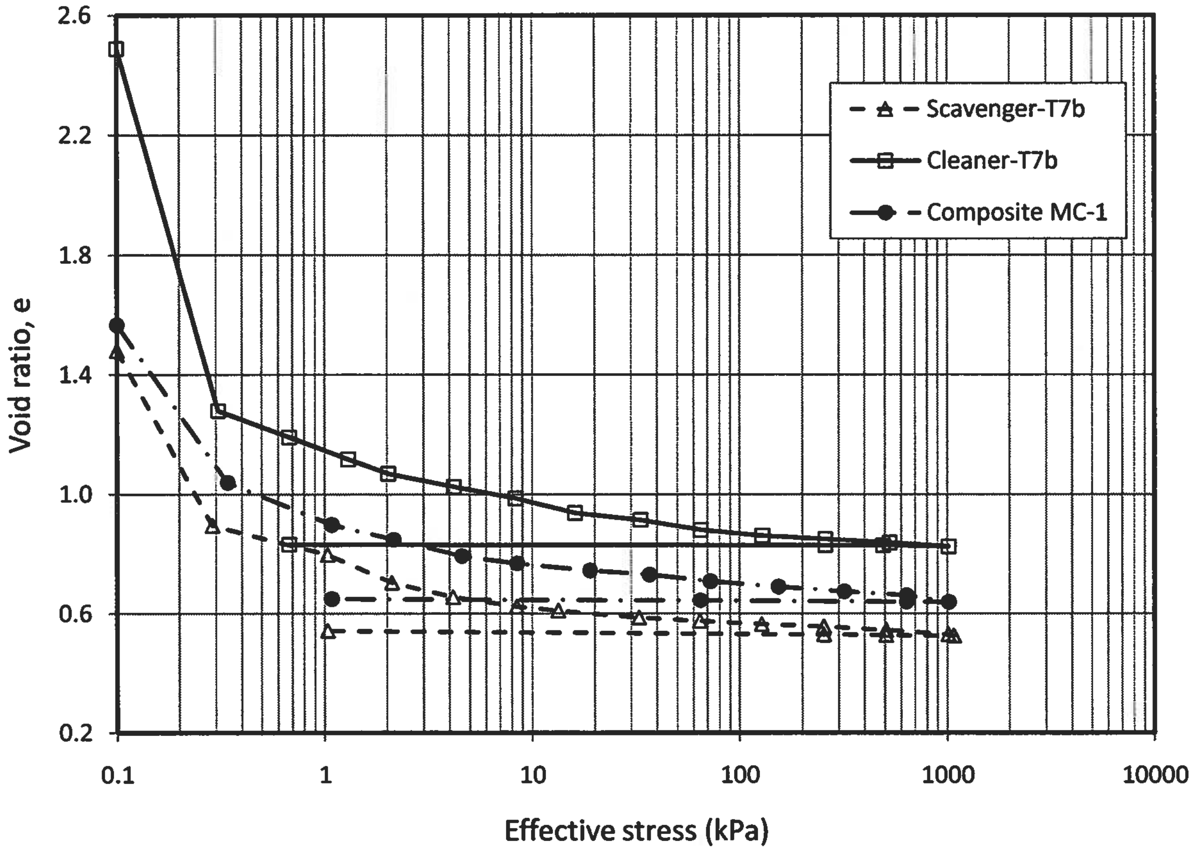

Figure 8: Compressibility of Composite MC-1 Tailings

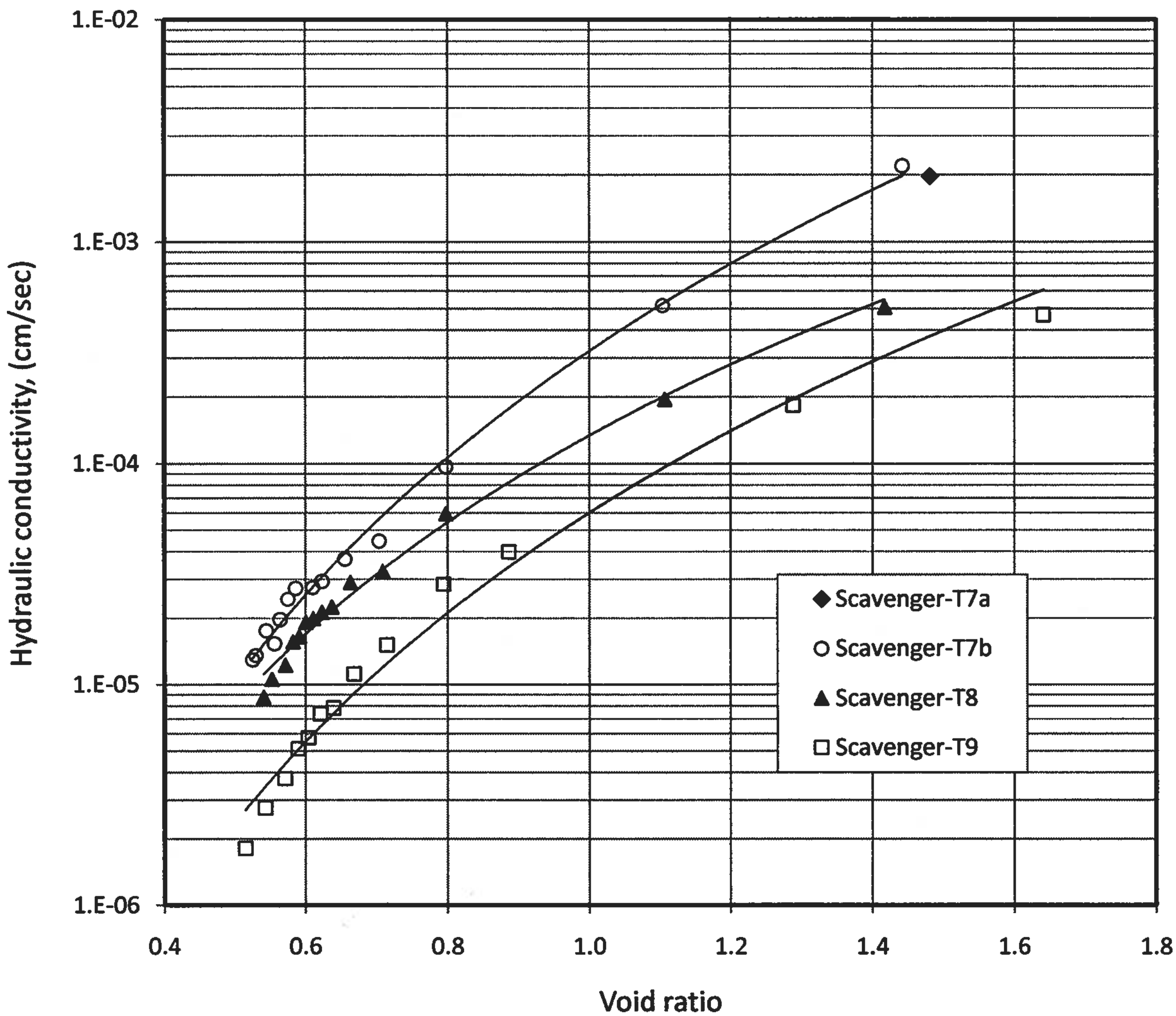

Figure 9: Hydraulic Conductivity of Scavenger Tailings

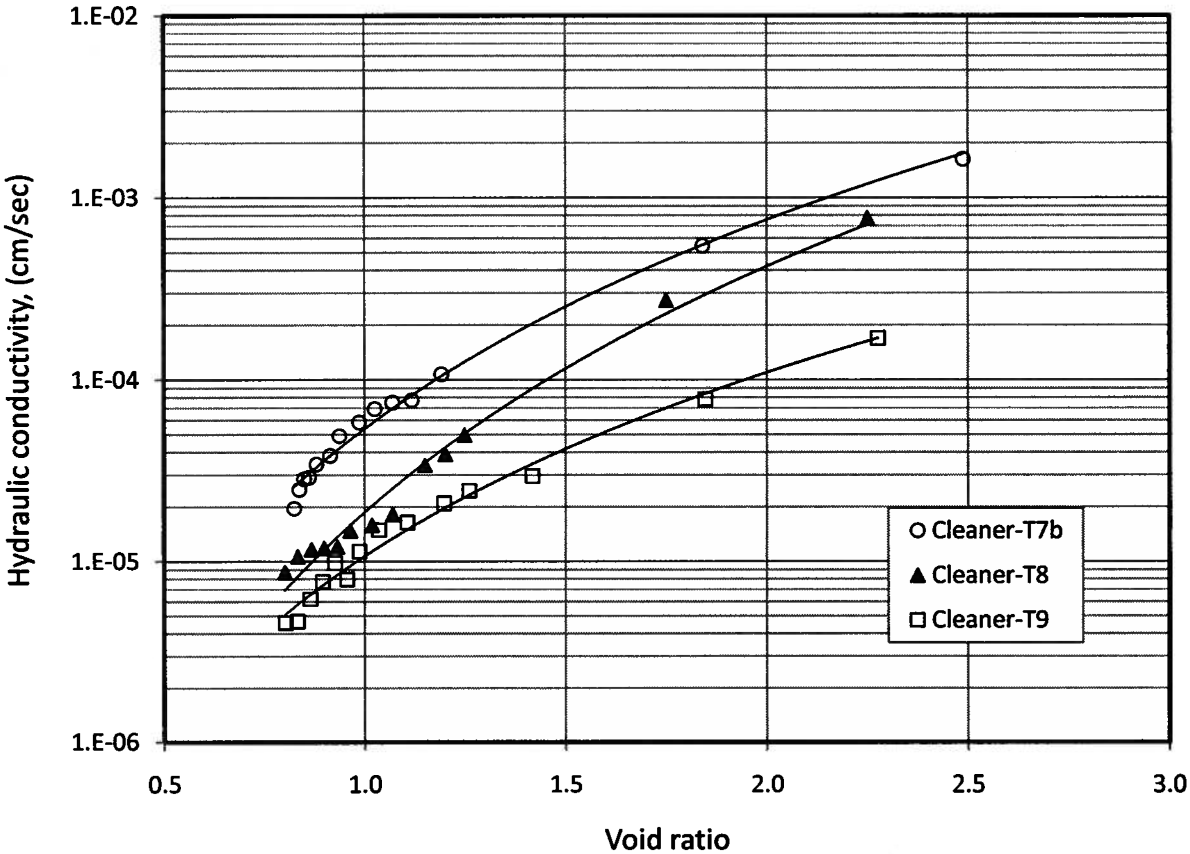

Figure 10: Hydraulic Conductivity of Cleaner Tailings

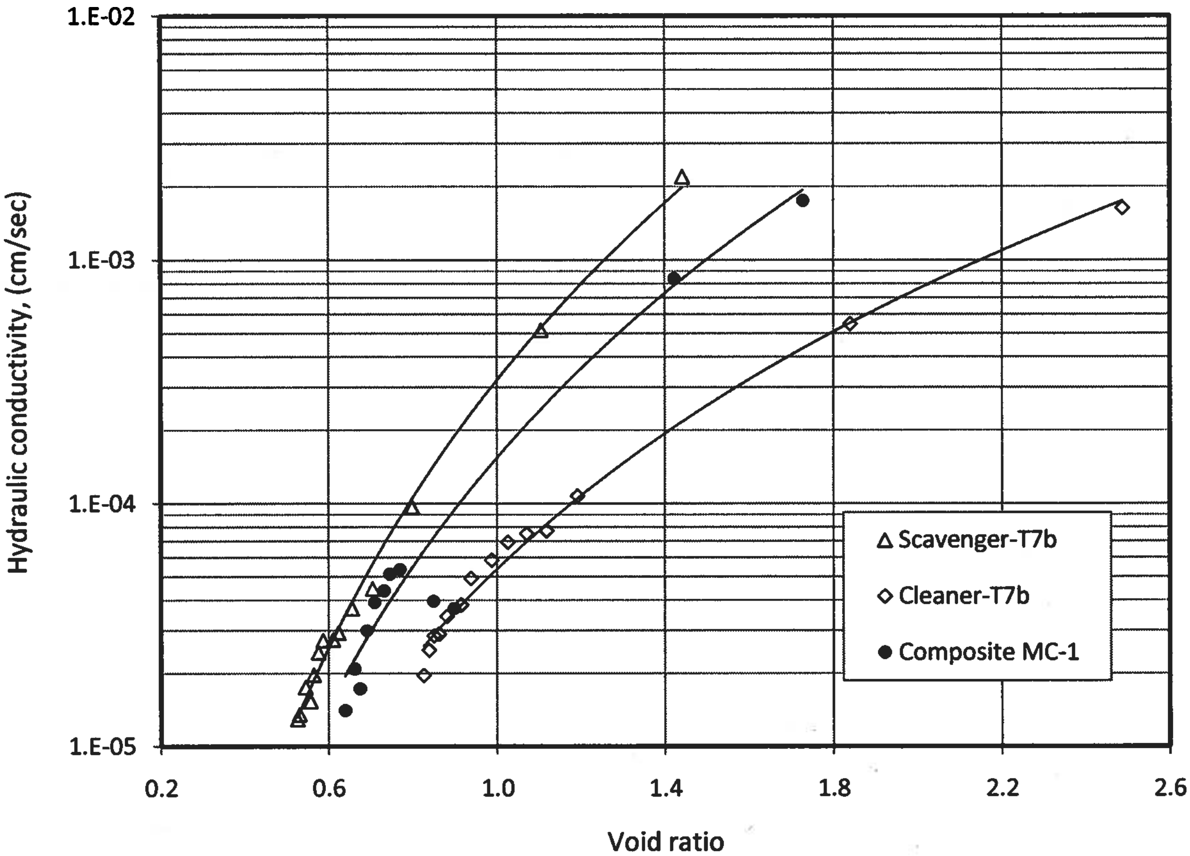

Figure 11: Hydraulic Conductivity of Composite MC-1 Tailings

APPENDIX A

AGAT Laboratories

University of Alberta

COMBINED BULK AND CLAY XRD ANALYSES OF SIX RESOLUTION TAILINGS DIVIDED INTO TWO TYPES: CLEANER (CL-7, CL-8, CL-9) AND SCAVENGER (SC-7, SC-8, SC-9) TAILINGS

Work Order A 14721

November, 2010

AGAT Laboratories Ltd.

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T2E 6T5

COMBINED X-RAY DIFFRACTION ANALYSIS

Six solids samples from the Department of Civil & Environmental Engineering at the University of Alberta were analyzed by AGAT Laboratories Ltd. for bulk and clay XRD mineralogy. All samples are defined as "Resolution Tailings", which are further divided into either "Cleaner" tailings labeled CL-7, CL-8 and CL-9 or "Scavenger" tailings labeled SC-7, SC-8 and SC-9. The samples were examined using XRD technique to determine their mineralogical composition.

In order to separate the particles less than 3μm (clay fraction) from the bulk fraction, the samples were treated in an ultrasonic bath using sodium metaphosphate as a deflocculating agent. The materials were then centrifuged at different speed, which separates the clay fraction from the bulk materials. Weight fraction was measured for both bulk and clay portions of the samples.

Cleaner Tailings (CL-7, CL-8 and CL-9)

The combined bulk and clay XRD results (Table 1) indicate that the three "Cleaner" tailings samples (C-7, C-8 and C-9 14) consist mainly of pyrite (47% to 53%) [iron sulfide FeS_2], with lesser amounts of muscovite mica (3% for CL-7, plus 23% for CL-8 and 19% for CL-9) [$(K,Na)(Al,Mg,Fe)_2(Si_{3.1}Al_{0.9})O$], quartz (8% to 14%) [silicon dioxide, SiO_2], kaolinite (6% to 13%) [aluminum silicate hydroxide, $[Al_4Si_4O_{10}(OH)_8)$], illite (7% to 11%) [potassium aluminum silicate hydroxide, $[KAl_2[OH]_2[AlSi_3(O,OH)_{10}]$ and minor potassium feldspar (1% to 3%) [potassium aluminum silicate, $KAlSi_3O_8$]. The CL-9 samples also has trace amounts of chlorite [iron magnesium aluminum silicate hydroxide $[Mg,Fe)_5Al(AlSi_3)\ O_{10}(OH)_9]$ and smectite $[1/2Ca,\ Na]_{0.7}[Al,Mg,Fe]_4[Si,Al]_8O_{20}[OH]_4.nH_2O]$ clays. A minor amount (1%) of calcite (calcium carbonate CaCO3) was detected in sample CL-8.

The clay fraction (<3μm) for these samples ranges from 3.51% to 4.44% of the total volume of rock. The clay fraction XRD (Table 1) results indicate that the samples CL-7 and CL-8 consist mainly of illite (53% and 42%), with lesser amounts of kaolinite (33% for both) pyrite (9% and

5%), quartz (5% and 3%) and muscovite mica (17% for sample CL-8). The clay fraction XRD (Table 1) results indicate that the sample CL-9 consist mainly of illite (53% and 42%), with lesser amounts of pyrite (16%), plus minor quartz (7%), smectite (6%), kaolinite (3%) and chlorite (3%).

The analyses indicate that the CL-7 to CL-9 are mostly iron sulfide heavy minerals (pyrite), with lesser to equal amounts of clays and sand (illite, quartz, kaolinite, potassium feldspar and minor smectite and chlorite), muscovite micas and rare calcium carbonate (calcite in CL-8 only).

Scavenger Tailings (SC-7, SC-8 and SC-9)

The combined bulk and clay XRD results (Table 1) for the three "Scavenger" tailings samples (SC-7, SC-8 and SC-9) consist mainly of quartz (59% to 62%) [silicon dioxide, SiO_2], with lesser amounts of illite (17% to 25%) potassium aluminum silicate hydroxide, [$KAl_2[OH]_2[AlSi_3(O,OH)_{10}]$, kaolinite (7% and 21%) [aluminum silicate hydroxide, [$Al_4Si_4O_{10}(OH)_8$)] and minor potassium feldspar (1% to 3%) [potassium aluminum silicate, $KAlSi_3O_8$]. In addition, the SC-9 samples has moderate amounts smectite (8%) [$1/2Ca,Na]_{0.7}[Al,Mg,Fe]_4[Si,Al]_8O_{20}[OH]_4.nH_2O$], muscovite mica (5%) [$(K,Na)(Al,Mg,Fe)_2(Si_{3.1}Al_{0.9})O$] and trace chlorite [iron magnesium aluminum silicate hydroxide [$Mg,Fe)_5Al(AlSi_3)O_{10}(OH)_9$].

The clay fraction (<3μm) for these samples ranges from 6.62% to 9.74% of the total volume of rock. The clay fraction XRD (Table 1) results indicate that the samples SC-7 and SC-8 consist mainly of illite (56% and 71%), with lesser amounts of kaolinite (43% and 28%) and minor quartz (1%). The clay fraction XRD (Table 1) results indicate that the sample SC-9 consist mainly of illite (53%), with lesser amounts of smectite (26%), kaolinite (15%), plus minor chlorite (5%) and quartz (1%).

The analyses indicate that samples SC-7 to SC-9 consist mainly of sand, clay and possible silts (quartz, illite, kaolinite, potassium feldspar, plus smectite and chlorite in SC-9) with minor muscovite in SC-9 only.

Conclusions:

These results show that the Cleaner Tailings samples CL-7 to CL-9 are rich in pyrite (heavy mineral) and muscovite when compared to the Scavenger Tailings samples SC-7 to SC-9, which only has minor amounts of muscovite in SC-9 only and has no pyrite heavy mineral. In addition, sample SC-9 has significantly higher amounts of smectite and moderately more chlorite when compared to sample CL-9. Smectite clays swell in presence of freshwater.

Table 1- Summary of XRD Analysis

Company: Department of Civil & Environmental Engineering, University of Alberta — **Work Order No. A-14721**
Location: Resolution Tailings, Cleaning (CL-7, CL-8, CL-9) & Scavenger (SC-7, SC-7, SC-8) Tailings — **November, 2010**

SAMPLE ID.	TYPE OF ANALYSIS	WEIGHT %	Qtz	Plag	K-Feld	Cal	Dol	Anhy	Pyr	Musc	Bar	Sider	Kaol (CLAYS)	Chl (CLAYS)	Ill (CLAYS)	ML (CLAYS)	Smec (CLAYS)	Total Clay
	BULK FRACTION:	96.49	12	0	3	0	0	0	65	3	0	0	12	0	5	0	0	17
1	CLAY FRACTION:	3.51	5	0	0	0	0	0	9	0	0	0	33	0	53	0	0	86
CL-7	BULK & CLAY	100	11	0	3	0	0	0	63	3	0	0	13	0	7	0	0	20
	BULK FRACTION:	96.13	14	0	1	1	0	0	49	23	0	0	5	0	6	0	0	11
2	CLAY FRACTION:	3.87	3	0	0	0	0	0	5	17	0	0	33	0	42	0	0	75
CL-8	BULK & CLAY	100	14	0	1	1	0	0	47	23	0	0	6	0	8	0	0	14
	BULK FRACTION:	95.56	8	0	1	0	0	0	56	20	0	0	6	0	9	0	0	15
3	CLAY FRACTION:	4.44	7	0	0	0	0	0	16	0	0	0	3	3	65	0	6	77
CL-9	BULK & CLAY	100	8	0	1	0	0	0	54	19	0	0	6	TR	11	0	TR	18
	BULK FRACTION:	93.38	63	0	1	0	0	0	0	0	0	0	19	0	17	0	0	36
4	CLAY FRACTION:	6.62	1	0	0	0	0	0	0	0	0	0	43	0	56	0	0	99
SC-7	BULK & CLAY	100	59	0	1	0	0	0	0	0	0	0	21	0	19	0	0	40
	BULK FRACTION:	92.24	67	0	2	0	0	0	0	0	0	0	10	0	21	0	0	31
5	CLAY FRACTION:	7.76	1	0	0	0	0	0	0	0	0	0	28	0	71	0	0	99
SC-8	BULK & CLAY	100	62	0	2	0	0	0	0	0	0	0	11	0	25	0	0	36
	BULK FRACTION:	90.26	65	0	3	0	0	0	0	6	0	0	6	0	14	0	6	26
6	CLAY FRACTION:	9.74	1	0	0	0	0	0	0	0	0	0	15	5	53	0	26	99
SC-9	BULK & CLAY	100	60	0	3	0	0	0	0	5	0	0	7	TR	17	0	8	32

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XRD LEGEND

- XRD Analysis is semi-quantitative (approx. 10% at best) and identifies only crystalline substances; amorphous (non-crystalline) substances will not be detected.
- Bulk Fraction – greater than 3 micron size fraction.
- Clay Fraction – less than 3 micron size fraction.
- Bulk and Clay – mathematical recalculation including the bulk and clay fraction representing the whole sample.
- Total Clay – sum of the clay minerals (may include authigenic and matrix clays plus clays in rock fragments).

ABBREVIATIONS

Amp	- Amphiboles	Dol	- Dolomite	Marc	- Marcasite	Pr	- Pure (95 – 100%)
Ana	- Analcime	Gyp	- Gypsum	ML*	- Illite-Smectite	NPr	- Near Pure (90 – 95%)
Anhy	- Anhydrite	Hal	- Halite	ML**	- Corrensite (chlorite-smectite)	Abnt	- Abundant (60 – 90%)
Ank	- Ankerite	Hem	- Hematite	Plag	- Plagioclase Feldspar	Com	- Common (30 – 60%)
Apa	- Apatite	Ill	- Illite	Pyr	- Pyrite	Mnr	- Minor (10 – 30%)
Bar	- Barite	Kaol	- Kaolinite	Qtz	- Quartz	Rre	- Rare (1 – 10%)
Cal	- Calcite	K-feld	- Potassic Feldspar	Sider	- Siderite	Tr	- Trace; detectable, but not measurable (0 – 1%)
Chl	- Chlorite	Mack	- Mackinawite	Smec	- Smectite (montmorillonite)		
Phos	– Phosphate	Musc	- Muscovite	Wues	- Wuestite	Unk	- Unknown

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BULK & CLAY PROCEDURES

1. Crush dry rock sample until grains disintegrate completely.
2. Weigh empty beaker and put sample in it. Weigh again "total weight". (≈3g of sample).
3. Add 50 mL of distilled water, plus a few drops of Sodium Metaphosphate.
4. Put in ultrasonic bath for 2 (two) hours.
5. Stir sample and pour out top portion into test tube.
6. Centrifuge for 5 minutes at 600 rpm.
7. Pour out top portion into another test tube for the clay fraction (<3μm) sample.
8. Recombine the coarser residue in the first test tube with the residue in the beaker and weight this "bulk sample" (after drying completely). Subtract this weight from the "total weight" to get the clay fraction weight.
9. Centrifuge the "clay fines" in the second test tube for 20 minutes at maximum rpms.
10. Pour out most of the water then shake test tube using Vortex Mixer.
11. Pipette onto a glass slide.
12. Put the slide on the hot plate (low) until dry then run sample in XRD.
13. Then put slide in a glycol vapour bath overnight (glycolated clay); Smectite will swell and be recognized.
14. If chlorite suspected, then treat the remaining sample in the test tube with diluted HCl and leave overnight (acidized clay). If chlorite was present in the sample this test causes it to disappear.
15. Run the "clay fraction" slide from 2-38 degrees.
16. Grind the "bulk sample" and spread the powder on an aluminum holder then run from 4-58 degrees.

APPENDIX B
Large Strain Consolidation Test, Equipment and Numerical Modeling
Geotechnical Centre, University of Alberta

1. Test Procedure

1.1 LARGE STRAIN CONSOLIDATION TEST

A large strain consolidation test is performed on slurried materials which are too soft and undergo too much volume change for testing in a standard consolidation apparatus. As well, materials that undergo large strains do not follow the Terzaghi consolidation equations. Specifically, the coefficient of permeability or hydraulic conductivity cannot be calculated from volumetric strain-time measurements and must be directly measured.

The large strain consolidation apparatus used in the University of Alberta Geotechnical Centre Laboratory confines the slurried material so it can be tested at any water content. As large volume changes take place with very small stress changes at high water contents, the first applied stress, the self-weight of the slurry, can be about 0.3 to 0.4 kPa.

Cells to confine the sample are of various sizes and a typical cell is 150 mm inside diameter and can accommodate samples up to 200 mm high. The initial height of the sample is chosen to minimize wall friction so that the diameter-height ratio is approximately 2.5 when effective stresses become significant above 10 kPa applied vertical stress. For a sample with an initial water content of about 75% (void ratio of 2.0) (solids content of about 60% depending on the specific gravity) it has been found, based on consolidation tests previously performed in our laboratory, that an initial height of 80 mm to 90 mm would result in a height of about 50 mm at effective stresses over 10 kPa. The height should be as large as possible, keeping in mind the diameter-height ratio, to obtain accuracy in the permeability test. An initial height of 80 mm to 90 mm appears to satisfy both requirements. The diameter-height ratio under these conditions has been found to be approximately 2.6 at a vertical effective stress of 10 kPa and over 3.0 at a vertical effective stress of 250 kPa. For samples with initial water contents greater than 75% a greater initial height is used.

The permeability is measured at the end of consolidation for each load step. An upwards flow constant head test is performed with the head loss being kept small enough so that seepage forces will not exceed the applied stress and cause further consolidation or sample fracturing during the permeability test. For example, for a 85 mm high specimen, consolidated under a vertical stress of 1 kPa, the head loss should not be greater than 200 mm, which results in a hydraulic gradient of 2.4. Generally, the head loss and hydraulic gradient are kept to less than half this maximum calculated value. Such small hydraulic gradients may require fairly long permeability tests. The inflow is monitored for at least 2 to 3 hours to ensure that steady state flow conditions are obtained.

The test results are presented in a plot of void ratio as a function of vertical effective stress and in a plot of hydraulic conductivity as a function of void ratio. Curve fits to these two plots define the material relationships to be used in large strain consolidation numerical modeling of tailings ponds, thickener vessels or slurry deposits.

1.2 PERMEABILITY AT HIGH VOID RATIO STANDPIPE TEST

The relationship between hydraulic conductivity and void ratio needs to be determined over the full range of water contents or void ratios that the field tailings deposit experiences. The initial volume change of high water content tailings (over 75% water content), however, is so large that this relationship cannot be measured at high void ratios over 2.0 in a step load consolidation test. As the initial volume change is a major part of the volume change during field deposition, the modeling parameters at low stresses must be determined by a different test procedure to allow field predictions to be made with confidence. The test procedure developed for this purpose uses a series of standpipes containing tailings at very high water contents.

A standpipe test on a high water content slurry progresses through three stages. When the standpipe is filled with the slurry, a flocculation period or induction time may elapse during which no measurable settlement takes place. Following this period, settlement in the form of hindered sedimentation may occur for a short time and then long term consolidation settlement continues until the excess pore pressures are fully dissipated. During hindered sedimentation the tailings remain at the initial void ratio and little or no effective stress exists in the settling material. The settlement rate during this period can be used to calculate the hydraulic conductivity and, therefore, a relationship between the tailings initial void ratio and hydraulic conductivity can be determined. Performing such tests with different initial water contents (void ratios) allows the determination of the hydraulic conductivity relationship for large initial void ratios. The values can then be added to the data from consolidation tests to give the relationship between void ratio and hydraulic conductivity over the complete water content range that will occur in field deposits.

At large void ratios the hydraulic conductivity dominates large strain consolidation numerical modeling of tailings pond deposits and the effective stress relationship is not as important. Therefore, the effective stress-void ratio relationship determined from the step load consolidation test can be extrapolated to large void ratios with little error.

1.3 COMPRESSIBILITY STANDPIPE TEST

If the effective stress-void ratio relationship is required at large void ratios, a compressibility standpipe test can be performed. Void ratios at vertical stresses from a fraction of a kPa up to 1 kPa can be measured with this test and added to the data from consolidation tests.

2. Test Apparatus

2.1 CONSOLIDATION TEST

The vertical stress in the large strain consolidation apparatus is applied by dead load acting on the loading ram up to 8 kPa and by compressed air in a bellofram acting on the loading ram up to the maximum stress of 750 kPa to about 1300 kPa. The initial set up of the apparatus before any load is applied is shown in Figure A1. Only self-weight of the sample exists at this stage and the total effective stress at mid-height of the sample is about 0.3 to 0.4 kPa from the buoyant mass of the sample. After the consolidation is complete from this effective stress, an upward flow constant head permeability test may be conducted. However, as the void ratio of the sample at this stage decreases with depth, the void ratio controlling the permeability is difficult to estimate. Subsequent loads are approximately doubled for each load step and the void ratio becomes more uniform with depth. Effective stresses up to about 8 kPa are applied by dead loads acting on the piston as shown in Figure A2. Effective stresses over 8 kPa are applied in a loading frame by an air pressure bellofram as shown in Figure A3.

Vertical strain is measured with a LVDT. The samples are usually drained from the top and bottom to conduct the test as rapidly as possible. For special cases only top drainage is used and pore pressures at the base of the sample are measured as shown in the figures. The load is maintained until the vertical strain and/or base pore pressure dissipation are significantly completed before adding the next load. The horizontal tube for inflow to the bottom of the sample during permeability testing is positioned at a height to give the required head across the sample as shown in Figures A2 and A3. All measurements are continuously recorded manually and on a data logger, downloaded and plotted.

2.2 PERMEABILITY STANDPIPE TESTS

The hydraulic conductivity standpipe tests only have to run for a few hours to the end of the hindered sedimentation phase and, during this time, effective stresses will be close to zero. The diameter-height ratio of the standpipes, therefore, is not important and standpipes with a height of 35 cm and a diameter of 6 cm are used. The only measurement taken is the slurry-water interface settlement with time.

Care must be taken to ensure that the slurry material in standpipe tests at large void ratios or high water contents does not segregate during the test. That is, the material remains homogeneous and the larger particles do not settle preferentially. If in doubt, segregation standpipe tests can be performed to determine the segregation boundary for the material. Segregation depends on the grain size distribution of the tailings material, the addition of flocculants or coagulants as well as the void ratio.

2.3 COMPRESSIBILITY STANDPIPE TEST

To determine the effective stress-void ratio relationship at very low effective stresses, a large diameter standpipe is filled with tailings at the initial water content, allowed to consolidate under self-weight and when consolidation is complete, sampled in layers to determine the effective stress and void ratio with depth. The test standpipe used is 20 cm in diameter and is filled to a height of 26 cm. At large void ratios the effective stress is small even after consolidation and the diameter-height ratio is satisfactory to prevent significant wall friction. The sample is allowed to settle under self-weight and pore pressures are monitored at the base. Consolidation is considered complete when the excess pore pressure at the base has fully dissipated.

2.4 PROCESS WATER

To prevent changes to the clay mineral bonding and structure in the tailings samples which may affect settlement, compressibility and hydraulic conductivity during the tests, all water added to the tailings must have the same water chemistry as the pore water in the tailings. The best source of such water is fresh process decant or runoff water from the tailings deposit. If necessary, the water chemistry of the tailings pore water can be determined and artificial process water can be made. Full water chemistry analyses can be performed in our Departmental Laboratories.

3. Numerical Modeling

In order to manage a containment pond or design a thickener for slurry materials, geotechnical engineers have to be able to predict interface settlement and the effective stress-void ratio profiles with time for the material. To achieve this, there are several models in the geotechnical field that can be used. There are a number of finite strain consolidation theories but these do not include sedimentation. The importance of combining sedimentation and consolidation into one analysis has led to many developments which can be generally divided into two categories which are geotechnical and fluid dynamic approaches. Both approaches, however, are theoretically similar. One valuable alternative approach to these models that enables the theory to predict sedimentation and consolidation is to include an interaction coefficient which takes advantage of the similarity of both phenomenon and connects them together. The result is a governing equation that can handle both the sedimentation and consolidation phases. The Geotechnical Centre at the University of Alberta has developed such a numerical model that is user friendly, simple to operate and available free online. The Geotechnical Centre will perform numerical modelling if requested or advise others on how to use the model.

The design and operation of a containment pond or a gravity thickener, however, are complicated by the mixing mechanism, complex material behaviour and the effects of chemical additives. The most important task for geotechnical engineers is to be able to define the appropriate geotechnical constitutive relationships of the material through laboratory and field experiments. It is also necessary to recognize changes in material behaviour and adapt the use of a thickener during production for maximum performance both during thickening and deposition stages.

November 30, 2010

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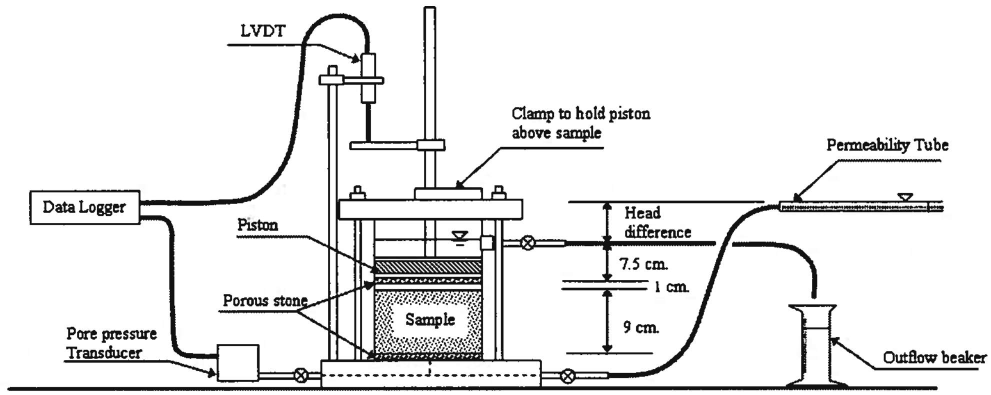
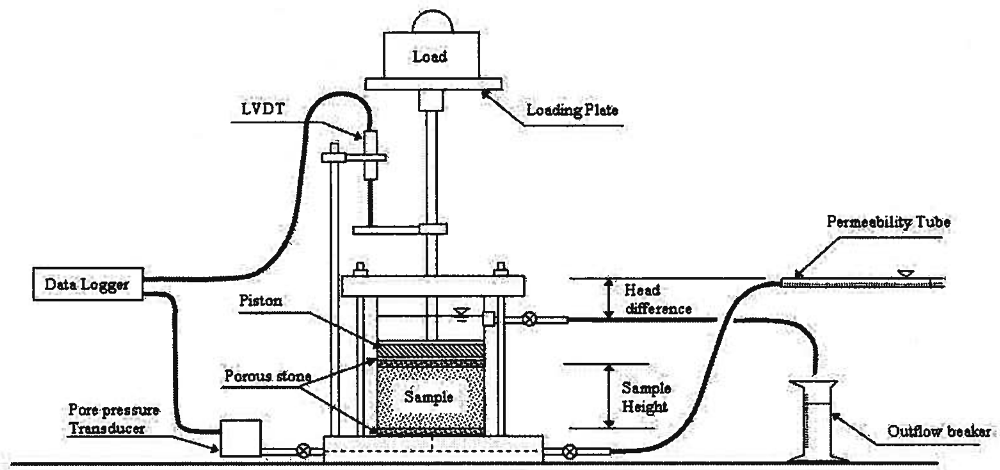


Figure A1 Initial set up of the large strain consolidation test before loading sample



FigureA2 Sample loaded with piston and dead loads up to about 8 kPa

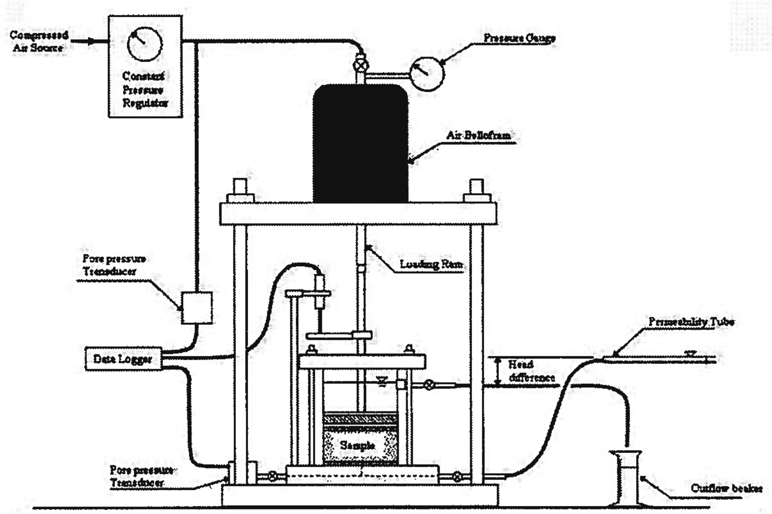


Figure A3 Sample in loading frame and loaded by bellofram up to 1000 kPa.

APPENDIX III

2007 Laboratory Test Program

LARGE STRAIN CONSOLIDATION AND PERMEABILITY TESTS ON SCAVENGER AND CLEANER TAILINGS FROM THE RESOLUTION MINING, ARIZONA PROJECT

for

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November 30, 2007

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1 INTRODUCTION

1.1 Large Strain Consolidation Test

A large strain consolidation test is performed on slurried materials which are too soft and undergo too much volume change for testing in a standard consolidation apparatus. As well, materials that undergo large strains do not follow the Terzaghi consolidation equations. Specifically, the coefficient of permeability or hydraulic conductivity can not be calculated from volumetric strain-time measurements and must be directly measured.

The large strain consolidation apparatus used in the University laboratory confines the slurried material so it can be tested at any water content. As large volume changes take place with very small stress changes at high water contents, the first applied stress, including self-weight of the slurry, is less than 1 kPa.

The cell is 100 mm inside diameter and can accommodate samples up to 200 mm high. The initial height of the sample was chosen so that the diameter-height ratio was over 1, so sample wall friction was minimized, when effective stresses became significant above 10 kPa applied vertical stress. For a sample with an initial solids content of 65% or a water content of about 54%, it was estimated that an initial height of 100 mm would result in a height of about 60 mm at high effective stresses. The height should be as large as possible, keeping in mind the diameter-height ratio, to obtain accuracy in the permeability test. An initial height of 100 mm appeared to satisfy both requirements. The cells therefore were filled with samples 100 mm in height. The diameter-height ratio under these conditions was approximately 1.4 at a vertical stress of 10 kPa and 1.6 at a vertical stress of 250 kPa.

The permeability was measured at the end of consolidation for each load step. An upwards flow constant head test was performed with the head loss being kept small enough so that seepage forces will not exceed the applied stress and cause further consolidation or sample fracturing during the permeability test. For example, for a 70 mm high specimen, consolidated under a vertical stress of 1 kPa, the head loss should not be greater than 160 mm, which results in a hydraulic gradient of 2.3. Generally, the head loss and hydraulic gradient were kept to less than a quarter of this maximum calculated value. Such small hydraulic gradients may require fairly long permeability tests. The inflow was monitored for about 30 minutes to ensure that steady state flow conditions were obtained.

The test results are presented in a plot of void ratio as a function of vertical effective stress and in a plot of hydraulic conductivity as a function of void ratio. Curve fits to these two plots will define the material relationships to be used in large strain consolidation analyses.

2.0 TEST APPARATUS

2.1 Consolidation Test

The vertical stress in the large strain consolidation apparatus was applied by dead load acting on the loading ram up to 10 kPa and by compressed air in a bellofram acting on the loading ram up to the maximum stress of 1000 kPa. The settlement was monitored during self-weight consolidation and when consolidation was complete in about 1 day, an upwards flow constant head permeability test was conducted. The next load, which is the submerged piston dead load was then applied. The total effective stress at this stage at mid-height of the sample was about 0.82 kPa which was composed of 0.29 kPa from the mass of the sample and 0.53 kPa from the submerged mass of the piston for the Scavenger Solids tailings and for Cleaner Solids tailings these values are 0.81 kPa, 0.27 kPa and 0.54 kPa.. After the consolidation was complete from this effective stress, another upward flow constant head permeability test was conducted. Subsequent loads were approximately doubled for each load step. Effective stresses up to 10 kPa were applied by dead loads acting on the piston. Effective stresses over 10 kPa are applied in a loading frame by an air pressure bellofram.

Vertical strain was measured with a LVDT. The samples were drained from the top and bottom to perform the test as quickly as possible. The compression was plotted as the test progressed to ensure that the compression was complete before adding the next load. The horizontal tube for inflow to the bottom of the sample during permeability testing was positioned at a height to give the required head across the sample. All measurements were continuously recorded on a data logger.

3.0 TAILINGS MATERIALS

Two 20L containers containing samples of Scavenger Solids tailings and Cleaner Solids tailings were received in the third week of October. In addition, bottles of process water were received. There were several litres of tailings in each container.

The solids had settled out into a dense layer with clear tailings water on top. The samples were thoroughly mixed and solids contents were taken. The Scavenger Solids tailings had a solids content of 65.0% and the Cleaner Solids tailings also had a solids content of 65.0%. As the design solids content for testing was 65%, these samples were used directly without adding or removing any process water.

The process waters were used to saturate the cell porous stones and equipment lines and used for the hydraulic conductivity tests to ensure there would be no change in the pore water chemistry during the tests. Changes to the pore water chemistry might have affected the surface chemistry and structure of the clay-sized particles.

Klohn Crippen Berger Ltd provided test data to show that the specific gravities of Scavenger and Cleaner Solids tailings solids are 2.75 and 4.20 respectively and these values have been used in the calculations.

4.0 REPORT OUTLINE

The consolidation tests started at initial void ratios of 1.48 and 2.26 for the Scavenger and Cleaner Solids tailings respectively, that is, initial water contents of 53.8% or solids contents of 65%. These solid contents were at the required design solids content of 65%.

For submerged samples 100mm high the effective stress at mid-height of the sample is approximately 0.28 kPa for both samples and this effective stress is used for the self-weight effective stress.

The two large strain consolidation test results will be presented first and then the following plots of test details are given:

- Settlement with time for each load.
- Hydraulic conductivity from hindered sedimentation.
- Hydraulic conductivity with time for each void ratio.

5.0 TEST RESULTS

5.1 Compressibility and Hydraulic Conductivity from Large Strain Consolidation Tests

Tables 1 and 2 and Figures 1 and 2 give the compressibility and hydraulic conductivity from the large strain consolidation test on Scavenger Solids tailings. Tables 3 and 4 and Figures 3 and 4 give these measurements on Cleaner Solids tailings. Figures 5 and 6 show the comparison of the compressibilities and hydraulic conductivities respectively of the two tailings materials.

6.0 DISCUSSION AND OBSERVATIONS

1. On the compressibility plots in Figures 1, 3 and 5, the initial void ratios (1.48 and 2.26) are plotted at 0.01 kPa for reference. The initial void ratios should be plotted at 0 kPa but this is not possible on a log plot.
2. On the hydraulic conductivity plots in Figures 2, 4 and 6, the hydraulic conductivity at the initial void ratios (1.48 and 2.26) has been determined from the initial 2 hours of self-weight settlement measurements assuming it is hindered sedimentation. These measurements are shown on Figures 31 and 32. At these

rather low initial void ratios some consolidation may be taking place which, if so, would make the resulting calculated hydraulic conductivity too low.

3. On the compressibility plots in Figure 1, 3, and 5 the measured data points have been joined with straight lines to show the trend of the compressibility. No power equation plot has been generated from this data. This determination has been left to the discretion of the user.
4. On the hydraulic conductivity plots in Figures 2, 4 and 6 the line through the points is an automatically generated best fit power equation. The determination of a better fit relationship has been left to the discretion of the user.
5. The settlement-time tests in Figures 7 and 19 for self-weight were only top drained to allow the determination of the initial hydraulic conductivity.
6. The small changes in settlement rates for Load 1 around 60 minutes in Figure 8 and 20 were caused by the change from single top drainage to double top and bottom drainage.
7. Loading of the samples was changed from dead loading with weights after 10 kPa to air pressure loading with a bellofram. The initial dead loads are necessary to achieve accuracy in the effective stress control at very low effective stresses. This change in loading procedure caused a smaller increase in load step 6 for the Scavenger Solids tailings than the usual doubling of the load. No apparent problem was caused by this change in loading procedure as the resulting compressibility plot is continuous.
8. The change in loading procedure after load step 5 requires that the dead load be completely removed before the bellofram load is applied. For both tests this apparently caused a small change in void ratio when load step 6 was applied. Although the change is not very apparent on the compressibility plots, it is apparent on the hydraulic conductivity plots at a void ratio of 0.64 for the Scavenger Solids tailings and a void ratio of 0.88 for the Cleaner Solids tailings.
9. The hydraulic conductivity values measured after self-weight consolidation appear too small. The void ratios shown after self-weight consolidation are the average void ratios of the samples at this time. The actual void ratios would vary from a higher value at the top of the sample to a lower value at the bottom. As

well, the hydraulic conductivity would vary from a higher value at the top to a lower value at the bottom. The smaller void ratio at the bottom probably governs the water flow through the sample resulting in a smaller value of hydraulic conductivity than would be found for the average void ratio.

10. The settlement-time plots for both samples progress smoothly from long term settlement under small effective stresses to short term settlement under high effective stresses. Although the hydraulic conductivity is smaller at high stresses, the compression is much smaller resulting in more rapid consolidation.
11. The hydraulic conductivity values shown in Figures 33 to 56 are incremental calculations, that is, the hydraulic conductivity measured between readings of the flow not cumulative readings from the start if the test. This calculation method eliminates the unsteady flow measurements at the beginning of the test. The last several readings during steady flow are averaged to obtain the values shown in Tables 2 and 4 and plotted on Figures 2 and 4.

J. Don Scott, Ph.D., P.Eng., Professor Emeritus November 30, 2007

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Table 1 Large strain consolidation test for Scavenger solids tailings

Load	Height (mm)	Δheight (mm)	Effective stress (kPa)	Void Ratio, *e*	Δ*e*	Hydraulic conductivity, k (cm/s)
	100.0	0.0	-	1.48	-	3.21E-04
Self-weight	82.3	17.7	0.290	1.04	0.44	4.26E-05
1	75.4	6.9	0.823	0.87	0.17	3.60E-05
2	73.5	1.9	1.77	0.82	0.05	2.88E-05
3	71.9	1.6	3.35	0.78	0.04	2.44E-05
4	70.7	1.2	5.91	0.75	0.03	2.29E-05
5	69.3	1.4	10.9	0.72	0.03	2.00E-05
6	68.6	0.7	13.7	0.70	0.02	2.30E-05
7	66.1	2.5	53.9	0.64	0.06	1.72E-05
8	65.0	1.0	104	0.61	0.03	1.50E-05
9	63.3	1.7	254	0.57	0.04	1.18E-05
10	61.9	1.4	508	0.54	0.03	9.40E-06
11	60.6	1.3	1015	0.50	0.03	7.85E-06
12	61.1	-0.5	103	0.52	-0.01	-
13	61.3	-0.2	4.01	0.52	-0.01	-

Table 2 Hydraulic conductivity tests for Scavenger solids tailings

Time	Effective stress (kPa)	h (mm)	L (mm)	Hydraulic Gradient, i	Hydraulic Conductivity, k (cm/s)
End of Self-weight	0.290	18.5	82.3	0.22	4.26E-05
End of Load Step 1	0.823	30.0	75.4	0.40	3.60E-05
End of Load Step 2	1.77	30.5	73.5	0.41	2.88E-05
End of Load Step 3	3.35	31.0	71.9	0.43	2.44E-05
End of Load Step 4	5.91	31.0	70.7	0.44	2.29E-05
End of Load Step 5	10.9	32.5	69.3	0.47	2.00E-05
End of Load Step 6	13.7	77.5	68.6	1.13	2.30E-05
End of Load Step 7	53.9	77.5	66.1	1.17	1.72E-05
End of Load Step 8	104	77.5	65.0	1.19	1.50E-05
End of Load Step 9	254	77.5	63.3	1.22	1.18E-05
End of Load Step 10	508	77.5	61.9	1.25	9.40E-06
End of Load Step 11	1015	77.5	60.6	1.28	7.85E-06

Table 3 Large strain consolidation test for Cleaner solids tailings

Load	Height (mm)	Δheight (mm)	Effective stress (kPa)	Void Ratio, *e*	Δ*e*	Hydraulic conductivity, k (cm/s)
	100.0	0.0	-	2.26	-	6.10E-04
Self-weight	72.8	27.2	0.267	1.37	0.89	1.77E-05
1	68.7	4.1	0.806	1.24	0.13	1.85E-05
2	66.4	2.3	1.75	1.16	0.07	1.43E-05
3	64.6	1.8	3.34	1.10	0.06	1.13E-05
4	63.3	1.3	5.85	1.06	0.04	1.03E-05
5	61.8	1.5	10.8	1.01	0.05	8.93E-06
6	58.9	2.9	27.9	0.92	0.09	8.89E-06
7	57.6	1.3	52.6	0.88	0.04	7.38E-06
8	56.3	1.3	103	0.83	0.04	6.42E-06
9	54.5	1.8	252	0.78	0.06	4.96E-06
10	53.1	1.4	503	0.73	0.05	4.03E-06
11	51.6	1.5	1007	0.68	0.05	3.27E-06
12	52.1	-0.5	102	0.70	-0.02	-
13	53.0	-0.9	0.768	0.73	-0.03	-

Table 4 Hydraulic conductivity tests for Cleaner solids tailings

Time	Effective stress (kPa)	h (mm)	L (mm)	Hydraulic Gradient, i	Hydraulic Conductivity, k (cm/s)
End of Self-weight	0.267	19.0	72.8	0.26	1.77E-05
End of Load Step 1	0.806	32.0	68.7	0.47	1.85E-05
End of Load Step 2	1.75	31.5	66.4	0.47	1.43E-05
End of Load Step 3	3.34	32.5	64.6	0.50	1.13E-05
End of Load Step 4	5.85	32.5	63.3	0.51	1.03E-05
End of Load Step 5	10.8	33.0	61.8	0.53	8.93E-06
End of Load Step 6	27.9	79.5	58.9	1.35	8.89E-06
End of Load Step 7	52.6	79.5	57.6	1.38	7.38E-06
End of Load Step 8	103	79.5	56.3	1.41	6.42E-06
End of Load Step 9	252	78.5	54.5	1.44	4.96E-06
End of Load Step 10	503	78.5	53.1	1.48	4.03E-06
End of Load Step 11	1007	78.5	51.6	1.52	3.27E-06

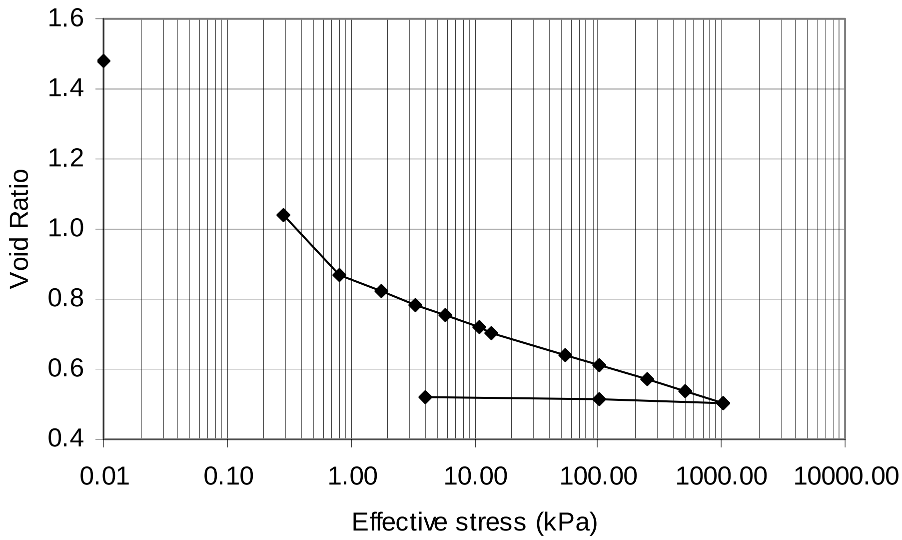


Figure 1 Compressibility of Scavenger solids tailings

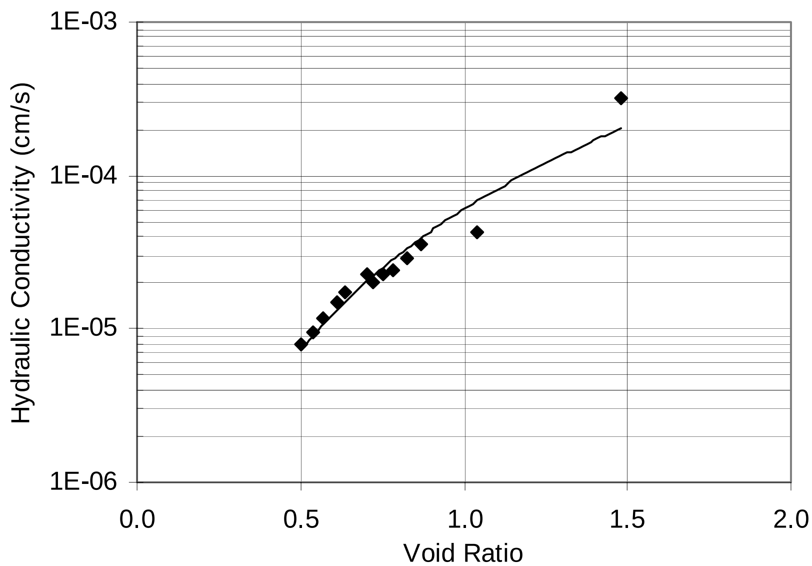


Figure 2 Hydraulic conductivity of Scavenger solids tailings

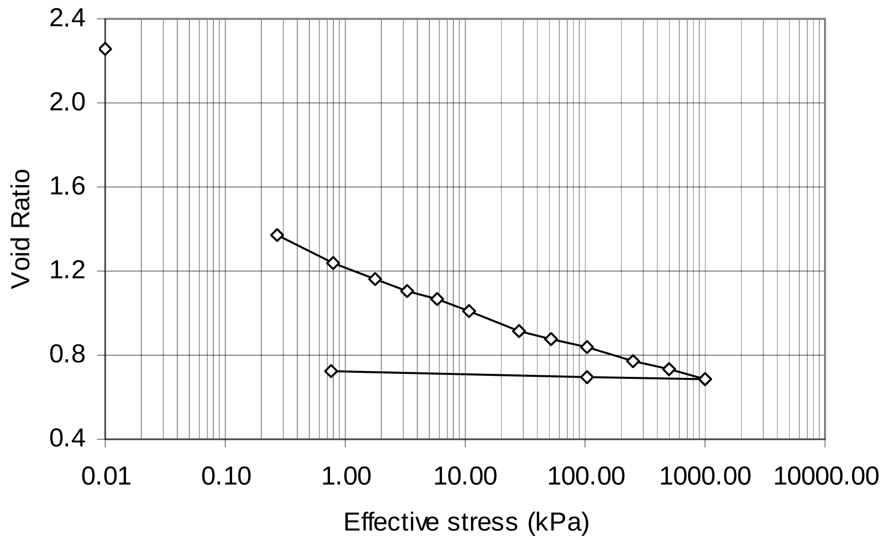


Figure 3 Compressibility of Cleaner solids tailings

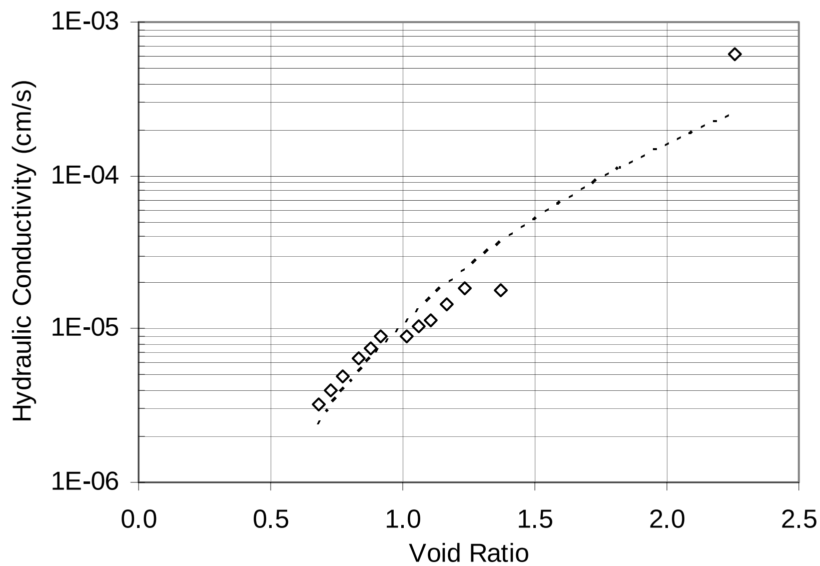


Figure 4 Hydraulic conductivity of Cleaner solids tailings

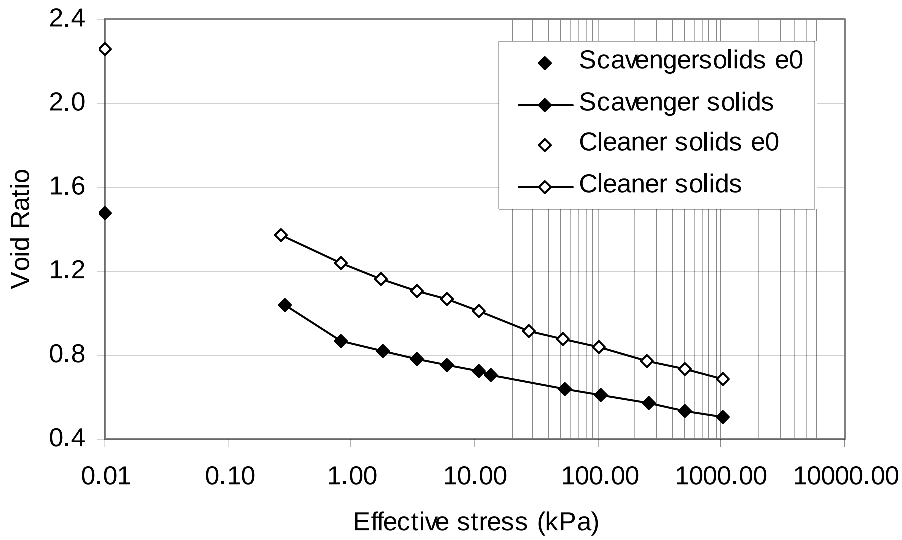


Figure 5 Comparison of compressibilities of Scavenger and Cleaner solids tailings

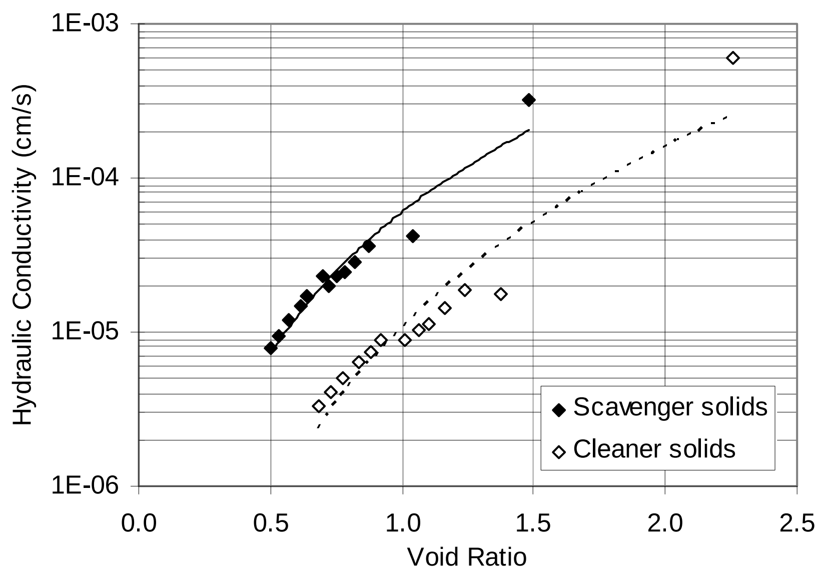


Figure 6 Comparison of hydraulic conductivities of Scavenger and Cleaner solids tailings

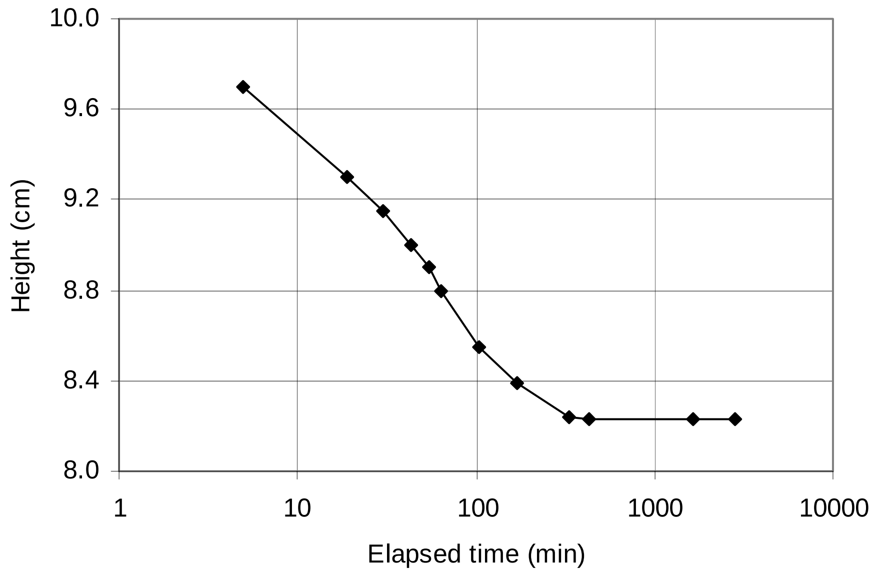


Figure 7 Settlement vs. time at self-weight stress (0.290 kPa) of Scavenger solids tailings

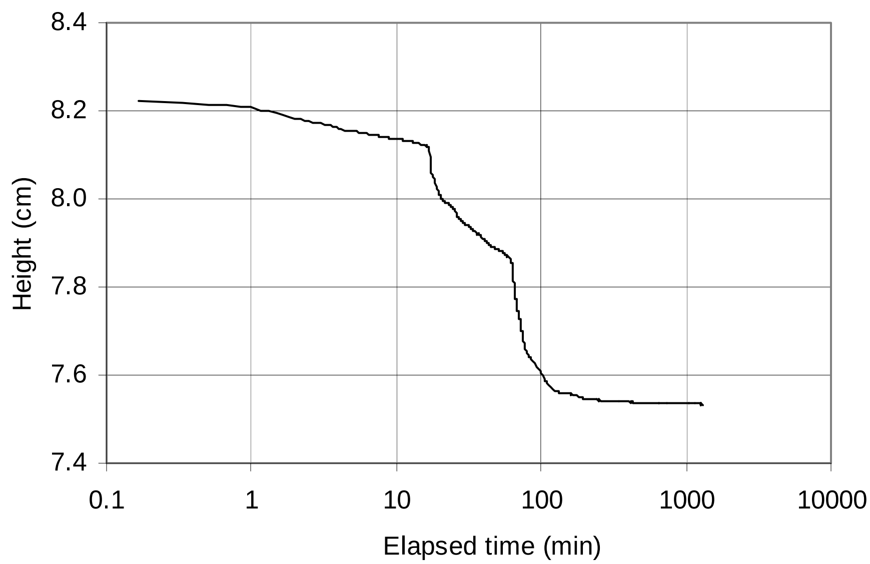


Figure 8 Settlement vs. time at Load 1 (0.823 kPa) of Scavenger solids tailings

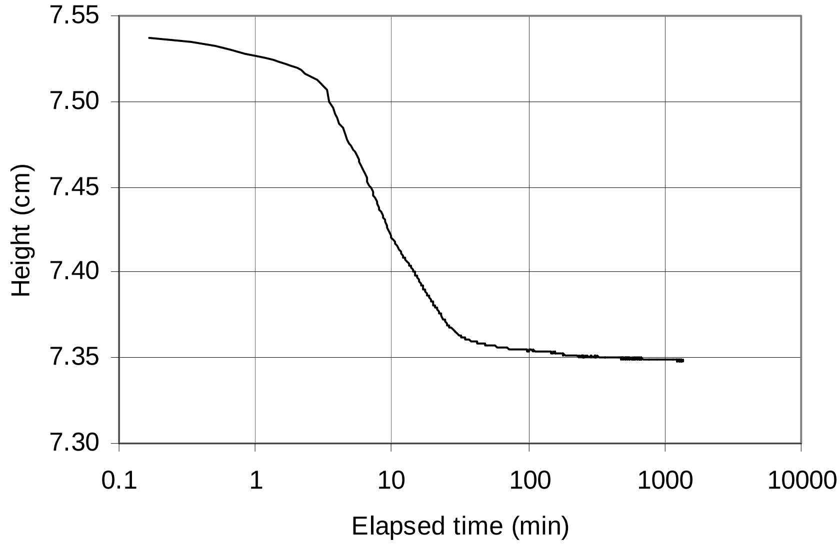


Figure 9 Settlement vs. time at Load 2 (1.77 kPa) of Scavenger solids tailings

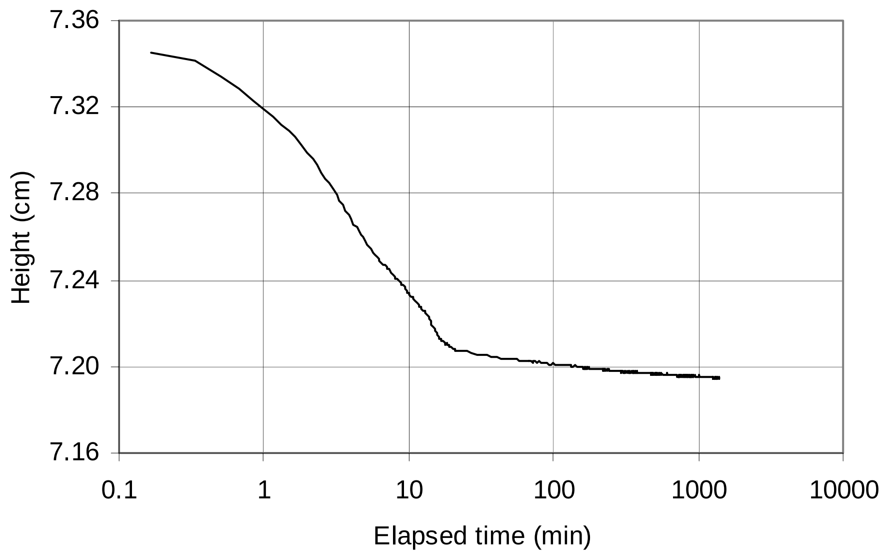


Figure 10 Settlement vs. time at Load 3 (3.35 kPa) of Scavenger solids tailings

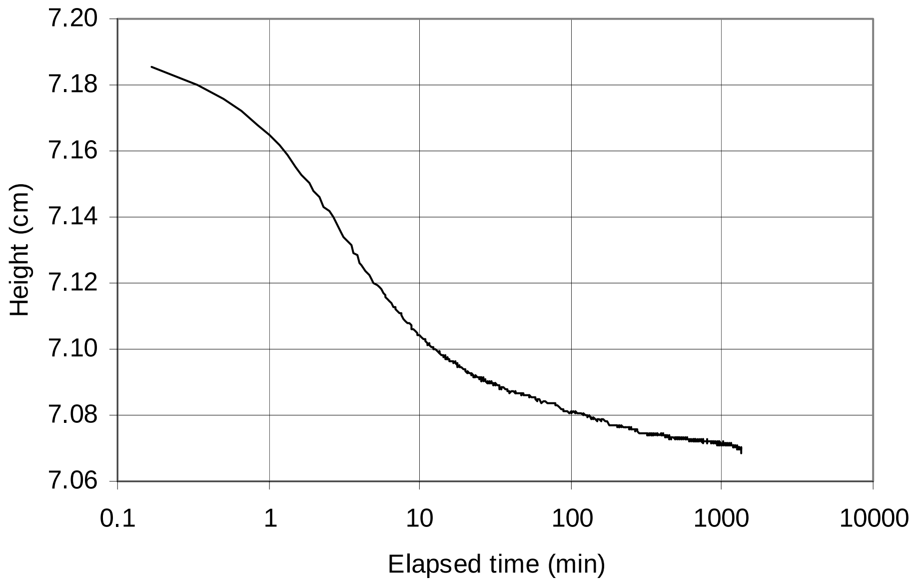


Figure 11 Settlement vs. time at Load 4 (5.91 kPa) of Scavenger solids tailings

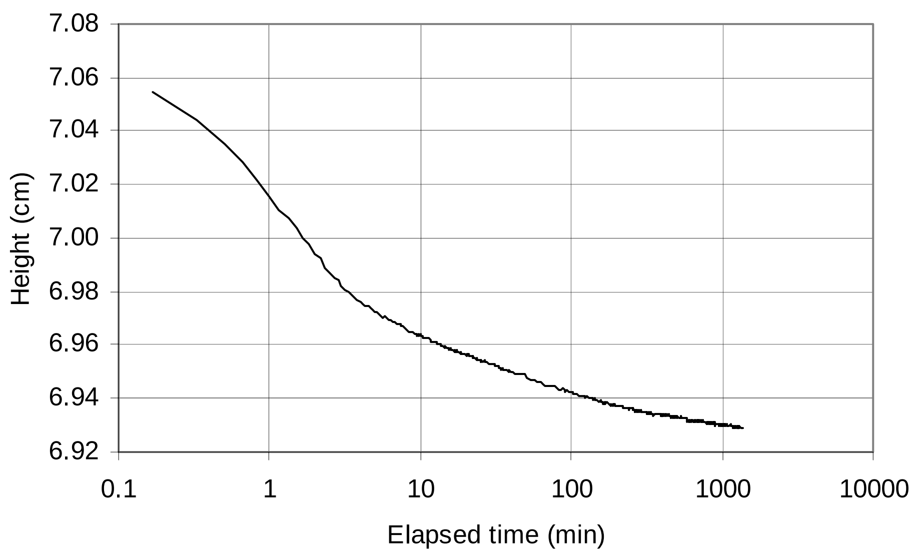


Figure 12 Settlement vs. time at Load 5 (10.9 kPa) of Scavenger solids tailings

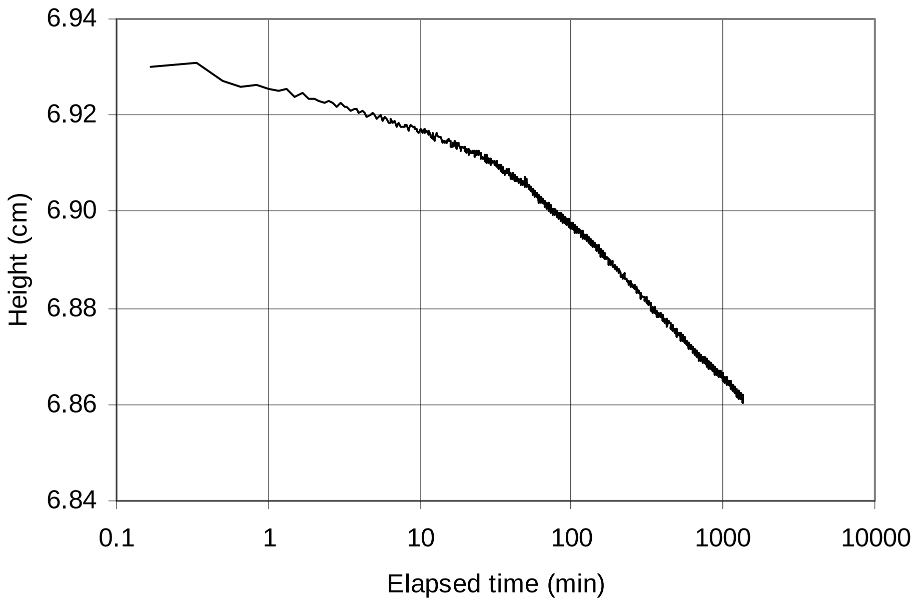


Figure 13 Settlement vs. time at Load 6 (13.7 kPa) of Scavenger solids tailings

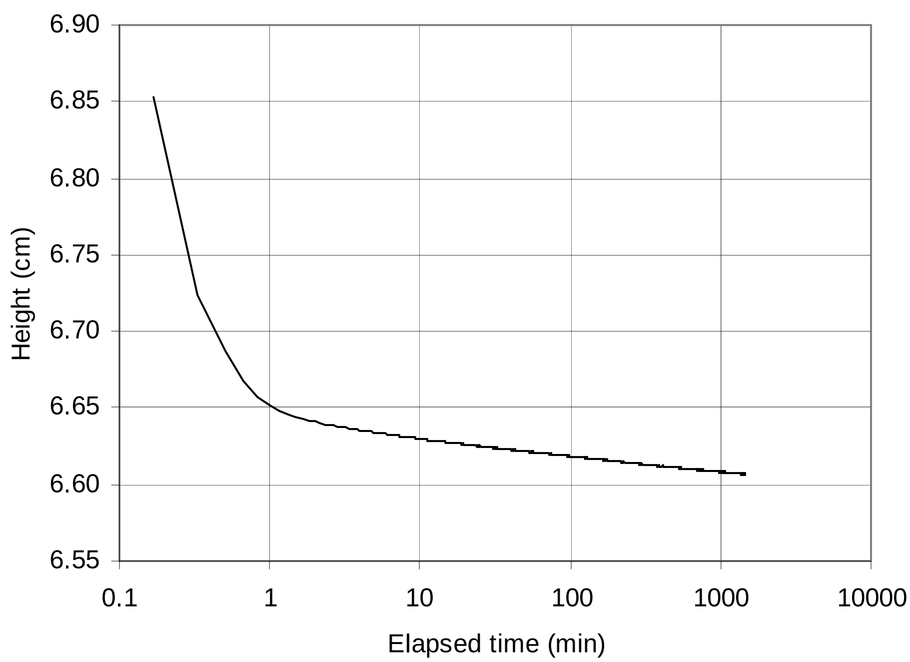


Figure 14 Settlement vs. time at Load 7 (53.9 kPa) of Scavenger solids tailings

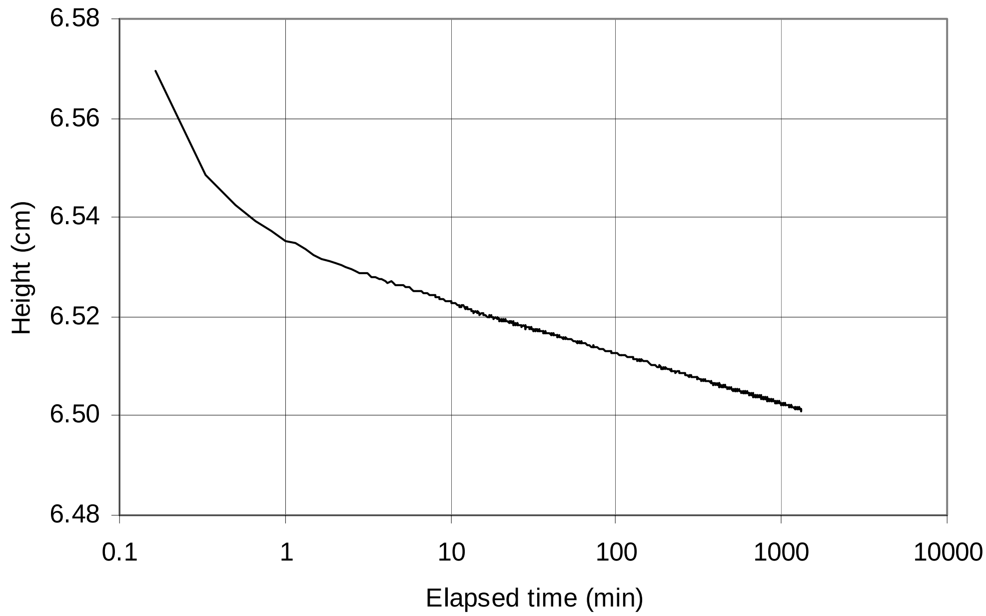


Figure 15 Settlement vs. time at Load 8 (104 kPa) of Scavenger solids tailings

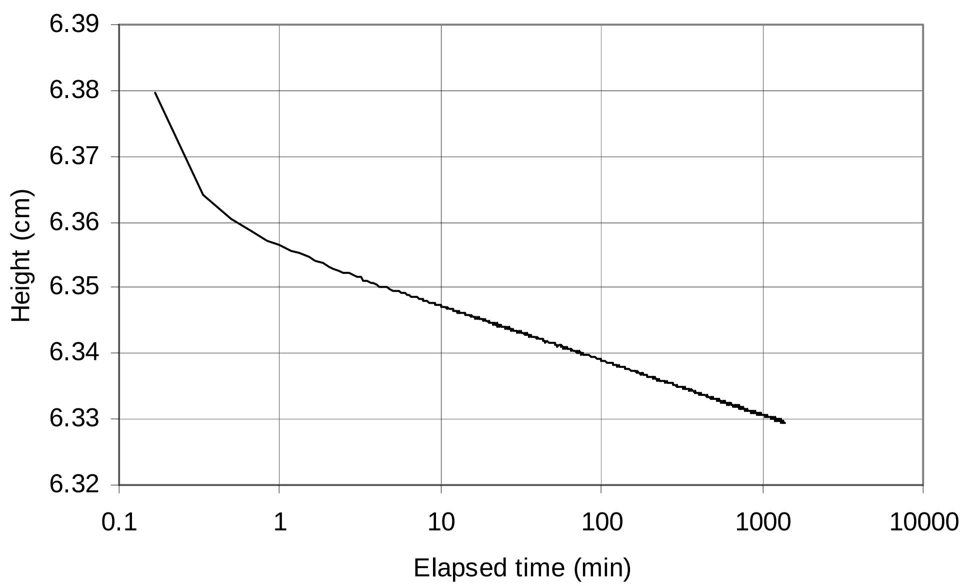


Figure 16 Settlement vs. time at Load 9 (254 kPa) of Scavenger solids tailings

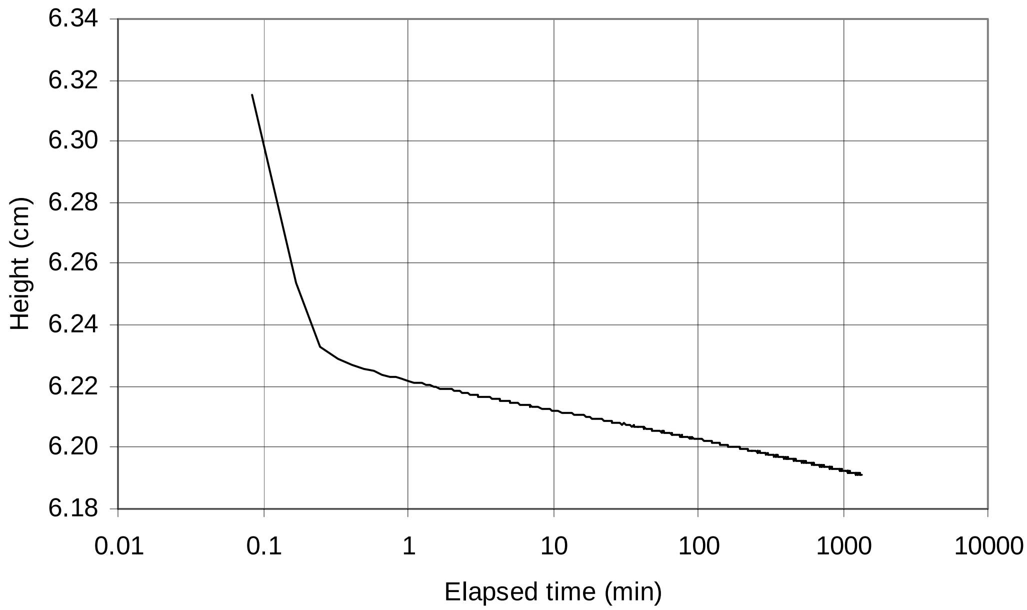
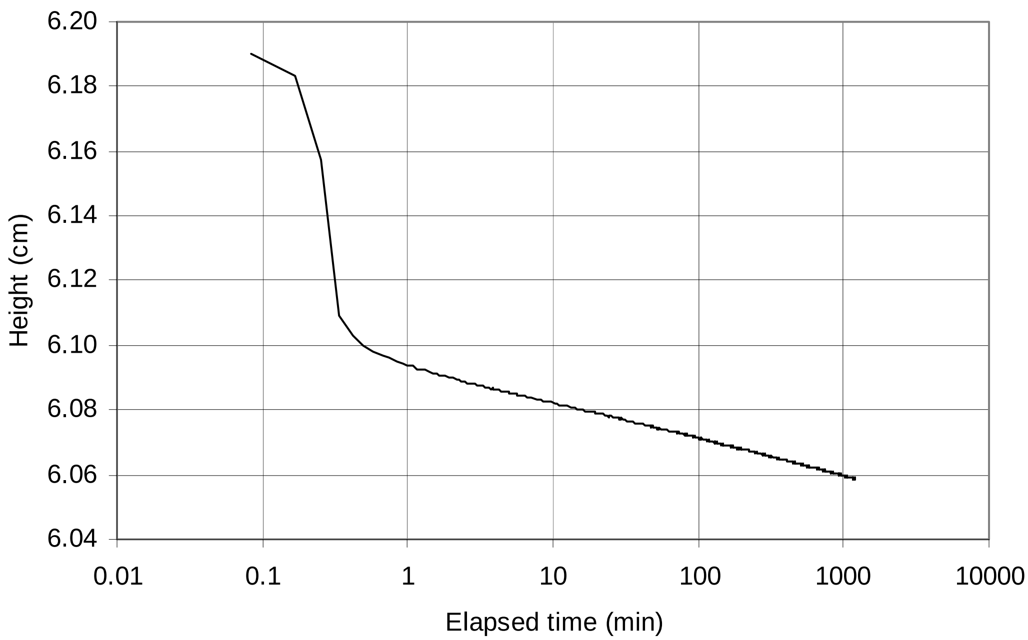


Figure 17 Settlement vs. time at Load 10 (508 kPa) of Scavenger solids tailings



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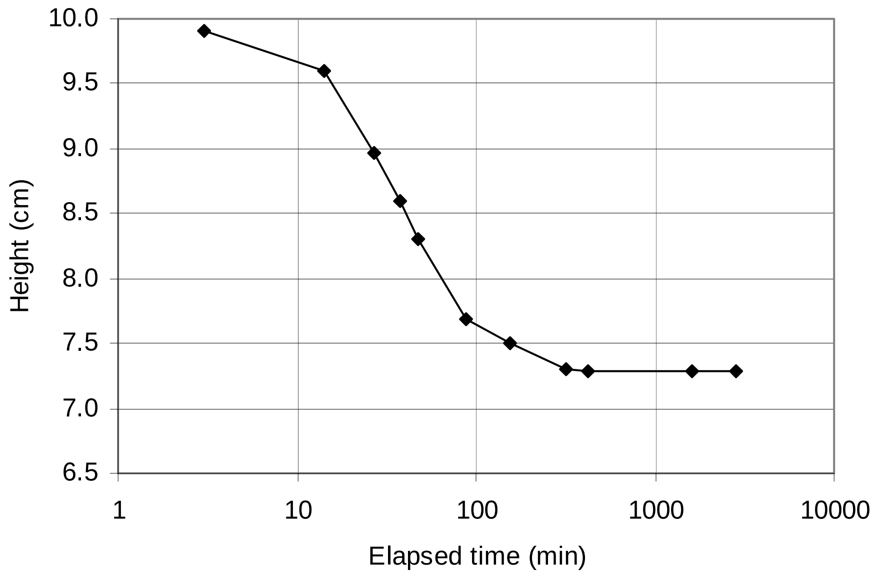

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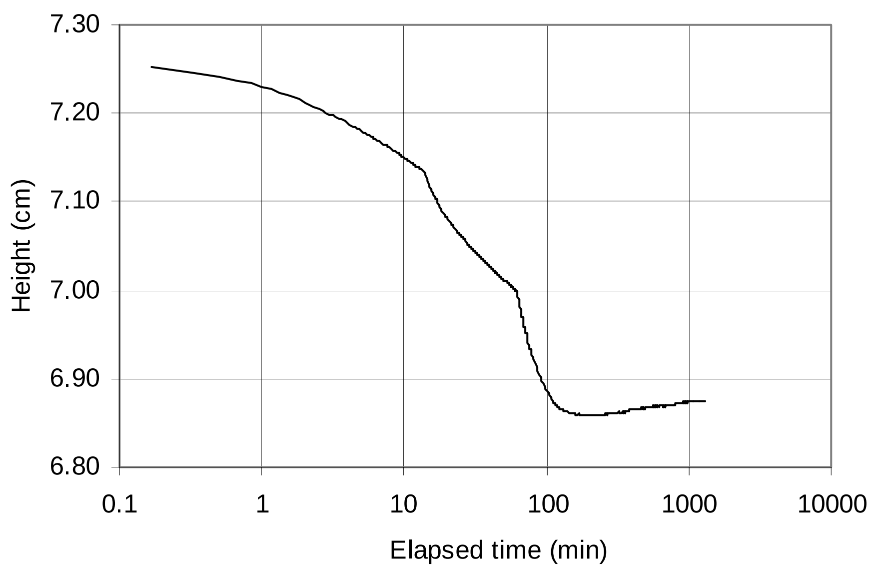

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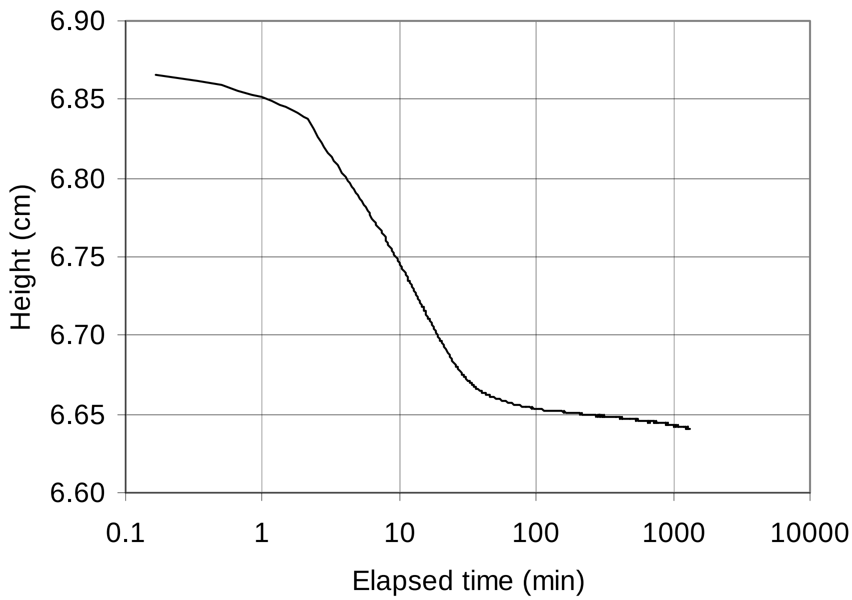

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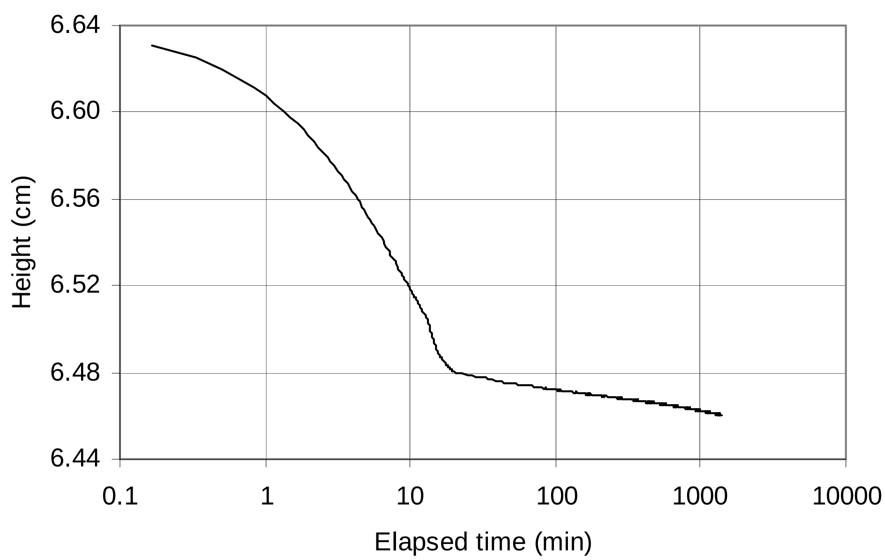

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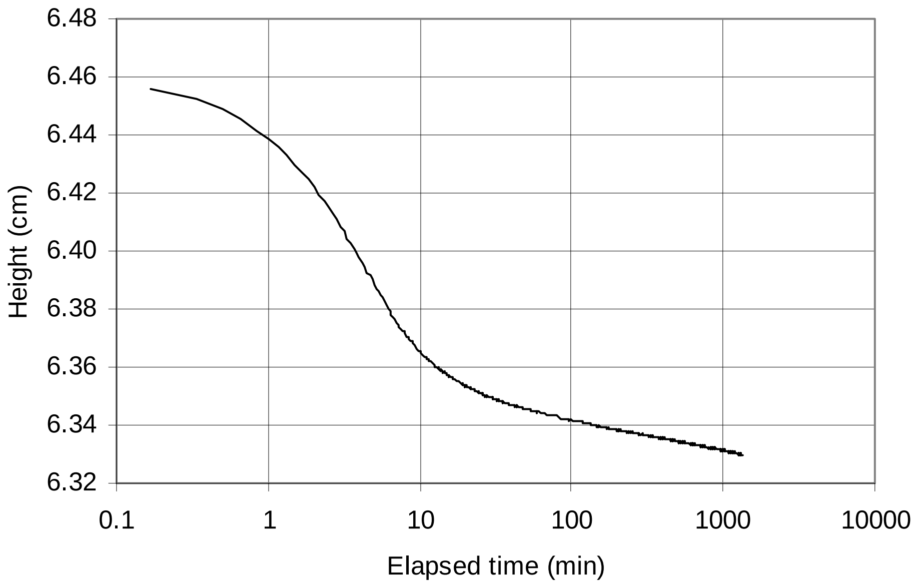

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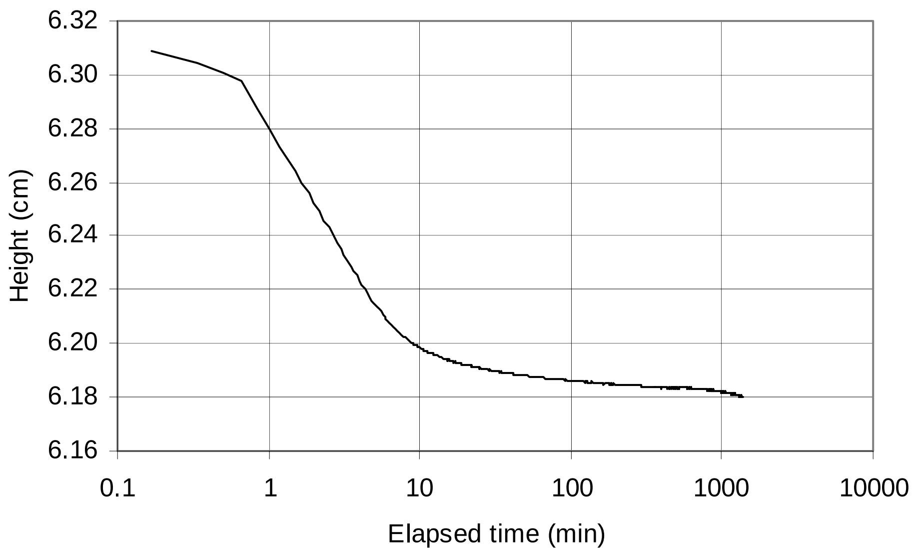

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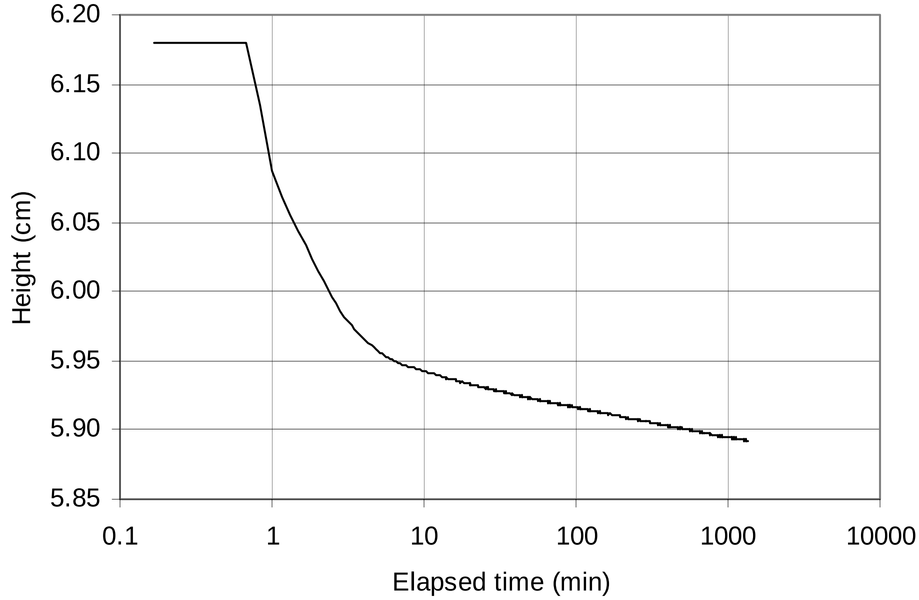

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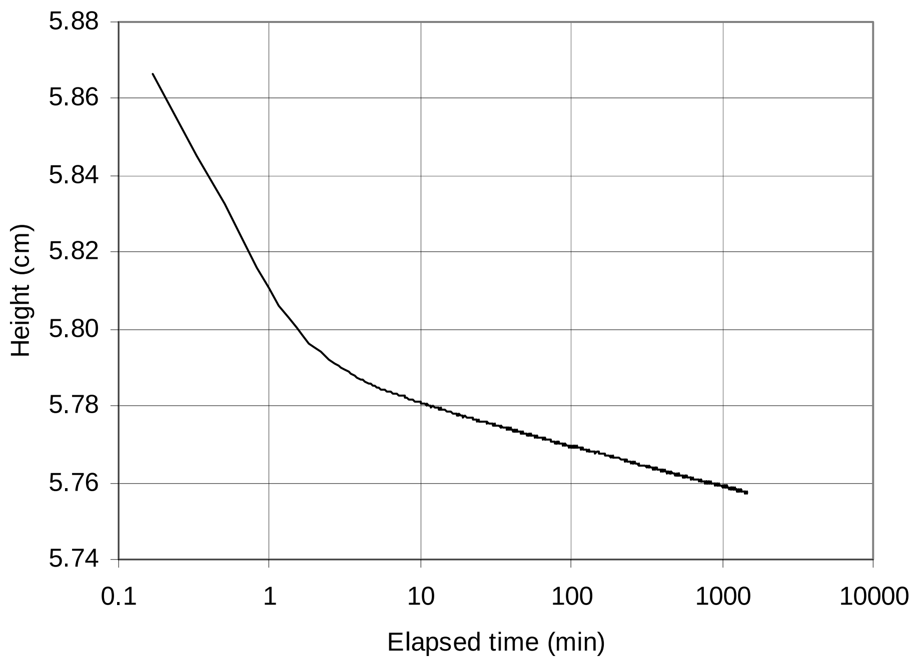

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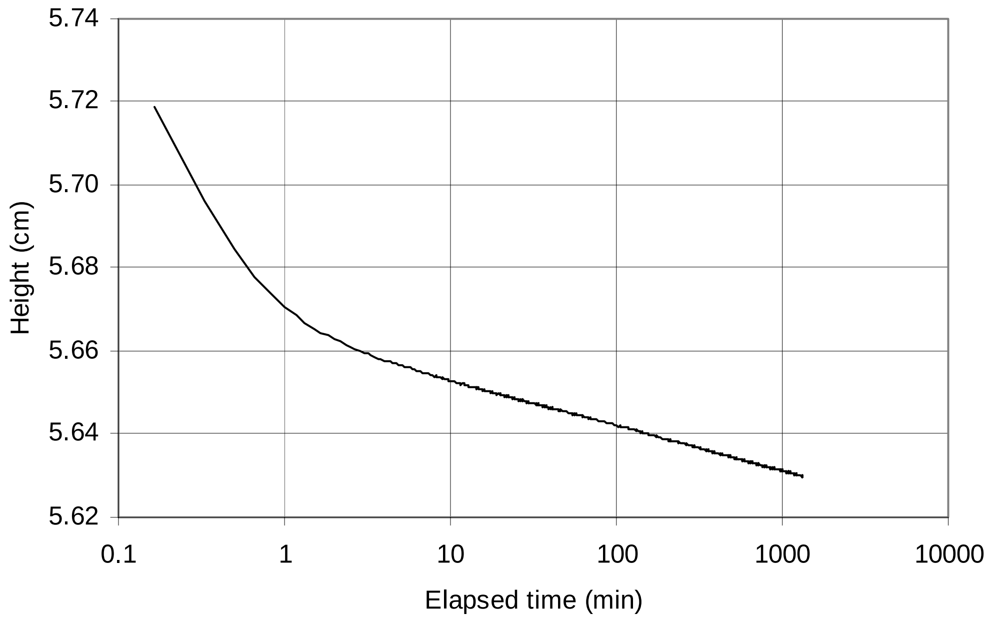

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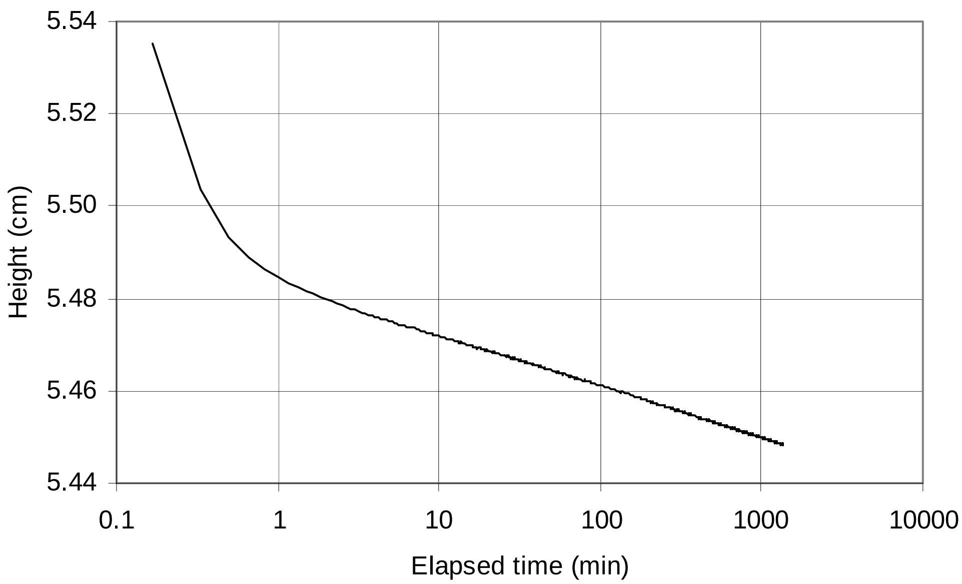

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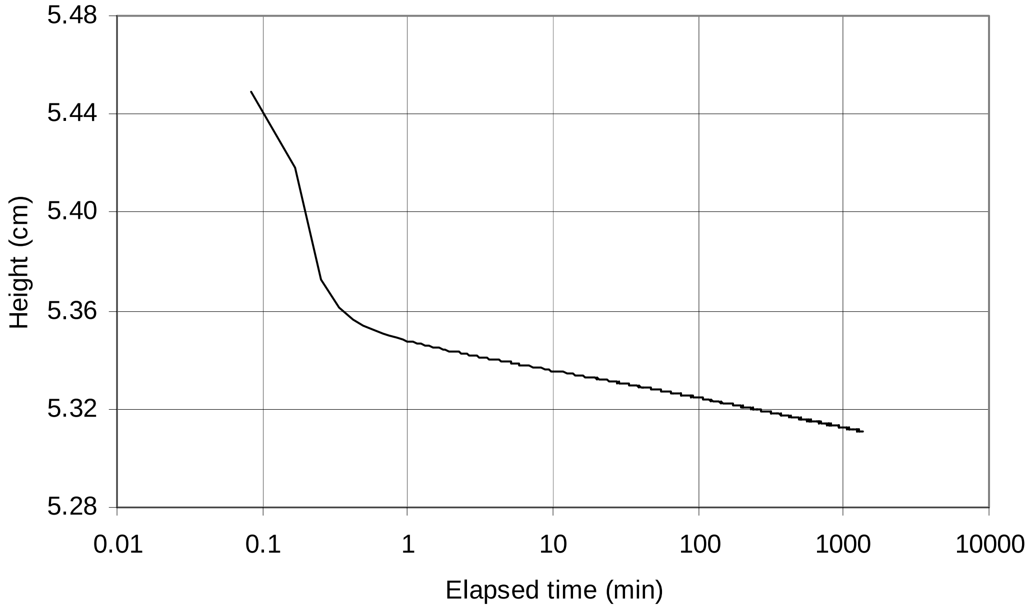

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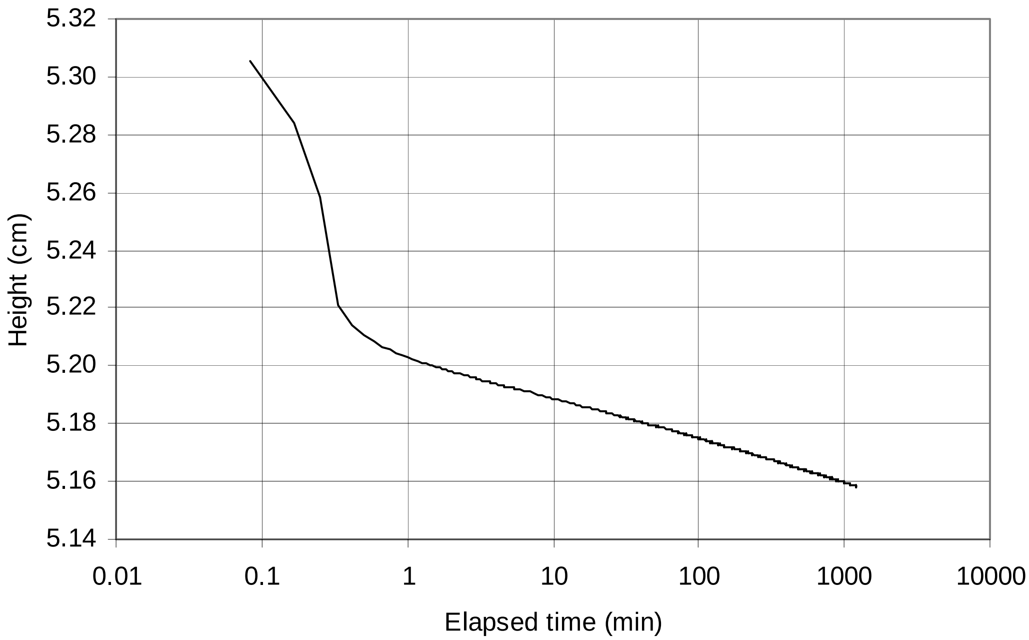

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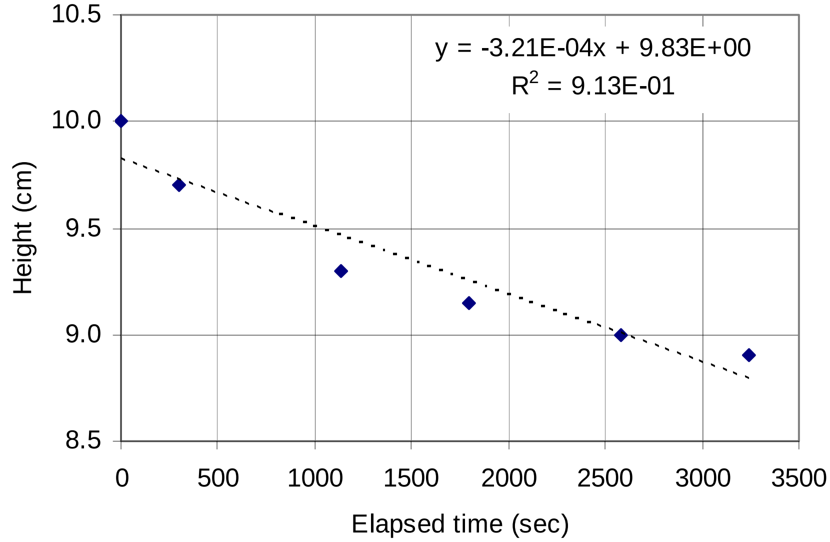

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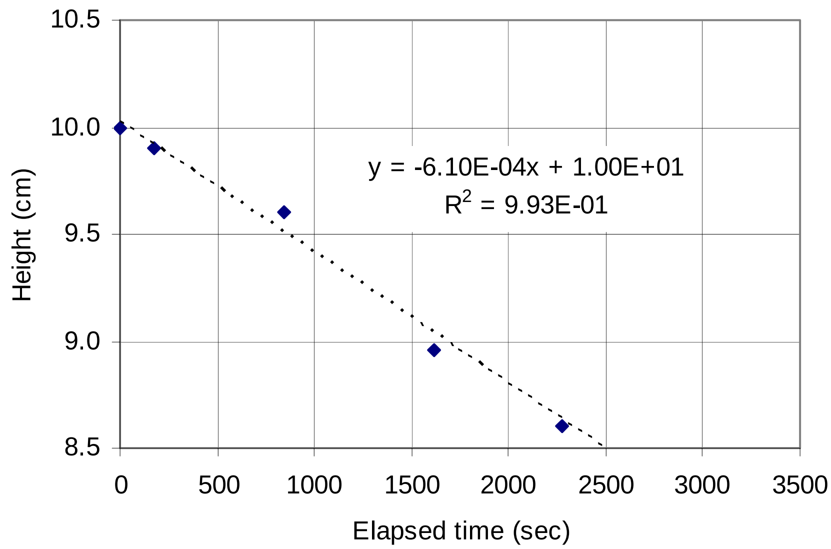

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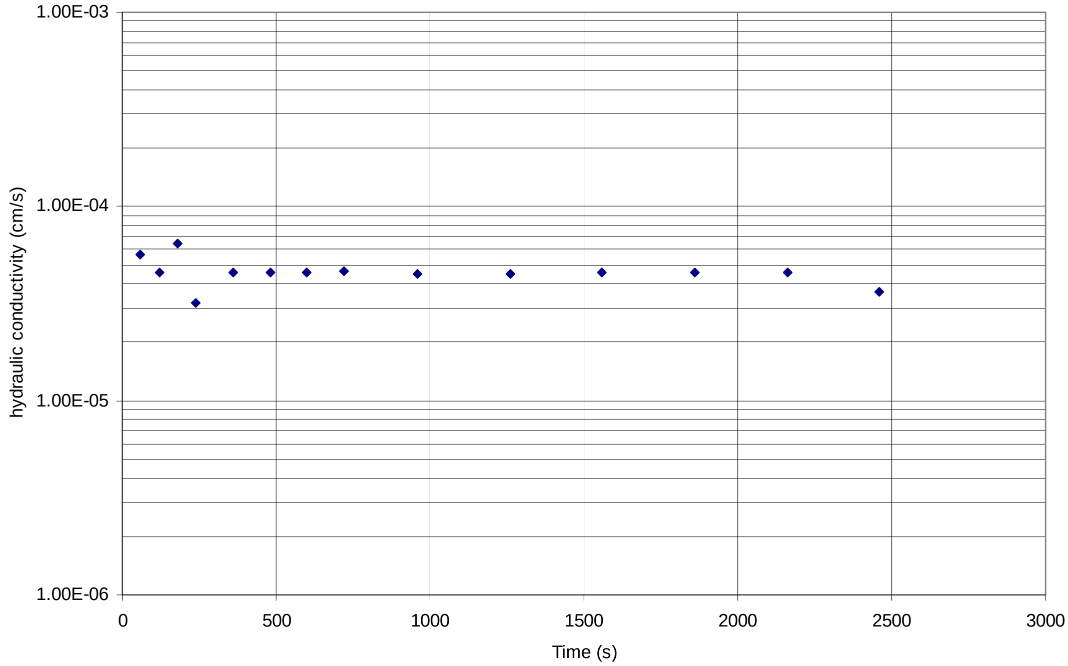

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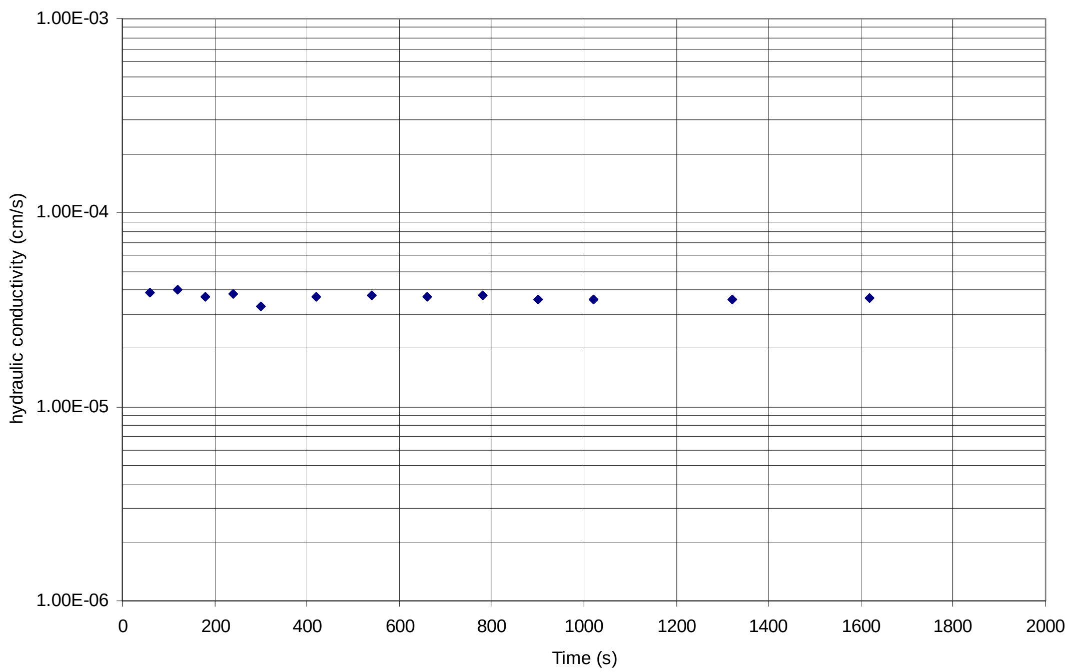

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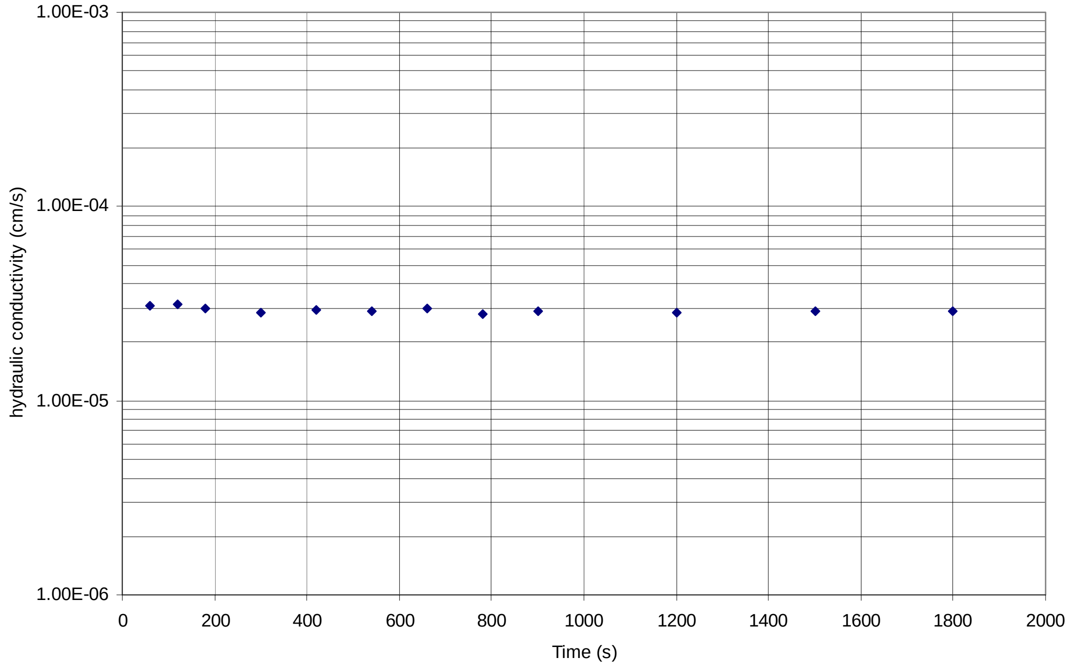

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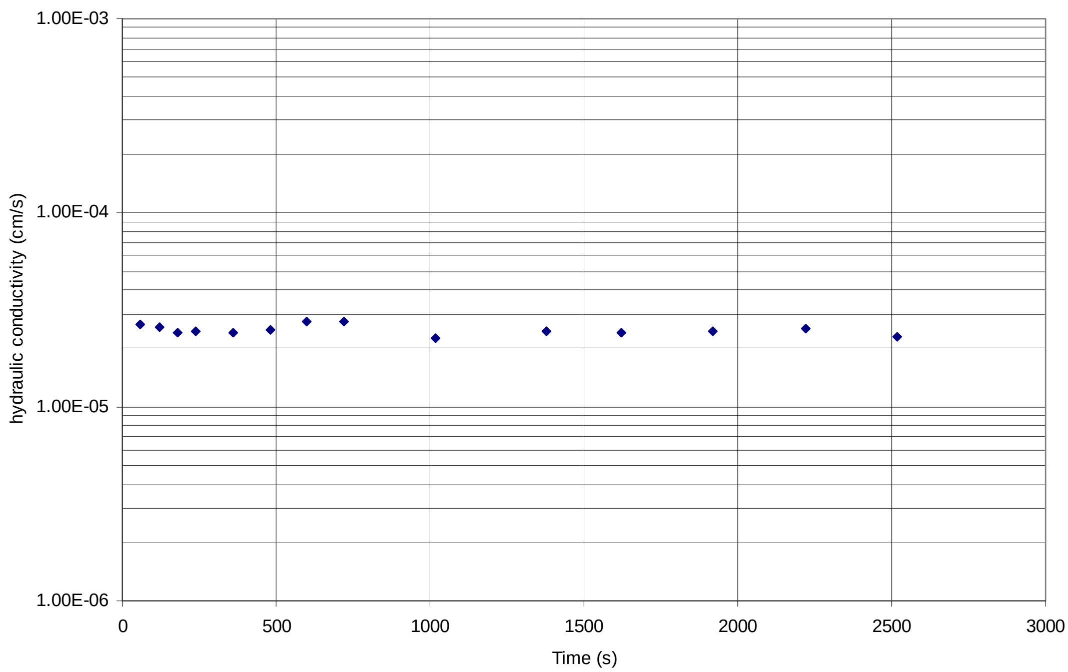

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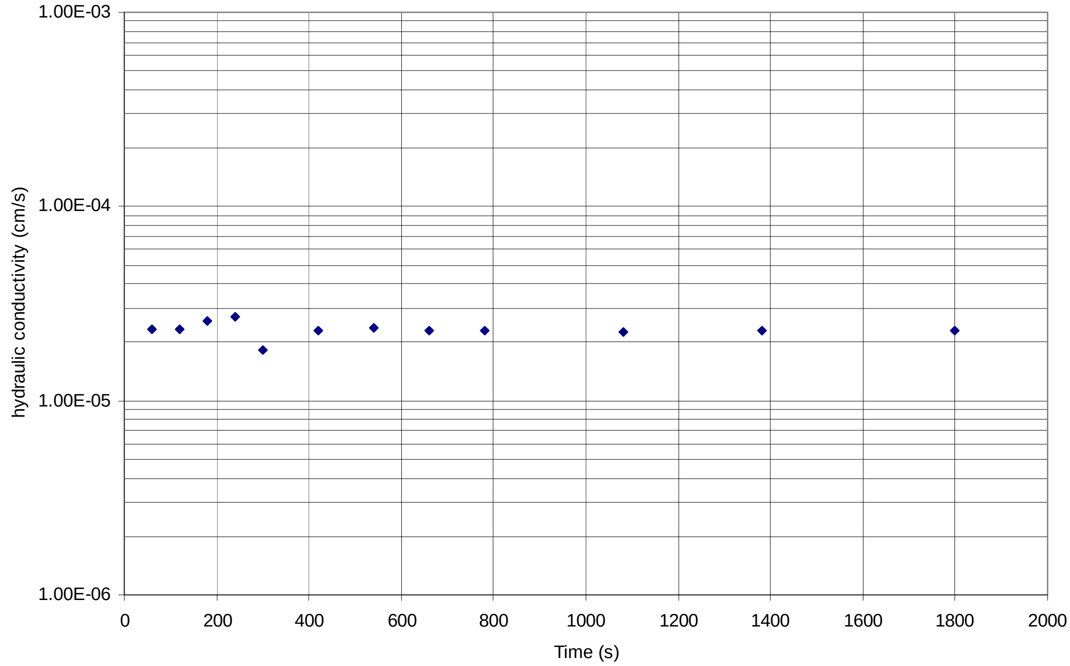

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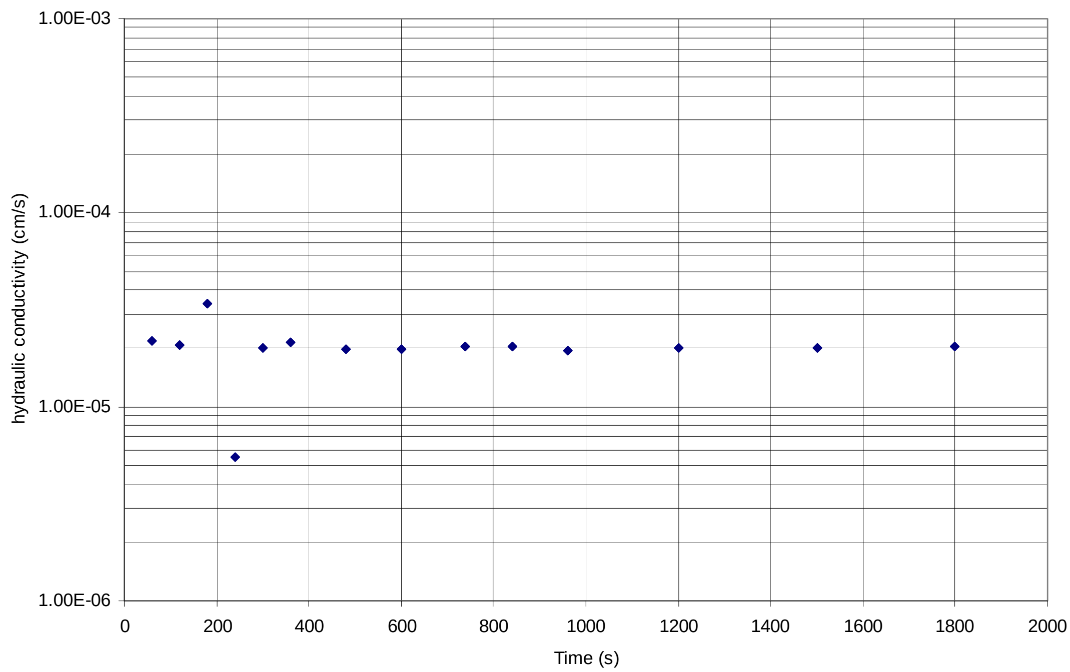

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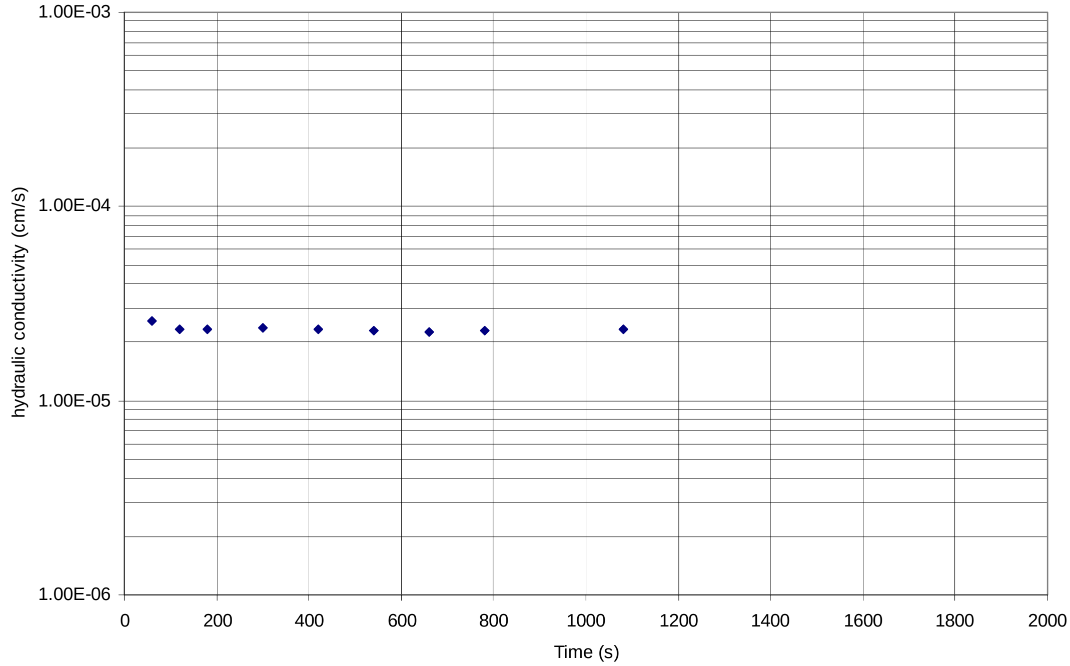

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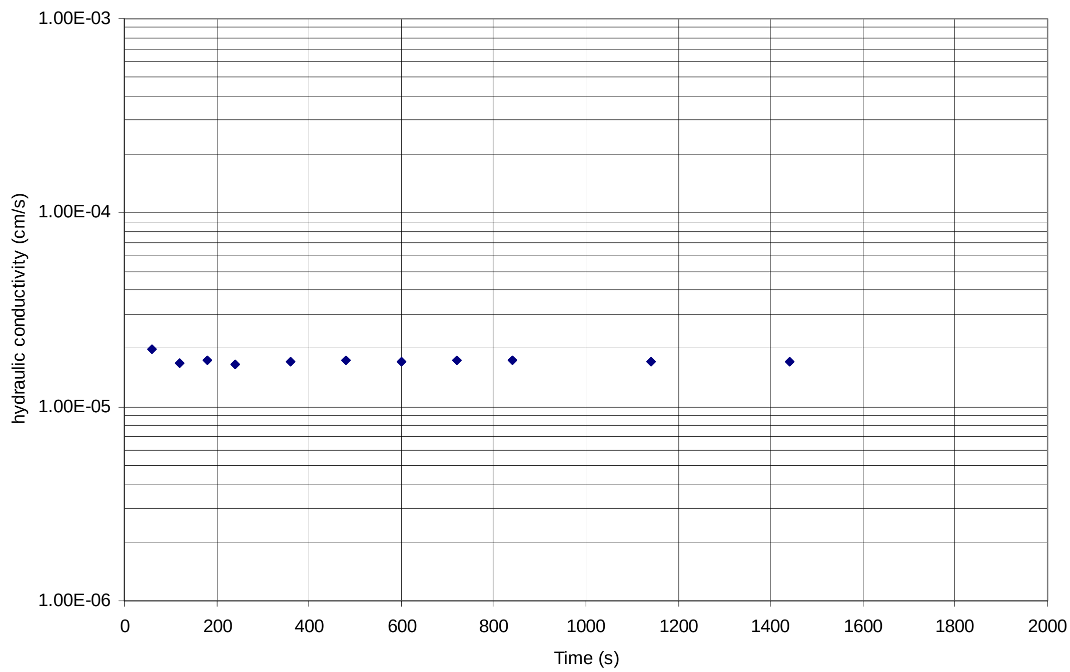

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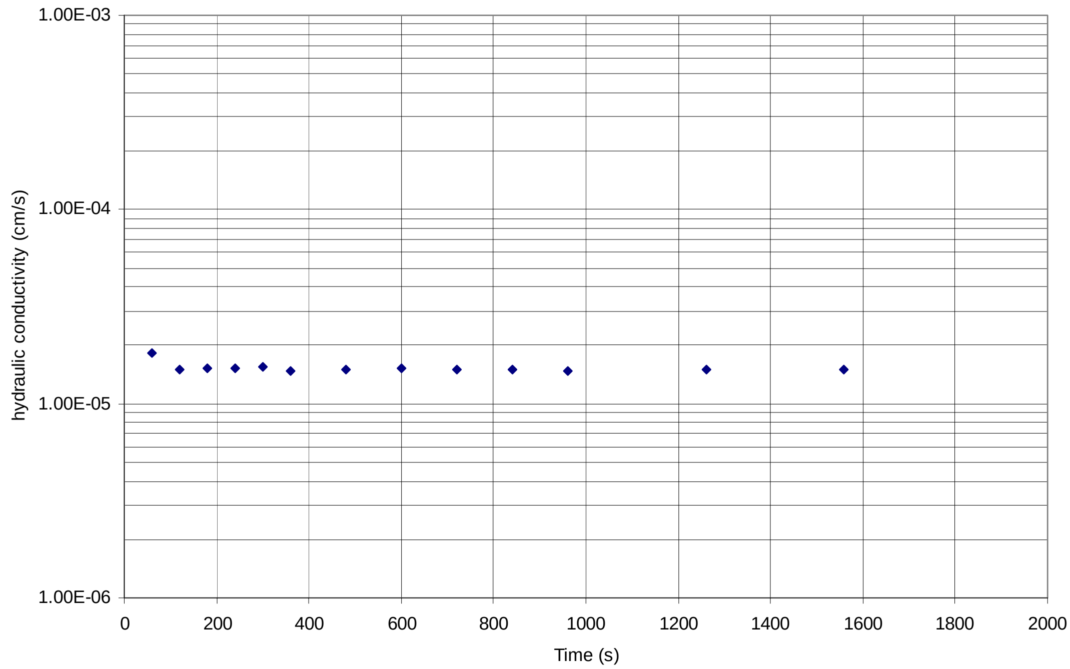

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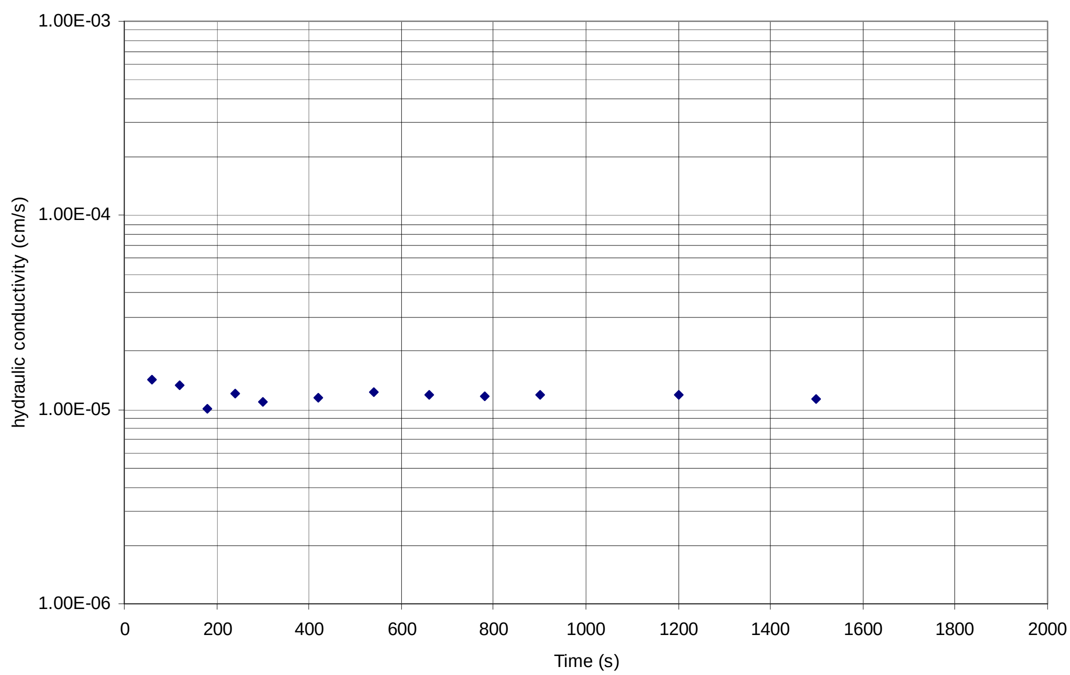

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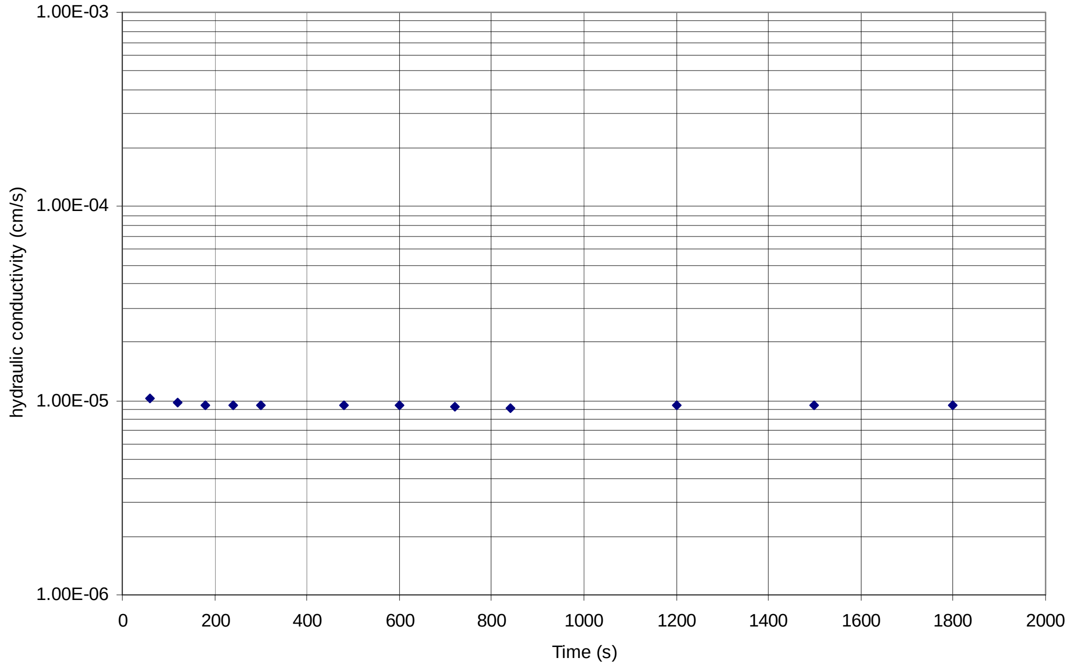

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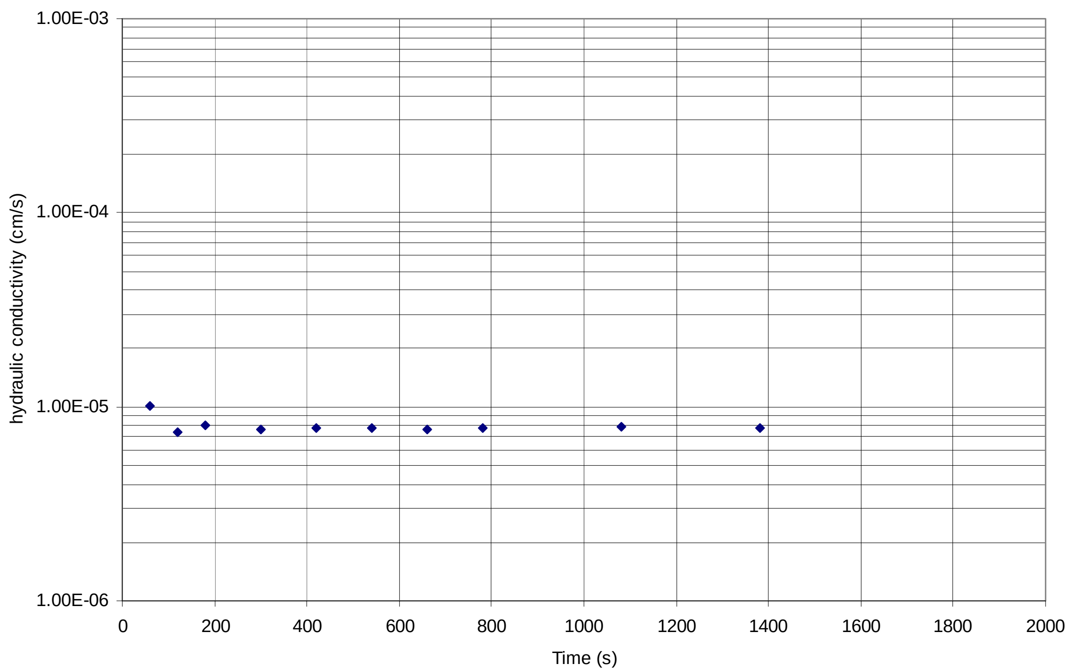

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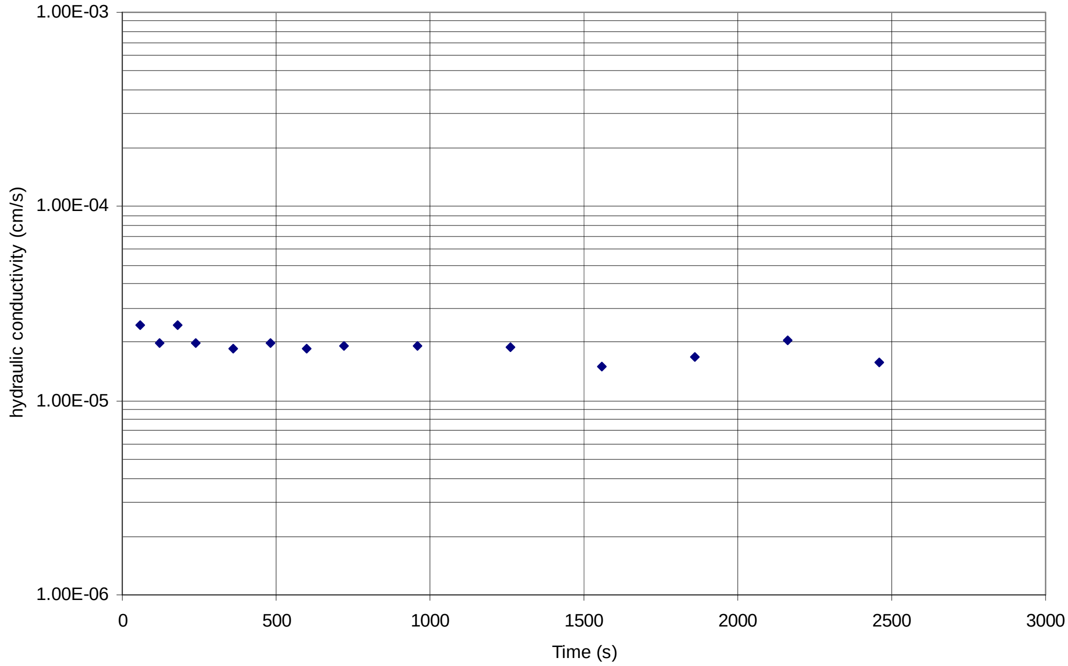

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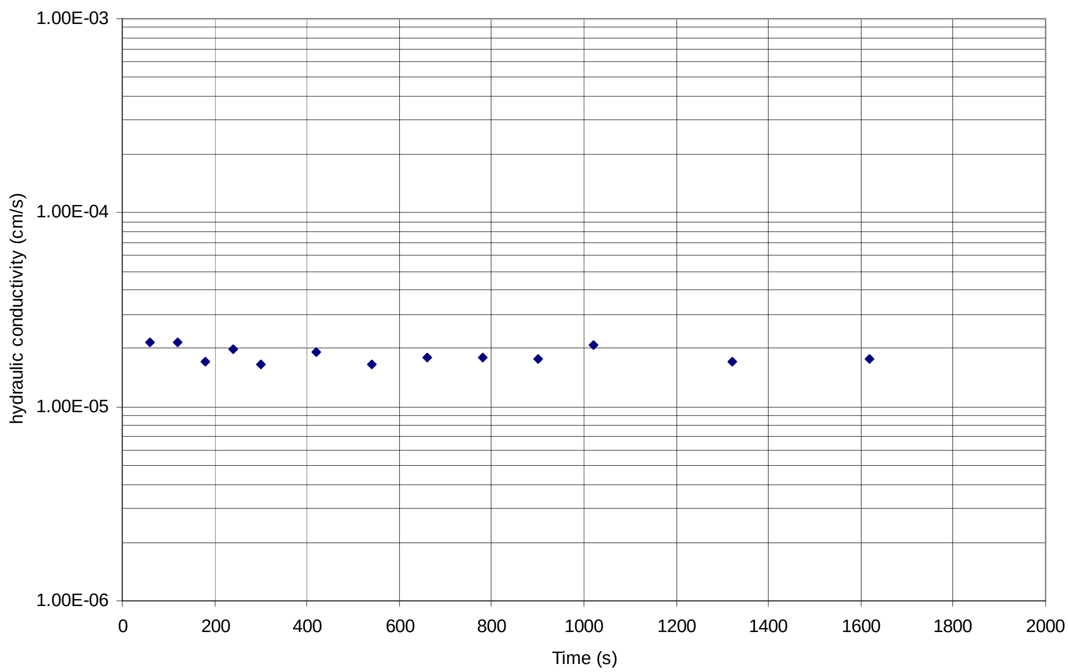

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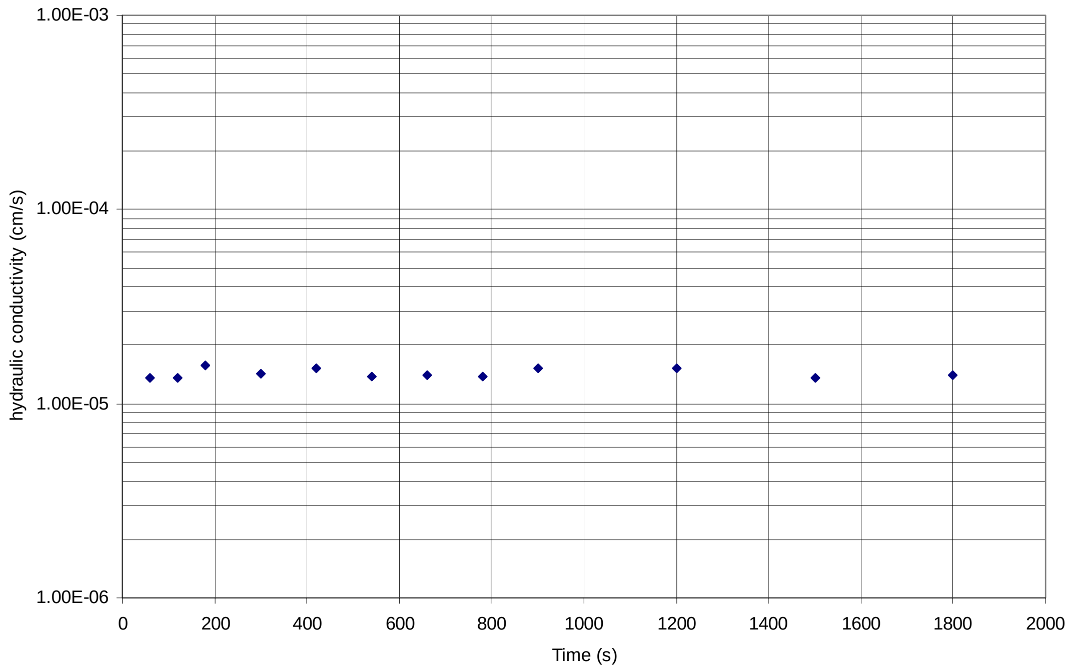

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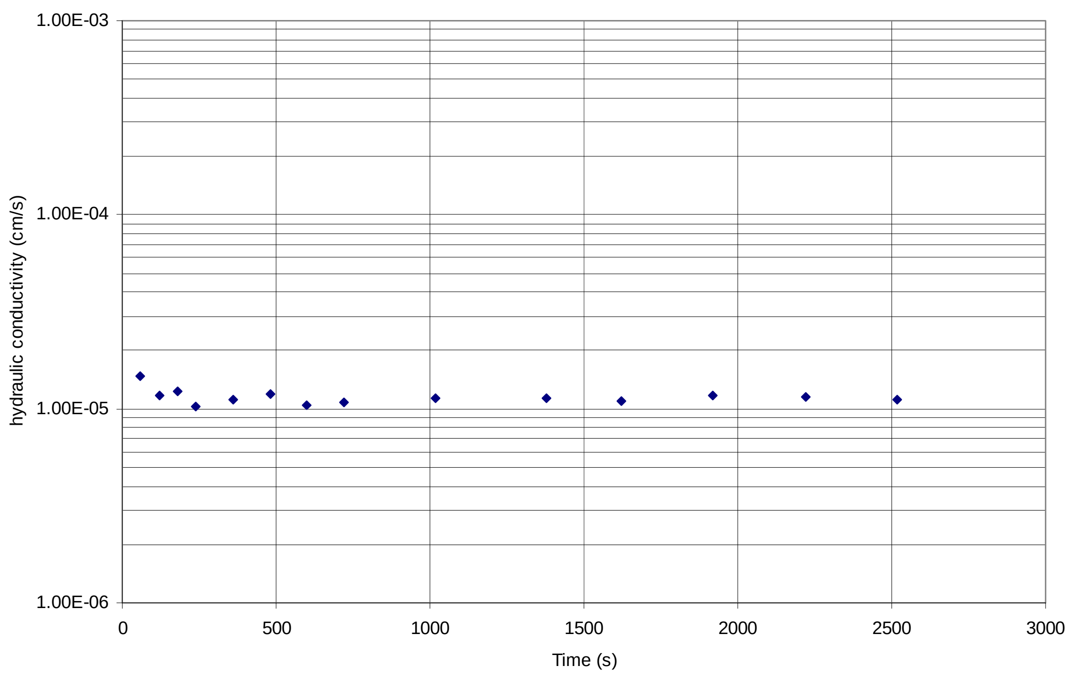

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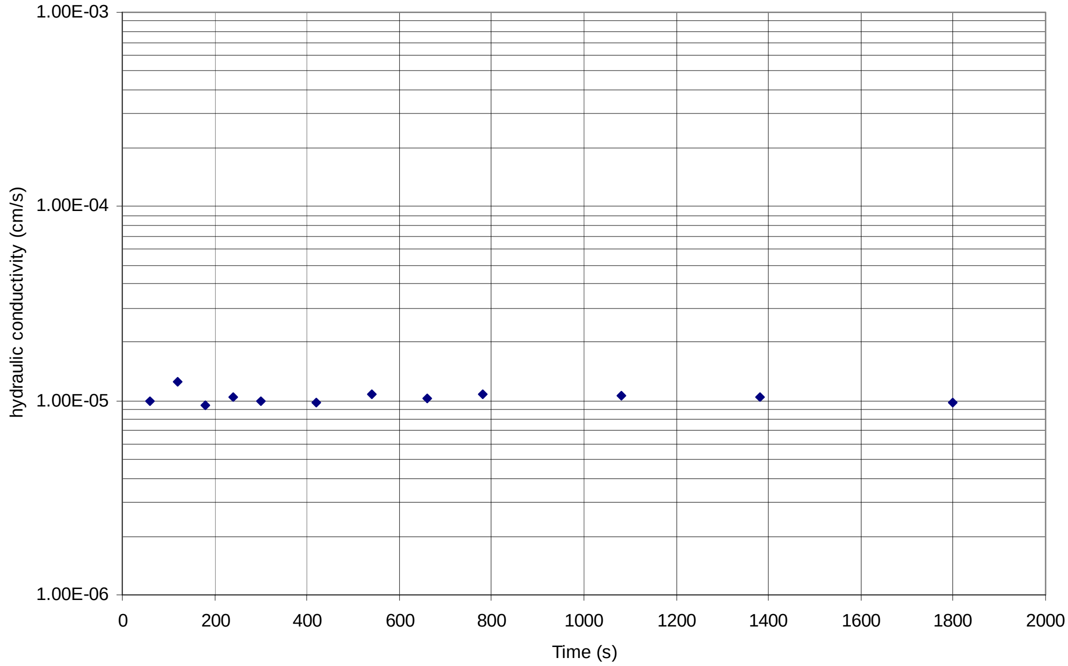

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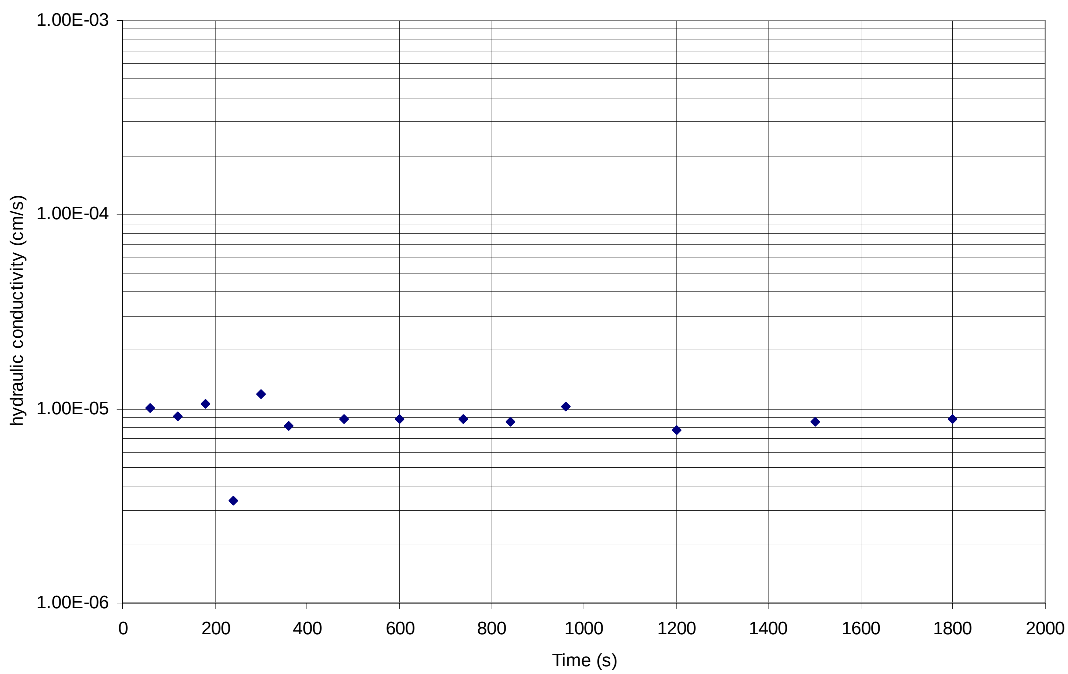

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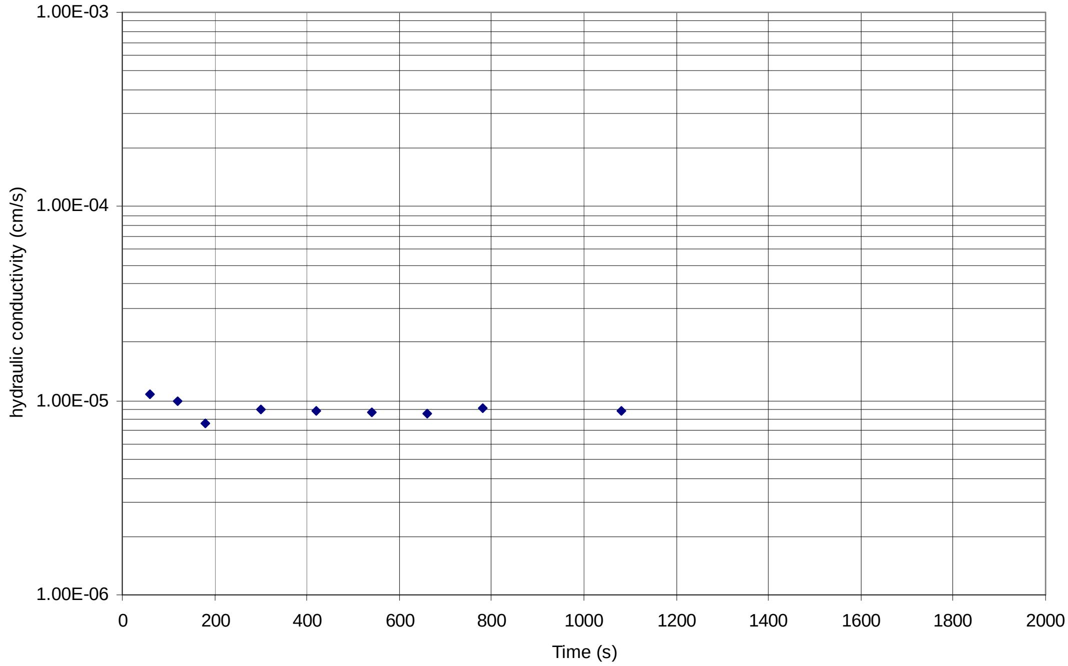

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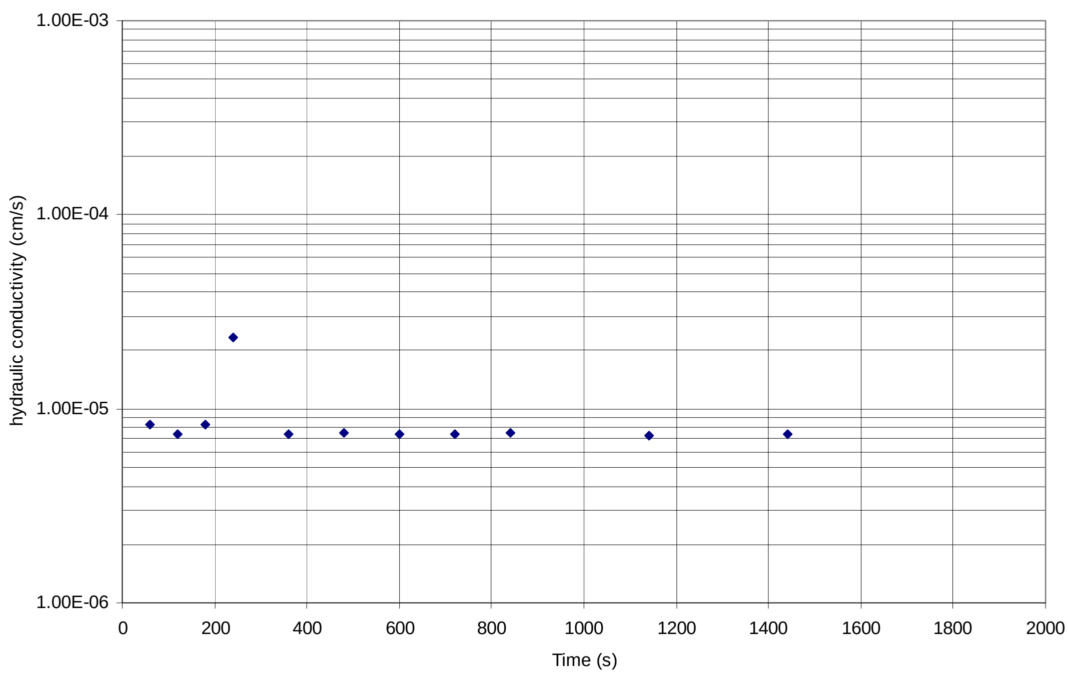

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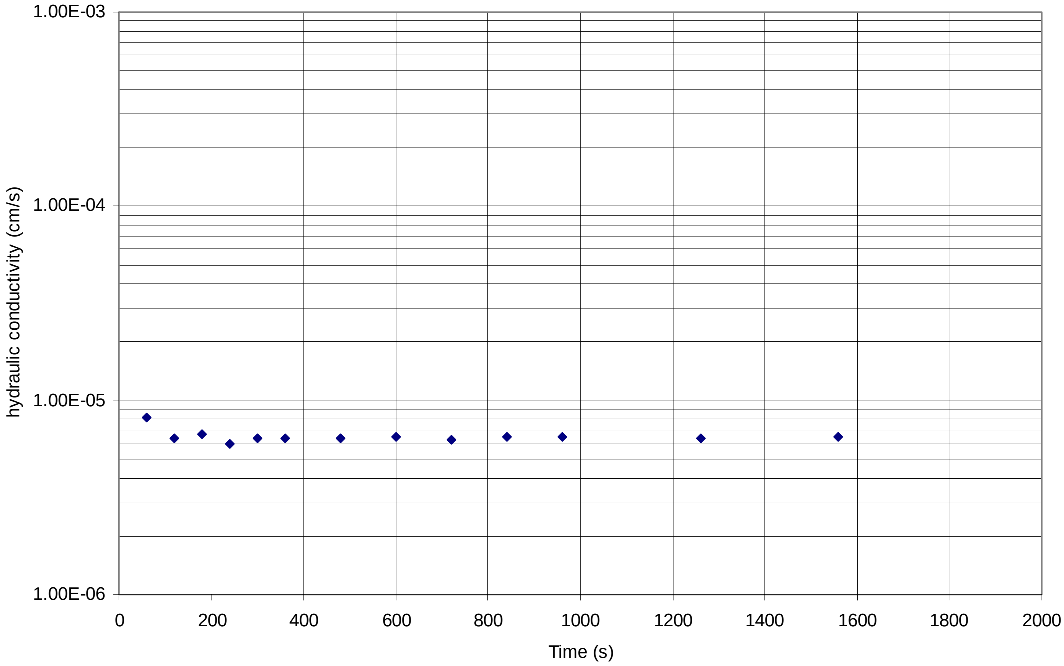

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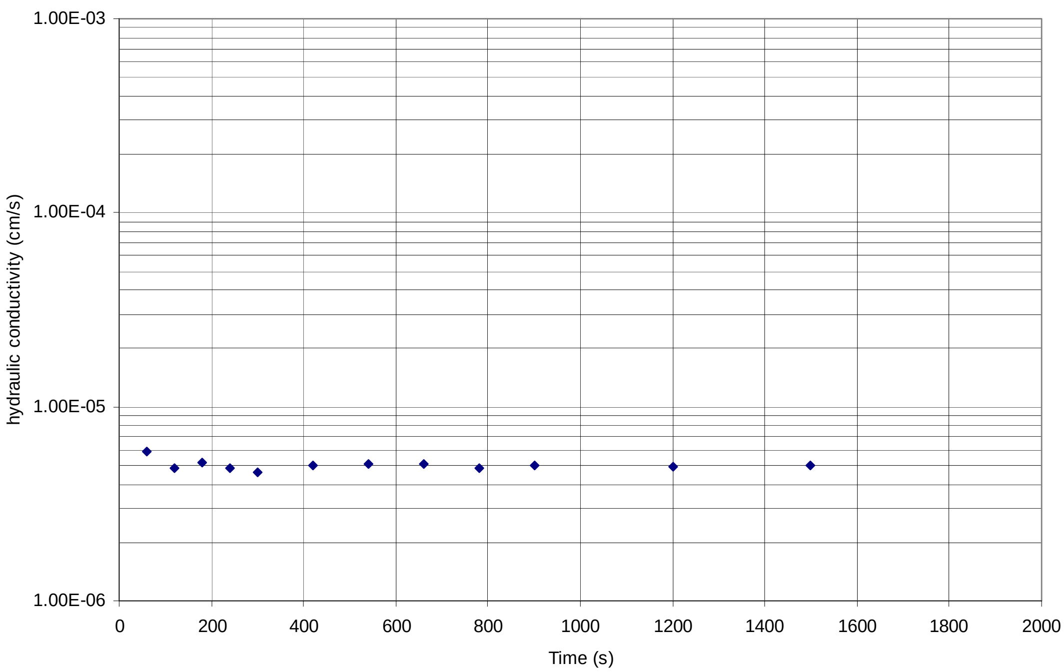

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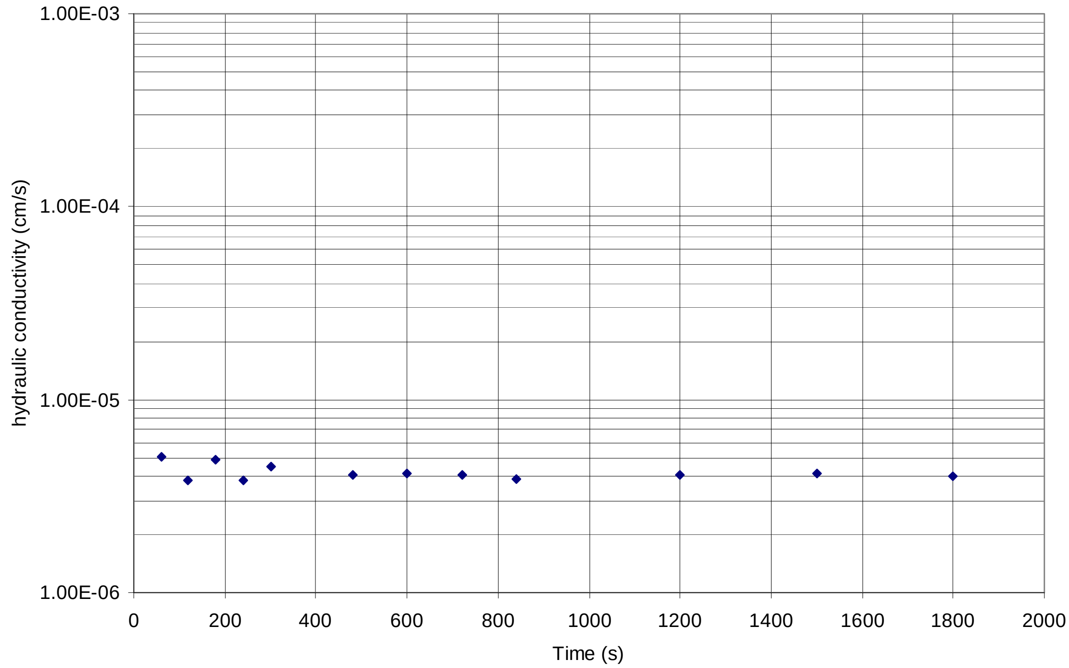

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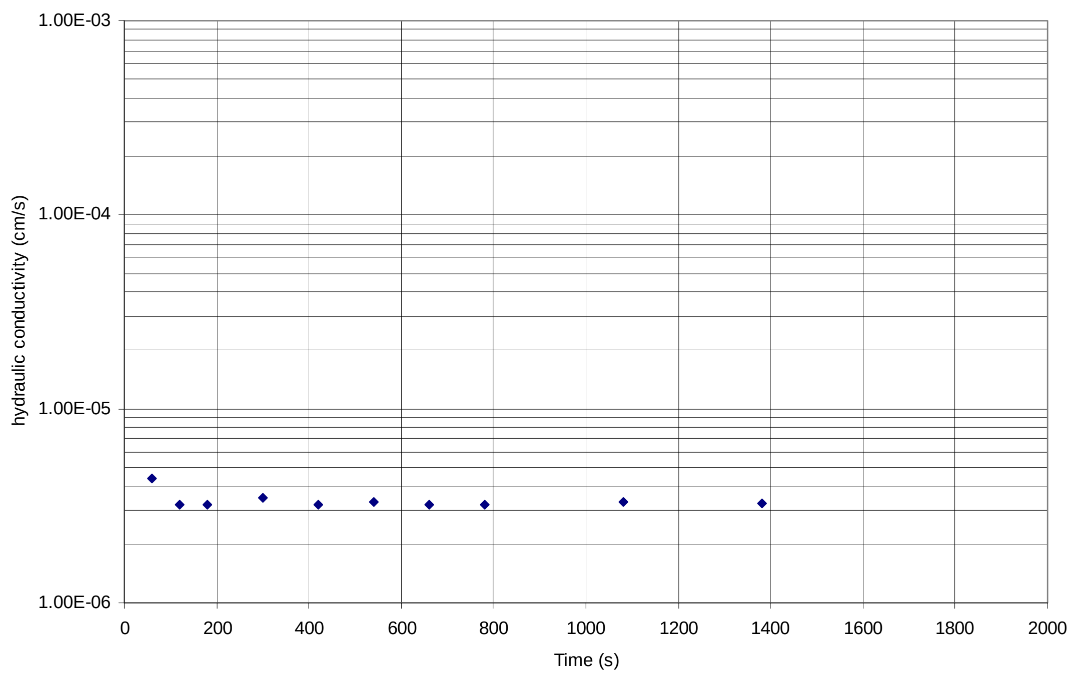

Figure 56 Hydraulic conductivity measurement for Cleaner solids tailings after Load 11 (1007 kPa)

APPENDIX IV

2009 Laboratory Test Program

Final Report
On
Consolidation Testing of Resolution Project Tailings

August 14, 2009

To:

Howard D. Plewes, M.Sc, P.Eng.
Principal

Klohn Crippen Berger Ltd.
Suite 500, 2955 Virtual Way
Vancouver, British Columbia
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From:

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1 Introduction

A consolidation testing program has been performed on three tailings samples from the Resolution Copper Mining Project: Scavenger Tails, Cleaner Tails and Mixed Tails (85% Scavenger and 15% Cleaner by dry weight). The testing program included the determination of the specific gravity and particle size distribution. The consolidation testing included hindered sedimentation tests and compressibility settling tests to determine the void ratio - hydraulic conductivity relationship and the effective stress - void ratio relationship respectively at large void ratios or low solids contents. At lower void ratios or higher solids contents these relationships are determined by large strain consolidation tests. The Test Procedures and Test Apparatus are outlined in the Appendix to this report.

All of the above testing has been completed. Test results for the tests are given in the following tables and figures followed by an analysis of the test results.

2 Initial Sample Properties

Table 1 includes some properties of the samples as received. Process water was also received and all three samples were mixed to 65% solids content for the large strain consolidation tests. The Cleaner Tails were very viscous which significantly affected its settlement properties.

3 Specific Gravity Test Results

Table 2 shows the specific gravity test results. As the Cleaner Tails did not have as high a specific gravity as found in previous testing programs by Klohn Crippen Berger Ltd, the test was performed by two different methods. The results from the two tests are similar.

4 Particle Size Distribution Test Results

Figure 1 shows the particle size distribution by sieve and hydrometer testing for the three samples. It should be noted that the specific gravity and particle size distribution for the mixed sample are test results. These properties were also determined by a weighted average of the Scavenger and Cleaner test results and the results were the same as the test results.

5 Report Outline

The design solids content for the consolidation testing was 65%. As the specific gravity of the three materials is different, the initial void ratios are different. The initial void ratios for the Scavenger Tails, Cleaner Tails and Mixed Tails were 1.46, 1.74 and 1.49 respectively.

As self-weight settlement in the consolidation cells results in significant increases in solids content before any test measurements can be taken, the initial consolidation properties are determined by the hindered sedimentation tests and the compressibility standpipe tests. To achieve reasonable data from these tests, the initial solids contents are usually chosen to be lower than the design solids content of 65%. Hindered sedimentation tests in this case had initial solids contents of 60% and 65% and the compressibility settling tests, initial solids contents of 60%.

The results of the hindered sedimentation tests will be presented first followed by the compressibility settling tests. The void ratio – hydraulic conductivity measurements and the effective stress – void ratio measurements from the large strain consolidation tests will then be presented. These relationships determined by combining all of the above results will be shown with an analysis of the test results.

6 Hindered Sedimentation Test Results

Hindered sedimentation tests have to be performed at a low enough solids content that hindered sedimentation can be measured before consolidation dominates the settling process. The tests also have to be performed at a high enough solids content that segregation, that is the larger particle settling faster than the smaller particles, does not occur. Some experimentation and evaluation was therefore necessary to determine the accuracy of the test results. This evaluation will be given in the analysis section.

Table 3 gives the test results for the hindered sedimentation tests that appear to be valid. Figures 2, 3 and 4 show the settlement plots for these tests. The initial settling velocity measurements are shown in Figure 5. In Figure 3, Cleaner Tails, the two 65% solids test results plot on top of one another so they cannot be distinguished on the plot.

The hydraulic conductivity is calculated from the initial settling velocity by the following equation:

$$v_s = -\left(\frac{\gamma_s}{\gamma_w} - 1\right)\frac{k}{1+e} \qquad [1]$$

Where v_s is initial settling velocity, γ_s is unit weight of solids, γ_w is unit weight of water, k is hydraulic conductivity and e is the initial void ratio.

Figure 6 is a plot of the results in Table 3 showing the void ratio-hydraulic conductivity relationships at large void ratios.

7 Compressibility Settling Standpipe Tests

Table 4 shows the initial properties of the samples in these tests. Initial solids contents of about 60% were chosen to ensure that the lowest solids contents after settlement and consolidation were approximately 65%. The height of the standpipe was chosen so the maximum effective stress would be over 1 kPa. As the lowest stress in the large strain consolidation test will be about 0.3 kPa (under self-weight) there will be some overlap in the low effective stress region between the two tests to check the results.

The diameter of a compressibility standpipe is chosen so there is a large enough diameter /height ratio to ensure that solids friction is not a problem.

Figure 7 shows the settlement in these standpipes and Figure 8 shows the excess pore pressure at the bottom of the standpipes. When the excess pore pressure has fully dissipated indicating that consolidation is complete, the standpipe is sampled in layers to determine void ratio and effective stress with depth. These results are shown in Figures 9 to 14.

As both void ratio and effective stress are plotted against depth, this allows the void ratio to be plotted against effective stress. This plot is shown in Figure 15 which is the effective stress – void ratio relationship at very low effective stresses.

Initial hydraulic conductivities can also be determined in these standpipes from the initial settlement velocities and these are shown in Table 4 and Figure 17.

8 Large Strain Consolidation Tests

The initial height of the samples was about 90 mm at 65% solids. Self-weight settlement was about 18 mm, 12 mm and 17 mm for the Scavenger Tails, Cleaner Tails and Mixed Tails respectively. This increased the solids contents to about 74%, 70% and 73% respectively. For submerged samples about 90 mm high the effective stress at mid-height of the sample is approximately 0.3 to 0.4 kPa depending on the specific gravity and these effective stresses are used for the self-weight effective stress.

The first load in the consolidation cells is about 0.8 kPa from the submerged mass of the top plate which results in an effective stress of 1.1 to 1.2 kPa including self-weight. The load is approximately doubled for each load step up to the maximum effective stress of over 1300 kPa resulting in 12 load steps including self-weight. The samples were then unloaded in 4 load steps and the rebound measured.

Tables 5, 6 and 7 show the change in height and change in void ratio from each load step. Hydraulic conductivity tests are conducted after consolidation from each load step is complete. The results from these tests are also shown on Tables 5, 6 and 7. After self-weight has completed consolidation, the void ratio varies from a high void ratio at the surface of the sample to a much lower void ratio at the bottom. The void ratio values in the tables for self-weight are the average values. Hydraulic conductivity tests are not performed after self-weight as it is not known what void ratio controls the hydraulic conductivity.

Hydraulic conductivities at the initial void ratios can also be determined in the consolidation tests from the initial settlement velocities and these are also shown in Tables 5, 6 and 7.

The effective stress – void ratio relationships and void ratio – hydraulic conductivity relationships given in Tables 5, 6, 7 are plotted in Figures 18 to 23.

9 Combined Test Results

The effective stress – void ratio relationships from compressibility standpipe tests are plotted with those of the large strain consolidation tests for Scavenger Tails, Cleaner Tails and Mixed Tails and are shown in Figures 24, 26 and 28 respectively.

The void ratio – hydraulic conductivity relationships from the hindered sedimentation tests, the compressibility standpipe tests and the large strain consolidation tests for Scavenger Tails, Cleaner Tails and Mixed Tails are shown in Figures 25, 27 and 29 respectively. Five or four data points at high void ratios are shown on each plot. This data is from the hindered sedimentation tests and the initial settlement in the compressibility standpipe and in the large strain consolidation cell assuming that the initial settlement is hindered sedimentation.

10 Observations and Analyses

1. In the combined compressibility results in Figures 24, 26, and 28 there is a sharp break in the compressibility curves around an effective stress of 0.3 kPa to 0.4 kPa. The void ratio at this break has been defined as e_{change} and may indicate where the domination of the physio-chemical effects at large void ratios becomes overpowered by the physical interparticle effective stresses. That is, where physics starts to dominate chemistry.
2. A bi-power law relationship for compressibility expressed as Equation 2 is suggested for each tails and plotted on Figures 24, 26 and 28

$$e = \begin{cases} A_1 \sigma'^{B_{11}} & for \quad e \geq e_{change} \\ A_2 \sigma'^{B_2} & for \quad e < e_{change} \end{cases} \qquad [2]$$

Where e is void ratio, σ' is effective stress in kPa

In Equation 2, a bi-power law is used instead of a conventional single power law because a single power law can not fit the data above and below e_{change}. Different A

and B values are used for the void ratios above e_{change} and below e_{change}. These values are shown in Table 8.

3. The compressibility standpipe test data for Cleaner Tails does not match the large strain consolidation test data (Figure 26). It is felt that this tails is so viscous that side friction in the compressibility standpipe was so large that it prevented the material settling so the measured void ratios are too large. The highest void ratio data point (at the surface of the tails in the standpipe) may be representative as there would be little friction at the surface of the material.
4. In the combined hydraulic conductivity results in Figures 25, 27 and 29 there is considerable scatter in the 4 or 5 test results at high void ratios. This data is calculated assuming that the initial settlement is only hindered sedimentation and that consolidation has no effect on the settlement rate. If consolidation is occurring as well as hindered sedimentation the initial settling velocity would be too low and the calculated hydraulic conductivity too small. The largest hydraulic conductivity values may, therefore, be the most representative. At fairly high solids contents around 65% as used in these tests, the likelihood of this occurring is greater.
5. The hydraulic conductivity values measured after self-weight consolidation appear too small for the Scavenger tails and mixed tails (Figure 25 and 29). The void ratios shown after self-weight consolidation are the average void ratios of the samples at this time. The actual void ratios would vary from a higher value at the top of the sample to a lower value at the bottom. As well, the hydraulic conductivity would vary from a higher value at the top to a lower value at the bottom. The smaller void ratio at the bottom probably governs the water flow through the sample resulting in a smaller value of hydraulic conductivity than would be found for the average void ratios.
6. For the Cleaner Tails, the hindered sedimentation test results are quite low (Figure 27) as the initial settling velocity was low. This may be due to the high viscosity of this material resulting in side friction in these small diameter standpipes slowing the settling rate. The larger diameter compressibility standpipe and consolidation cell had higher initial settling rates and may be more representative.

7. A power law relationship for hydraulic conductivity expressed as Equation 3 is suggested for each tails and plotted in Figures 25, 27 and 29. The *C* and *D* values are shown in Table 8.

$$k = Ce^{D} \qquad [3]$$

Where *e* is void ratio and *k* is hydraulic conductivity in cm/s.

8. Figures 30 and 31 show respectively the compressibility and hydraulic conductivity for all 3 tails. The similarity or dissimilarity between the test results are a guide to representative or non-representative data points.

J. Don Scott, Ph.D., Professor Emeritus August 14, 2009
Silawat Jeeravipoolvarn, M.Sc. Ph.D. Candidate

Geotechincal Engineering Centre
Dept. of Civil and Environmental Engineering
University of Alberta

Table 1 Resolution project tailings materials

ailings	Initial S%	Initial w%	Initial void ratio	Gs
Scavenger Tails	64.5	55.1	1.49	2.71
Cleaner Tails	73.6	35.9	1.16	3.23
Mixed Tails (85% Scavenger 15% Cleaner)	N/A	N/A	N/A	2.79

Table 2 Specific gravity tests on Resolution project tailings

Tailings	Scavenger	Scavenger	Cleaner	Cleaner	Mixed
Method of air removal	Suction	Boiling + Suction	Suction	Boiling + Suction	Suction
Specific gravity, Gs	2.71	2.72	3.22	3.24	2.79
Average Gs	2.71		3.23		2.79

Table 3 Summary of hindered sedimentation tests

Tailings	Solids content (%)	Void ratio	Initial velocity (m/D)	k (m/D)	k (cm/s)
Cleaner Tails 60%	59.9	2.16	0.0403	0.0301	3.49E-05
Cleaner Tails 65% no.1	65.0	1.74	0.0220	0.0143	1.65E-05
Cleaner Tails 65% no.2	65.0	1.74	0.0196	0.0127	1.47E-05
Scavenger Tails 60%	60.4	1.77	1.0380	0.7762	8.98E-04
Scavenger Tails 65%	65.4	1.43	0.9352	0.6135	7.10E-04
Scavenger Tails 68%	68.0	1.27	0.1781	0.1091	1.26E-04
Mixed 60%	60.09	2.15	0.9365	0.6963	8.06E-04
Mixed 65%	65.15	1.45	0.1670	0.1103	1.28E-04

Table 4 Compressibility standpipe tests on Scavenger, Cleaner and Mixed Tails

Tailings	Solids content (%)	Void ratio	Initial velocity (m/D)	k (m/D)	k (cm/s)
Cleaner Tails 60%	60.1	2.14	0.1181	0.0877	1.02E-04
Scavenger Tails 60%	60.7	1.75	1.5080	1.1197	1.30E-03
Mixed Tails 60%	61.0	1.78	0.5708	0.4196	4.86E-04

Table 5 Large strain consolidation test for Scavenger tails

Load	Height (mm)	ΔH (mm)	Effective stress (kPa)	Void Ratio, *e*	Δ*e*	Hydraulic conductivity, k (cm/s)
-	89.7	-	-	1.46	-	2.99E-04
Self-weight	71.8	17.9	0.3	0.97	0.49	-
1	67.0	4.8	1.1	0.84	0.13	2.66E-05
2	65.1	1.9	1.8	0.79	0.05	2.22E-05
3	63.7	1.3	2.9	0.75	0.04	1.95E-05
4	61.8	1.9	5.7	0.70	0.05	1.59E-05
5	59.9	1.9	10.7	0.64	0.05	1.36E-05
6	58.7	1.2	25.9	0.61	0.03	1.09E-05
7	57.8	0.9	50.1	0.59	0.02	9.94E-06
8	56.5	1.3	100.6	0.55	0.04	8.58E-06
9	55.5	1.0	249.7	0.52	0.03	7.03E-06
10	53.7	1.8	650.2	0.48	0.05	5.26E-06
11	52.2	1.5	1339.0	0.43	0.04	4.17E-06
12	52.5	-0.3	495.6	0.44	-0.01	-
13	53.4	-0.8	102.5	0.46	-0.02	-
14	53.9	-0.5	25.9	0.48	-0.01	-
15	54.4	-0.5	1.1	0.49	-0.01	-

Table 6 Large strain consolidation test for Cleaner tails

Load	Height (mm)	ΔH (mm)	Effective stress (kPa)	Void Ratio, *e*	Δ*e*	Hydraulic conductivity, k (cm/s)
-	95.8	-	-	1.74	-	2.70E-05
Self-weight	84.4	11.4	0.4	1.41	0.33	-
1	79.3	5.1	1.2	1.27	0.15	1.21E-05
2	76.9	2.4	1.8	1.20	0.07	9.81E-06
3	74.6	2.3	3.0	1.13	0.06	8.22E-06
4	71.5	3.1	5.8	1.04	0.09	6.40E-06
5	69.4	2.0	10.8	0.99	0.06	5.21E-06
6	66.7	2.7	25.5	0.91	0.08	3.87E-06
7	65.2	1.5	50.3	0.86	0.04	3.23E-06
8	63.5	1.7	100.8	0.82	0.05	2.81E-06
9	61.2	2.3	249.7	0.75	0.07	2.16E-06
10	58.5	2.7	650.4	0.67	0.08	1.52E-06
11	56.2	2.3	1340.4	0.60	0.07	1.14E-06
12	56.7	-0.5	495.6	0.61	-0.01	-
13	57.9	-1.2	101.3	0.65	-0.03	-
14	58.5	-0.7	26.8	0.67	-0.02	-
15	59.0	-0.5	1.2	0.68	-0.01	-

Table 7 Large strain consolidation test for Mixed tails

Load	Height (mm)	ΔH (mm)	Effective stress (kPa)	Void Ratio, *e*	Δ*e*	Hydraulic conductivity, k (cm/s)
-	91.4	-	-	1.49	-	2.14E-04
Self-weight	74.5	16.9	0.3	1.03	0.46	-
1	69.5	5.0	1.1	0.90	0.14	2.13E-05
2	67.5	2.0	1.8	0.84	0.05	1.74E-05
3	65.7	1.8	2.9	0.79	0.05	1.46E-05
4	64.1	1.6	5.9	0.75	0.04	1.16E-05
5	62.6	1.5	10.9	0.71	0.04	9.70E-06
6	60.3	2.4	25.0	0.64	0.06	8.04E-06
7	59.2	1.1	49.7	0.61	0.03	6.69E-06
8	58.0	1.2	100.1	0.58	0.03	5.57E-06
9	56.5	1.5	239.0	0.54	0.04	4.55E-06
10	54.9	1.6	642.3	0.50	0.04	3.44E-06
11	53.2	1.7	1342.8	0.45	0.05	2.53E-06
12	53.6	-0.3	501.0	0.46	-0.01	-
13	54.4	-0.9	100.4	0.48	-0.02	-
14	55.0	-0.6	25.5	0.50	-0.02	-
15	55.5	-0.5	1.1	0.51	-0.01	-

Table 8 Power law relationships for Resolution project tailings (units in kPa and cm/s)

Tailings	e_{change}	Compressibility function				Hydraulic conductivity function For all void ratios (cm/s)	
		From e_{change} to higher void ratio		From e_{change} to lower void ratio			
		A_1	B_1	A_2	B_2	C	D
Scavenger Tails	0.96	0.555	-0.457	0.860	-9.37E-02	7.500E-05	3.500
Cleaner Tails	1.40	1.060	-0.300	1.274	-0.101	5.666E-06	3.100
Mixed Tails	1.00	0.750	-0.271	0.901	-9.74E-02	4.600E-05	3.640

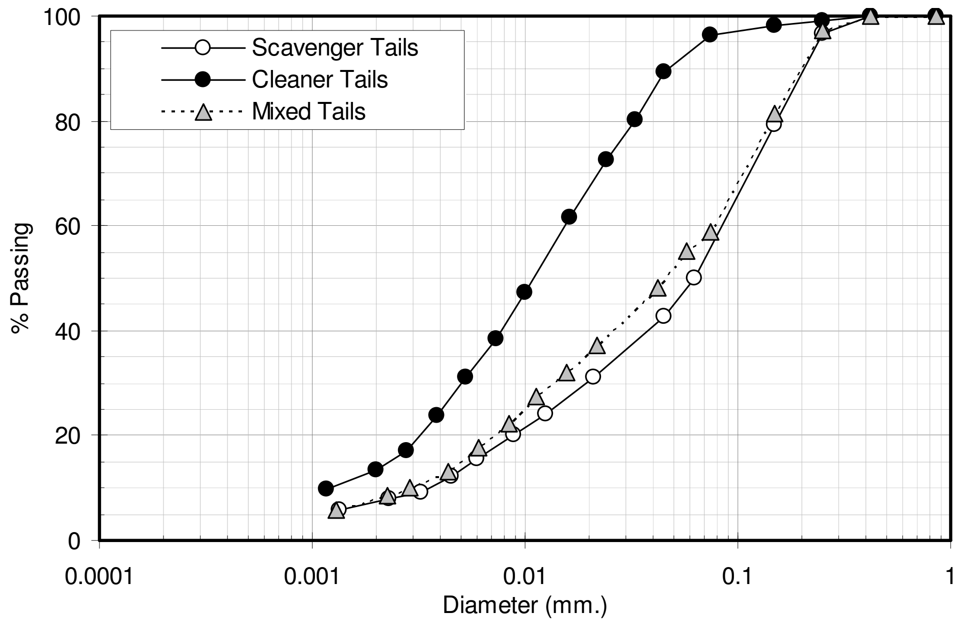

Figure 1 Particle size distribution of Scavenger, Cleaner and Mixed Tails

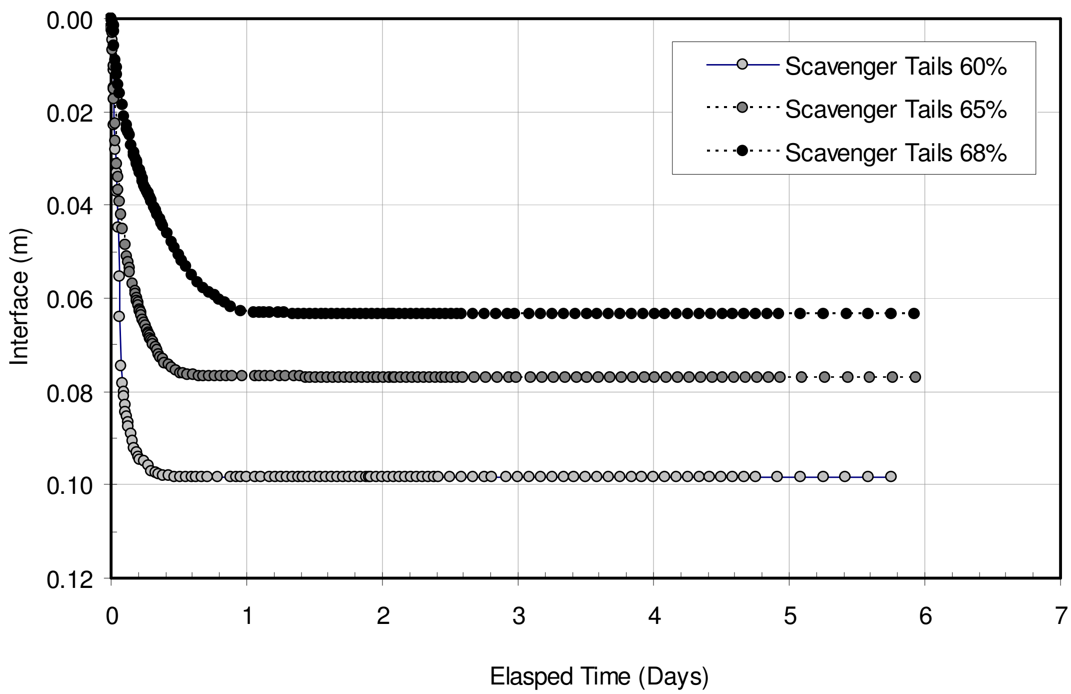

Figure 2 Hindered sedimentation tests on Scavenger Tails

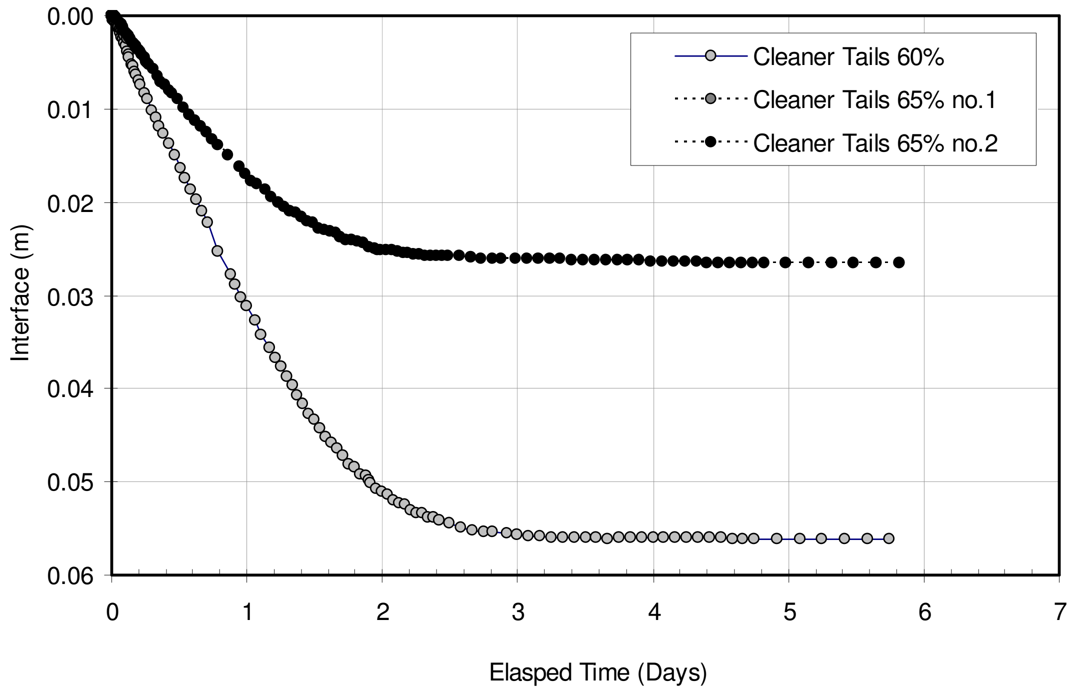

Figure 3 Hindered sedimentation test on Cleaner Tails

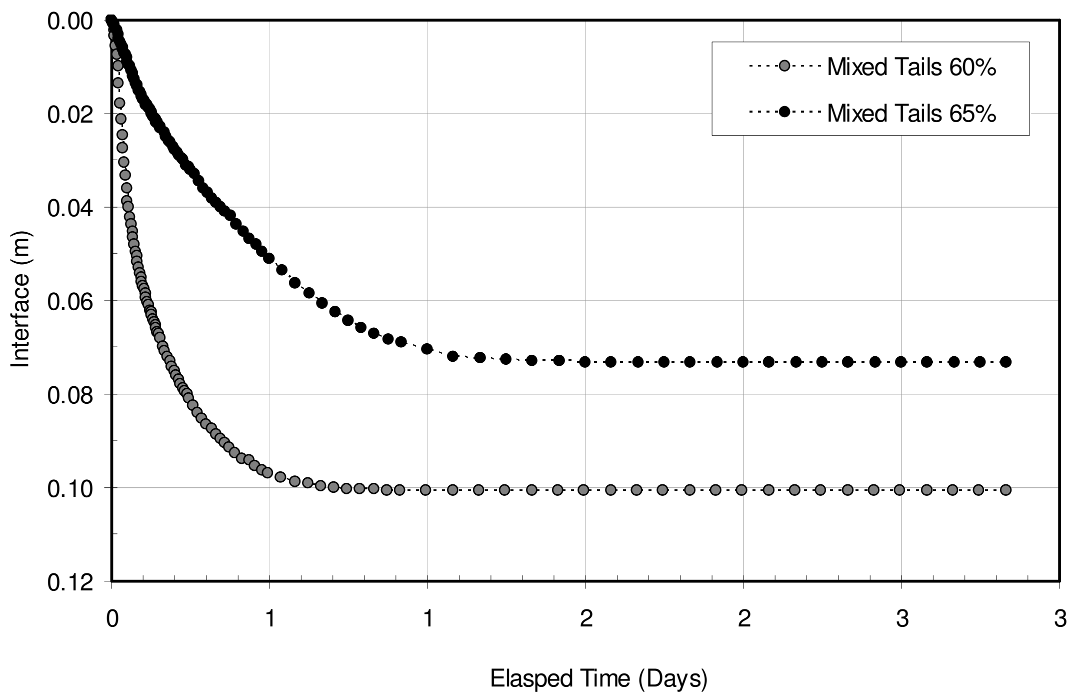

Figure 4 Hindered sedimentation tests on Mixed Tails

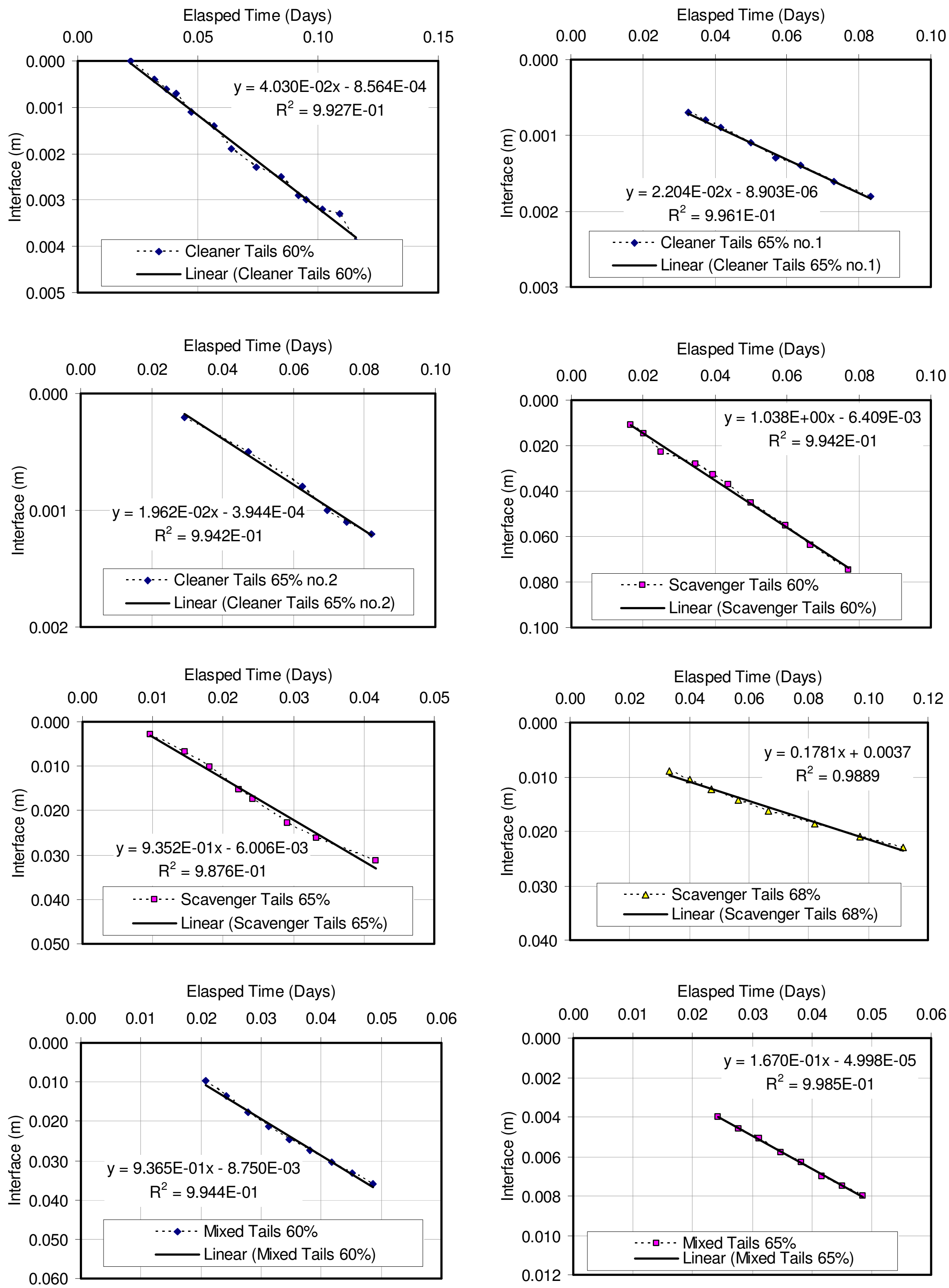

Figure 5 Initial settling velocity determination for the hindered sedimentation tests

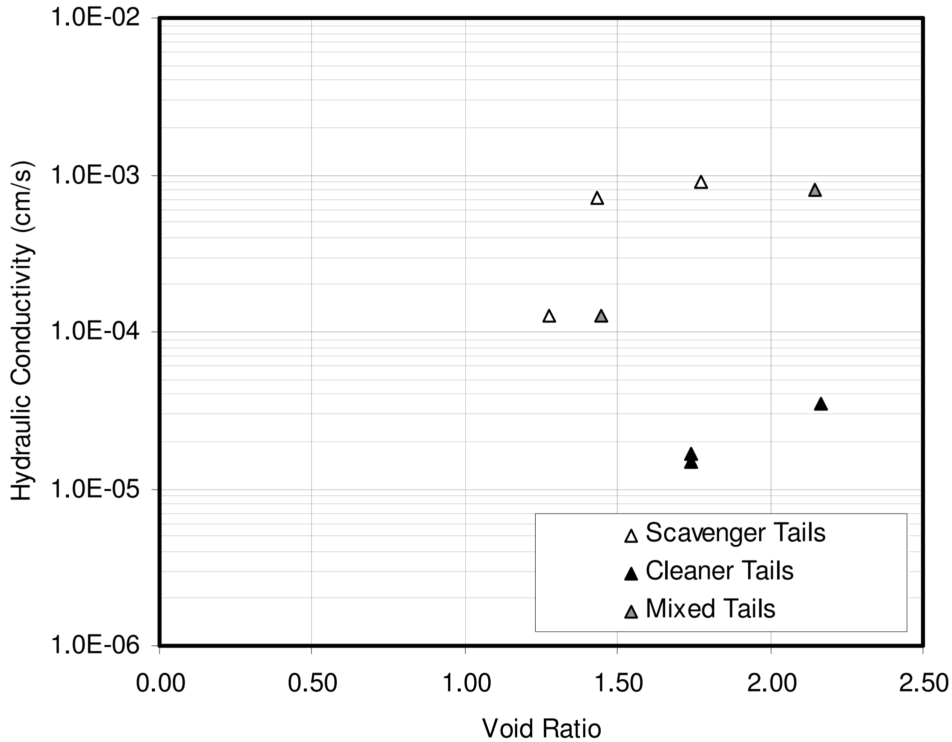

Figure 6 Hydraulic conductivity of Scavenger, Cleaner and Mixed Tails from hindered sedimentation tests

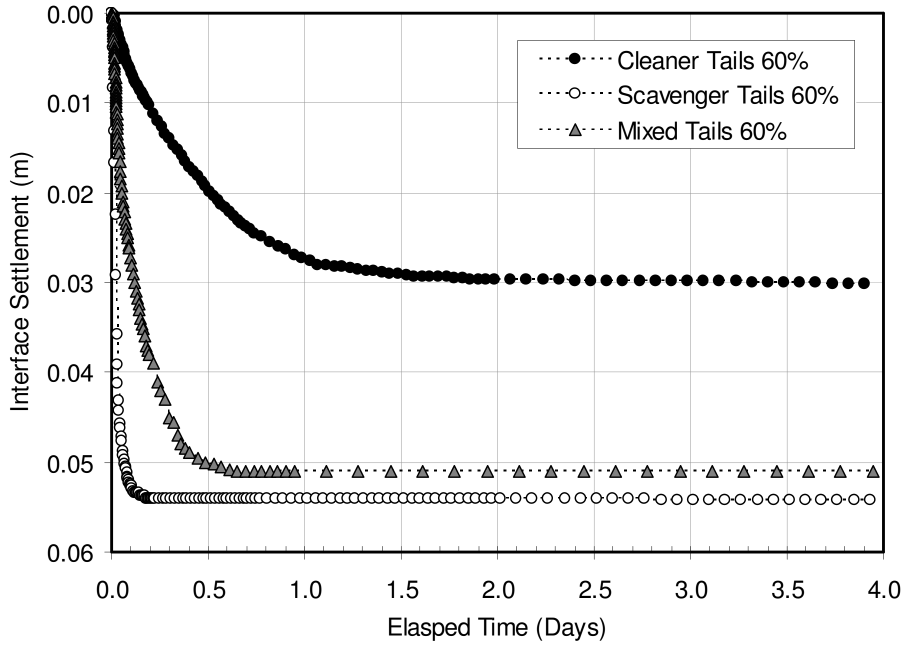

Figure 7 Interface settlement during compressibility standpipe tests

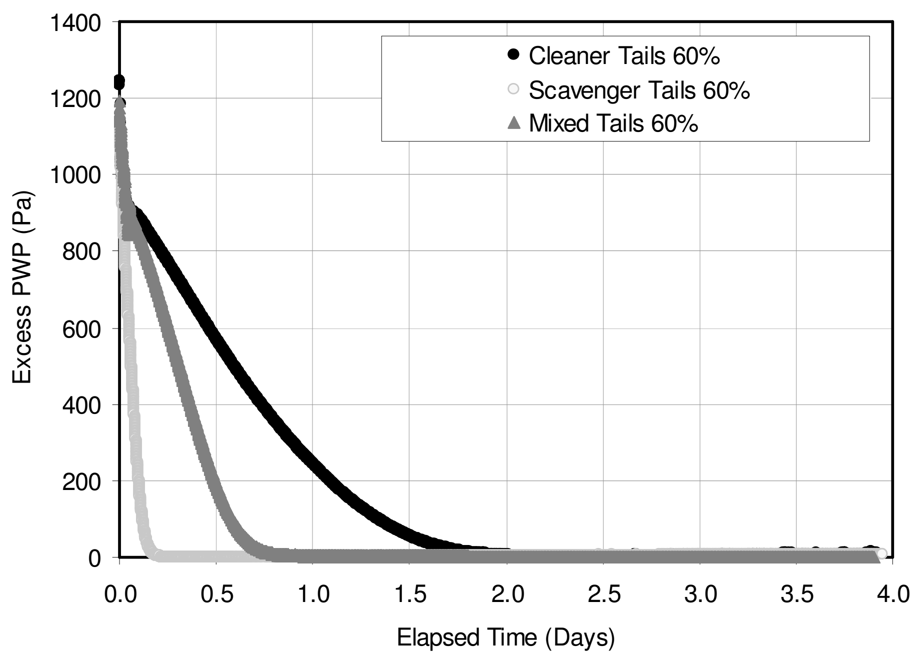

Figure 8 Excess pore pressure dissipation during compressibility standpipe tests

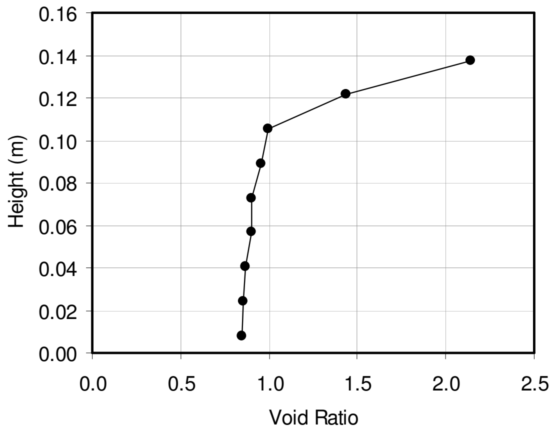

Figure 9 Void ratio profile of Scavenger Tails

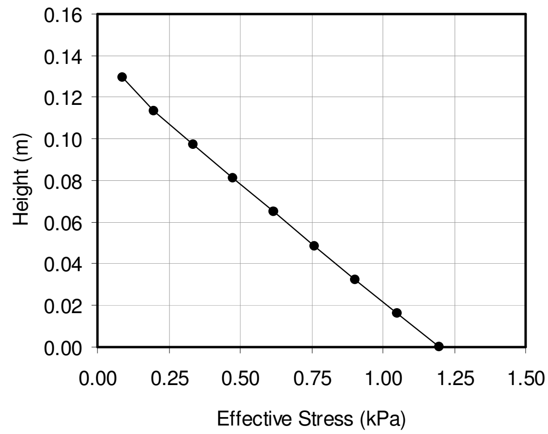

Figure 10 Effective stress profile of Scavenger Tails

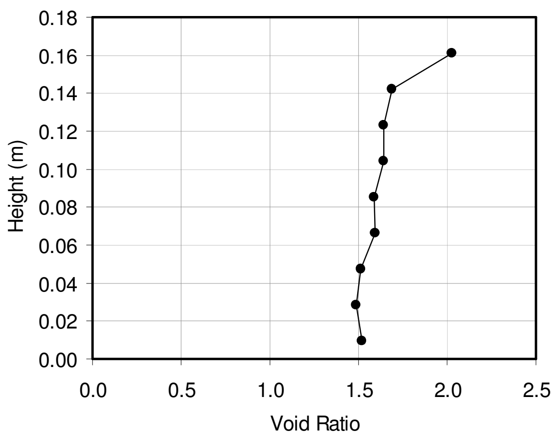

Figure 11 Void ratio profile of Cleaner Tails

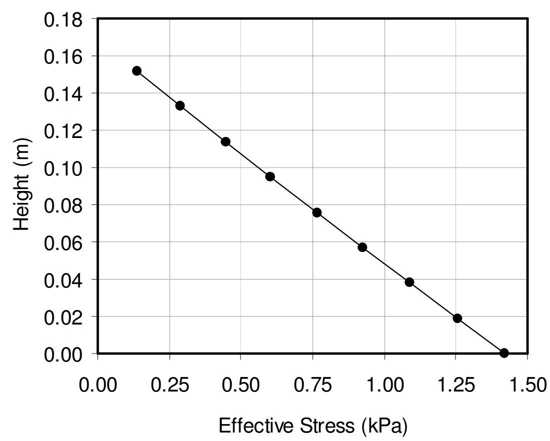

Figure 12 Effective stress profile of Cleaner Tails

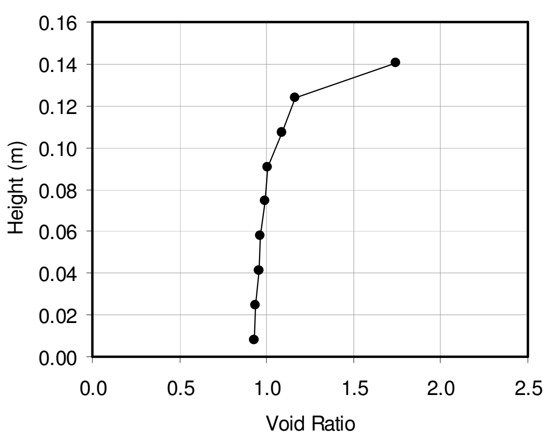

Figure 13 Void ratio profile of Mixed Tails

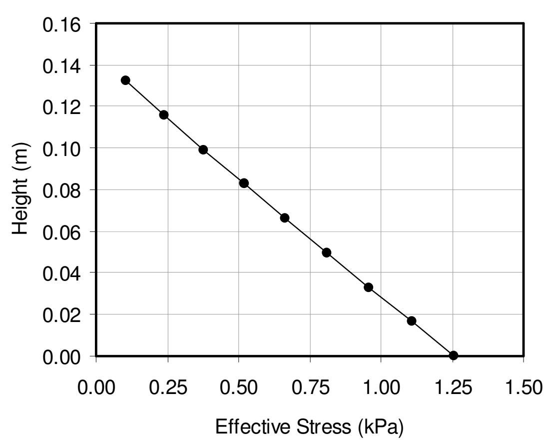

Figure 14 Effective stress profile of Mixed Tails

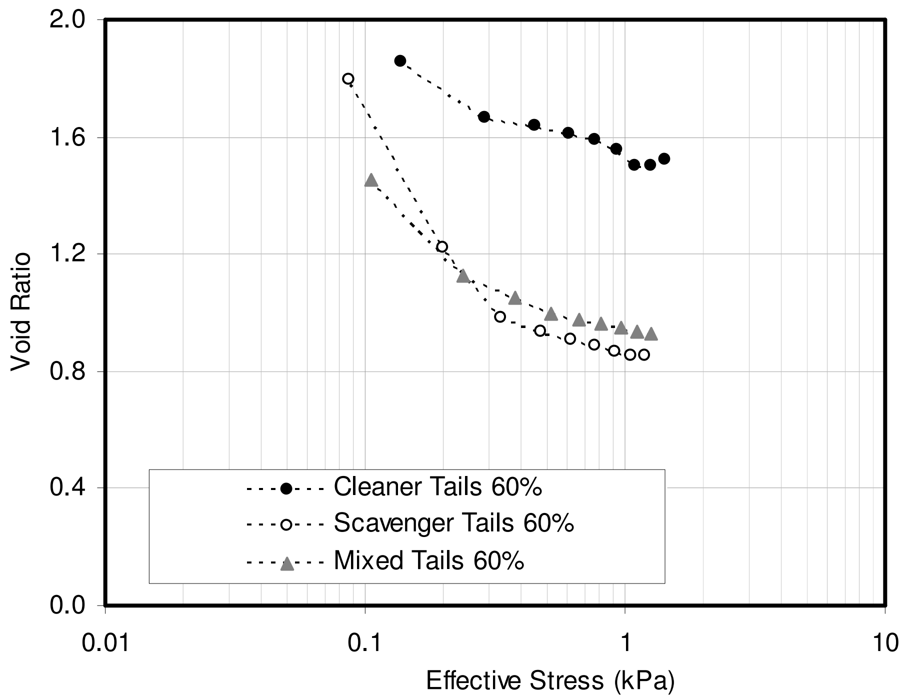

Figure 15 Compressibility of Scavenger, Cleaner and Mixed Tails from compressibility standpipe tests

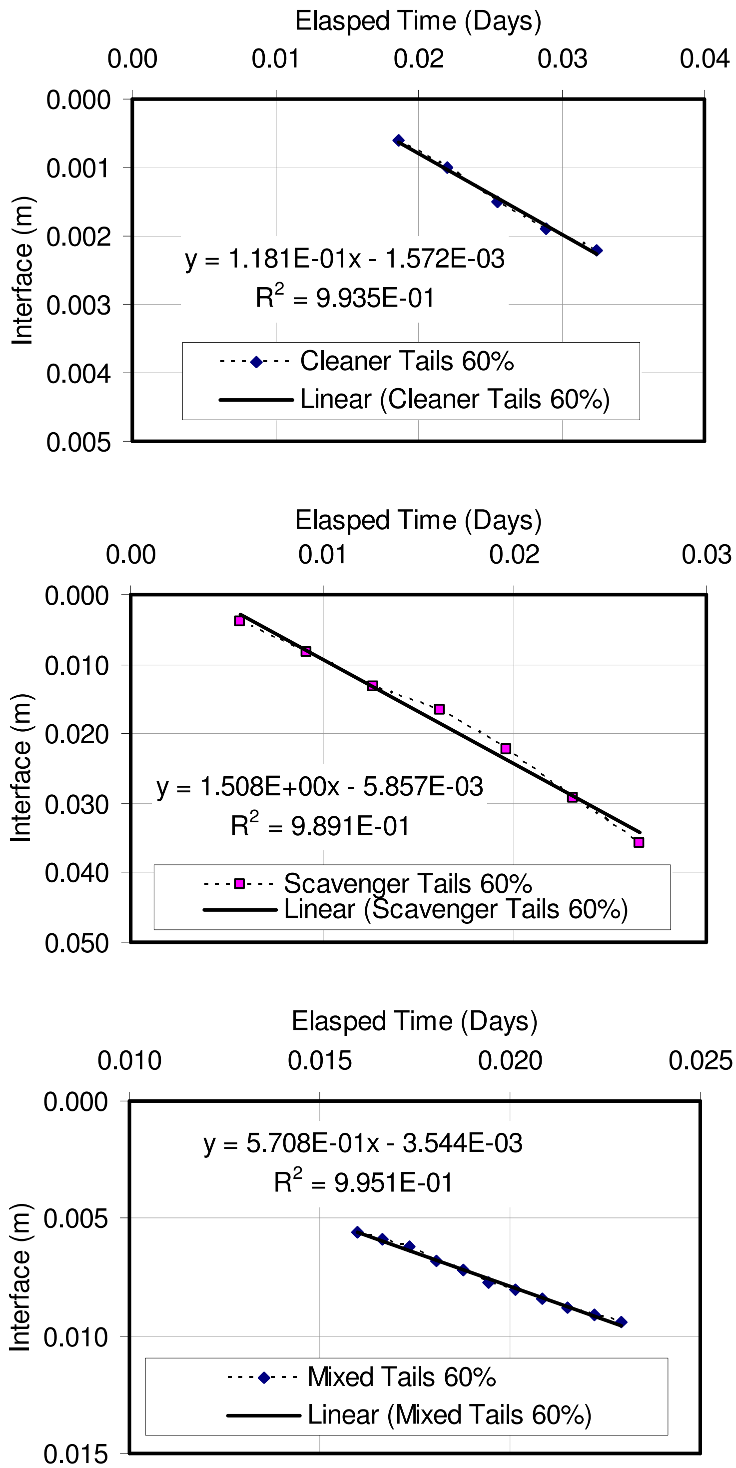

Figure 16 Initial linear settling velocity determination for compressibility standpipe tests

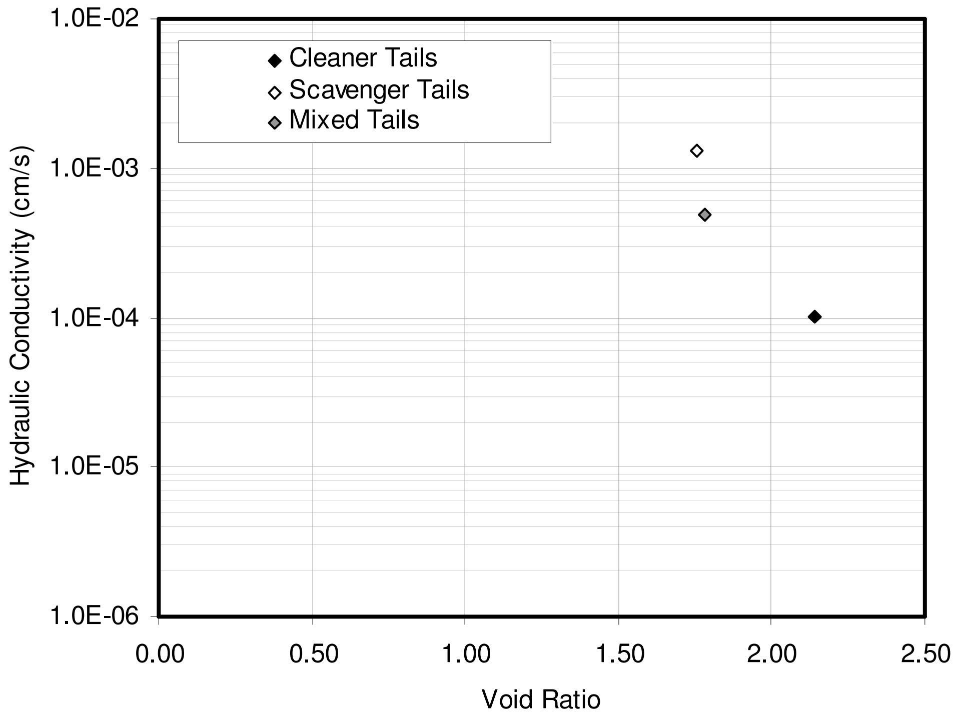

Figure 17 Hydraulic conductivity of Scavenger, Cleaner and Mixed Tails from compressibility standpipe tests

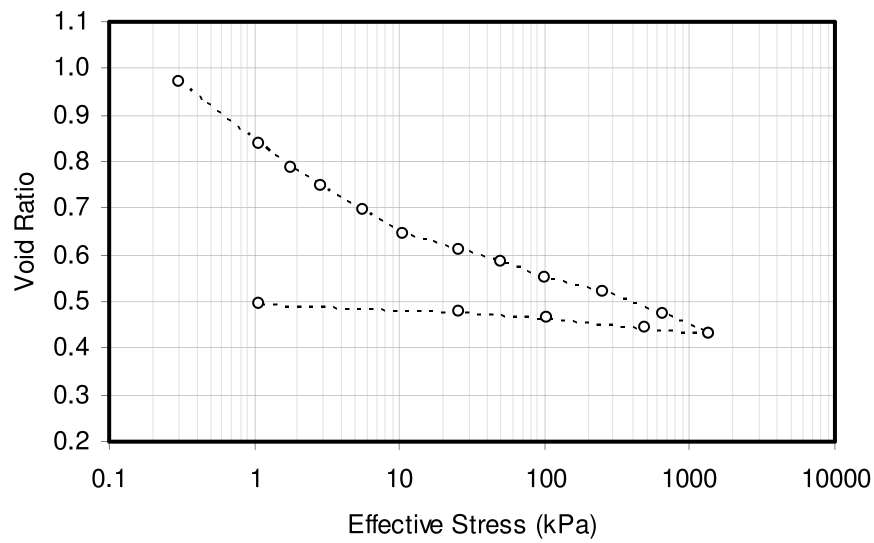

Figure 18 Compressibility of Scavenger tails from Consolidation Test

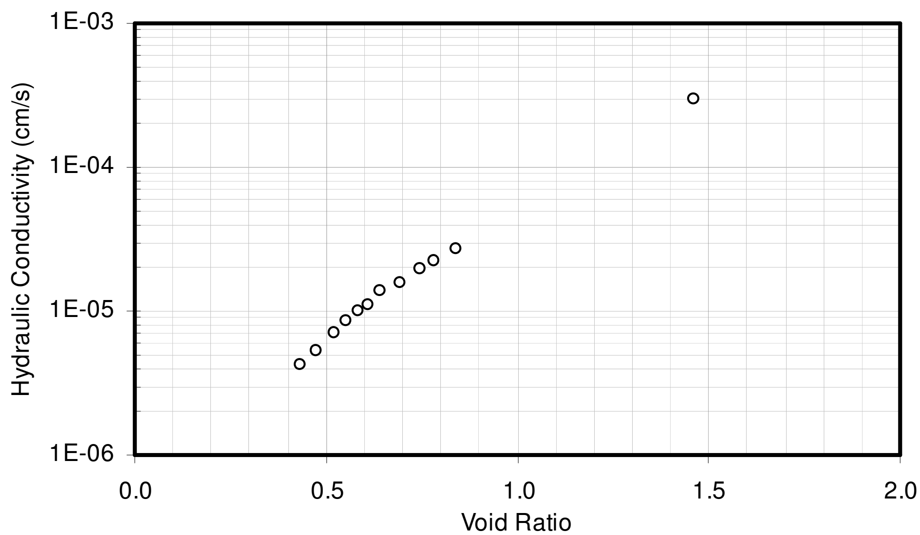

Figure 19 Hydraulic conductivity of Scavenger tails from Consolidation Test

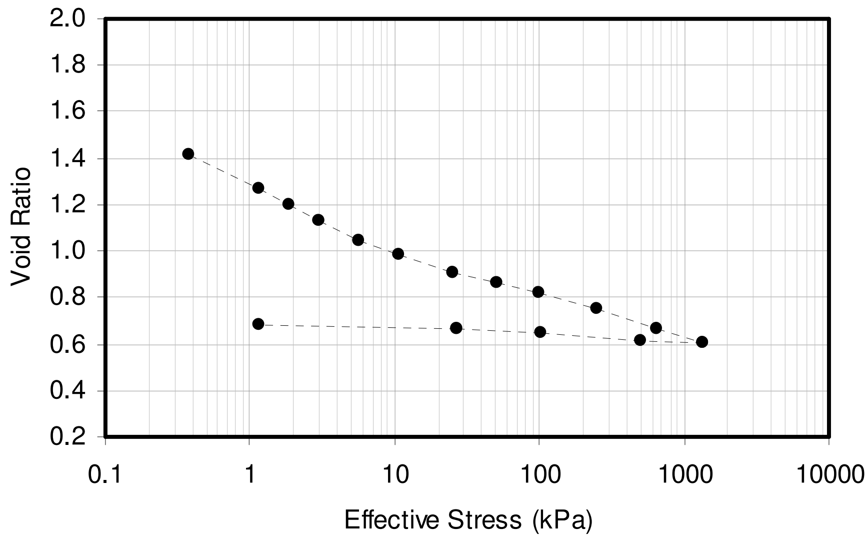

Figure 20 Compressibility of Cleaner tails from Consolidation Test

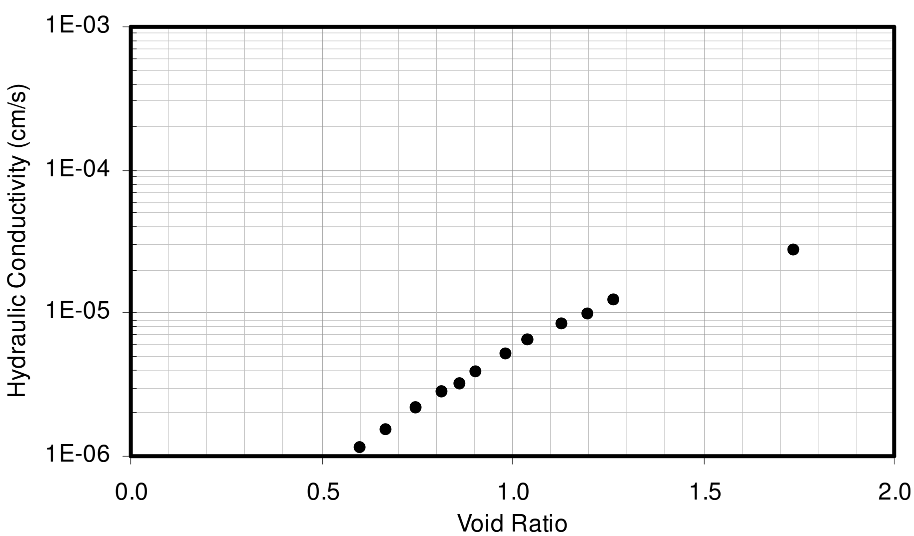

Figure 21 Hydraulic conductivity of Cleaner tails from Consolidation Test

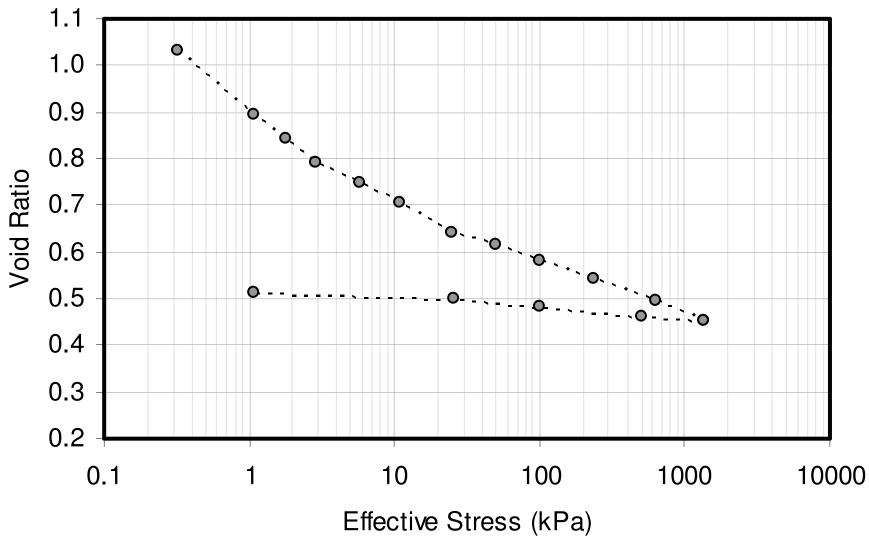

Figure 22 Compressibility of Mixed tails from Consolidation Test

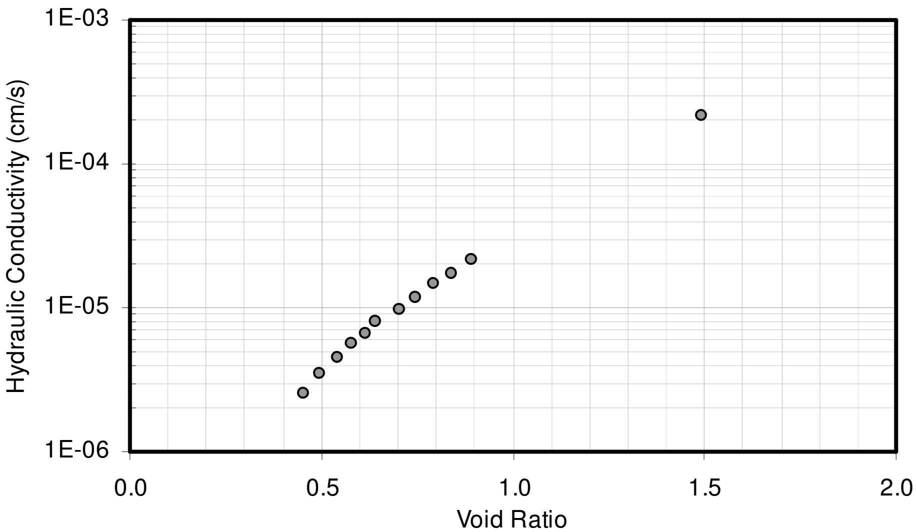

Figure 23 Hydraulic conductivity of Mixed tails from Consolidation Test

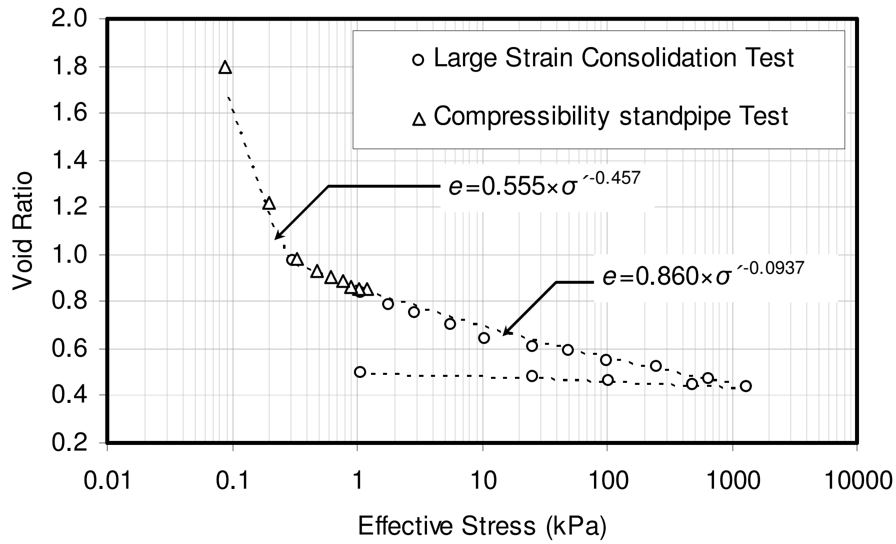

Figure 24 Combined compressibility results for Scavenger tails

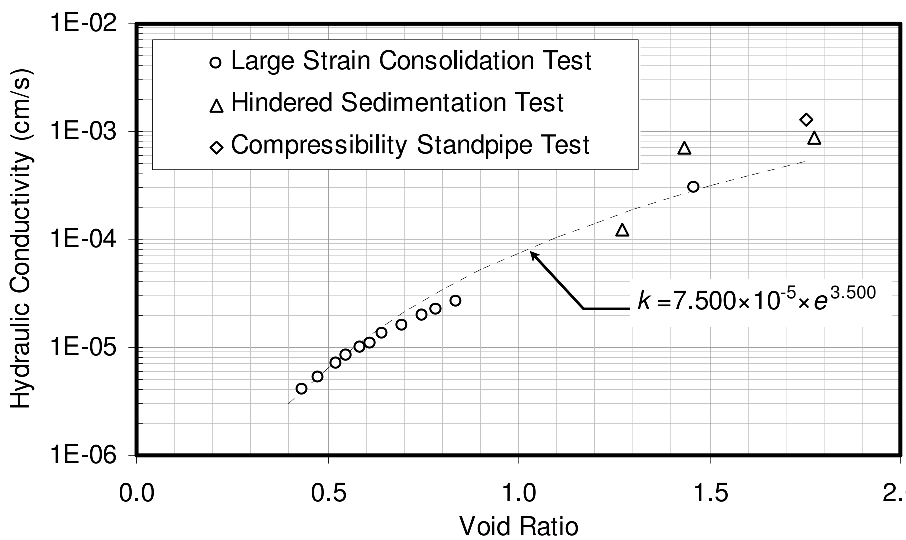

Figure 25 Combined hydraulic conductivity results for Scavenger tails

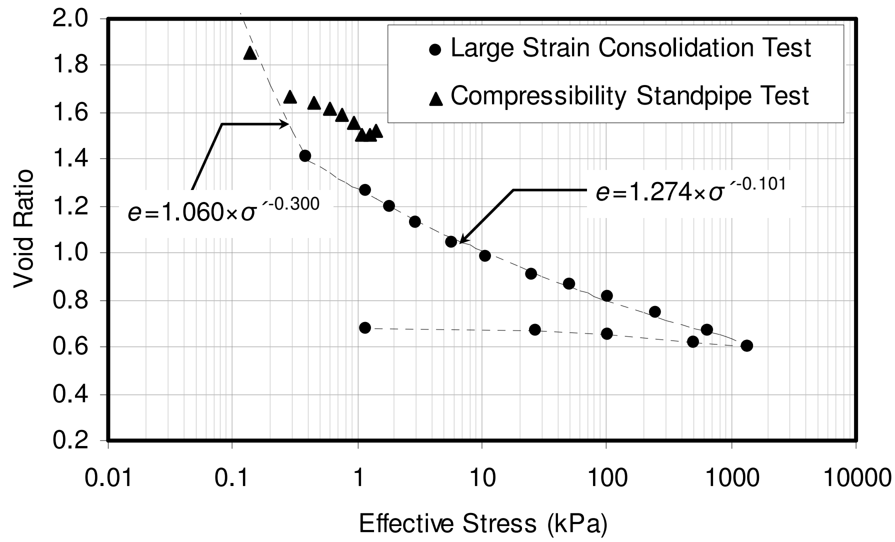

Figure 26 Combined compressibility results for Cleaner tails

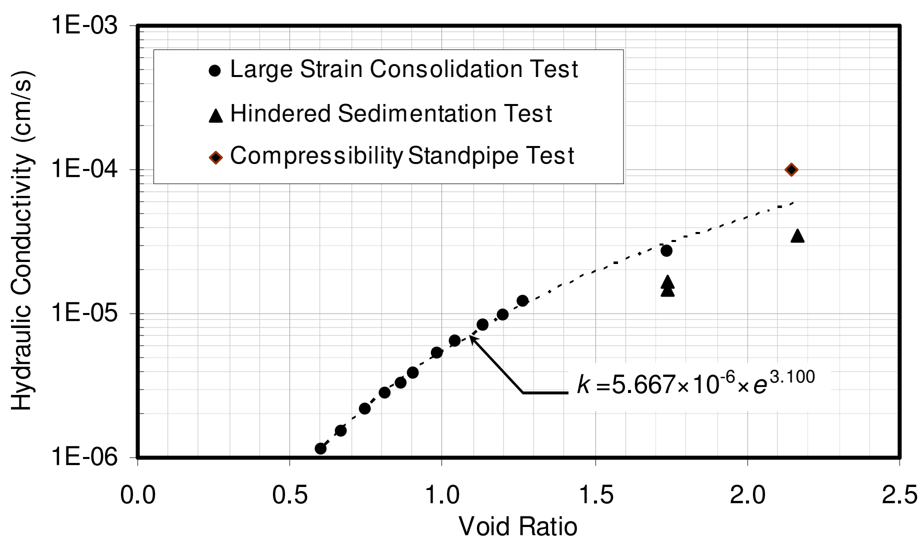

Figure 27 Combined hydraulic conductivity results for Cleaner tails

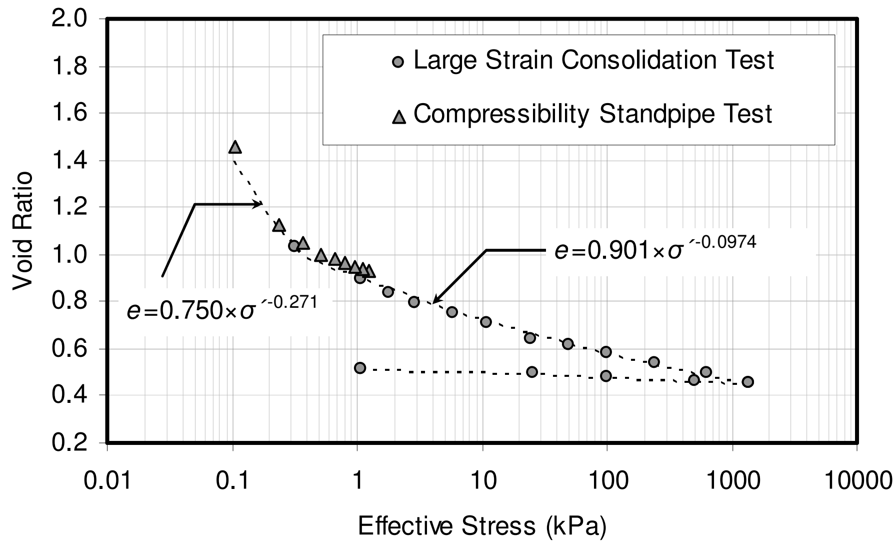

Figure 28 Combined compressibility results for Mixed tails

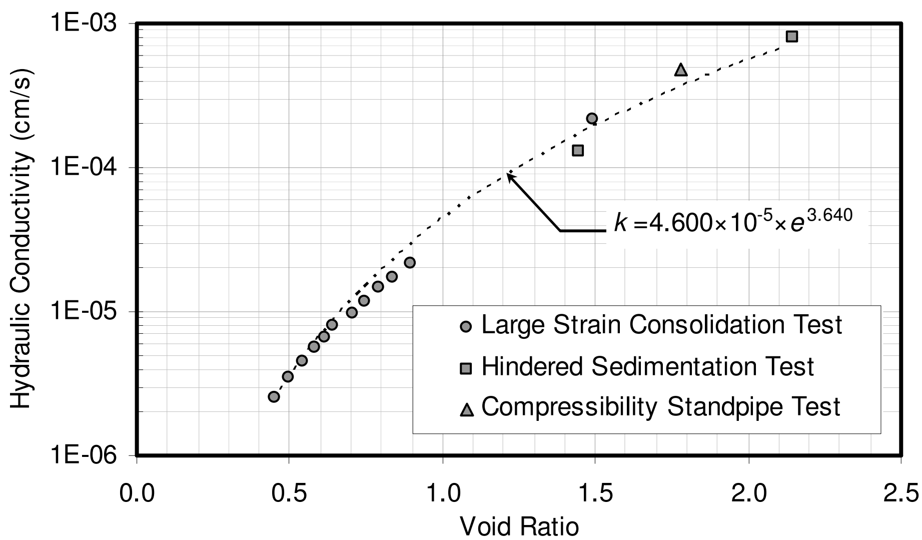

Figure 29 Combined hydraulic conductivity results for Mixed tails

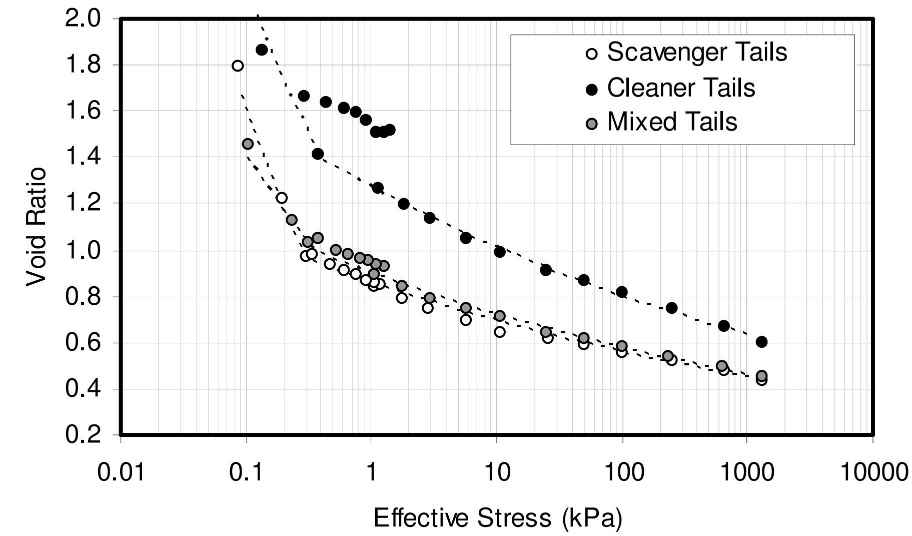

Figure 30 Compressibility of Scavenger, Cleaner and Mixed tails

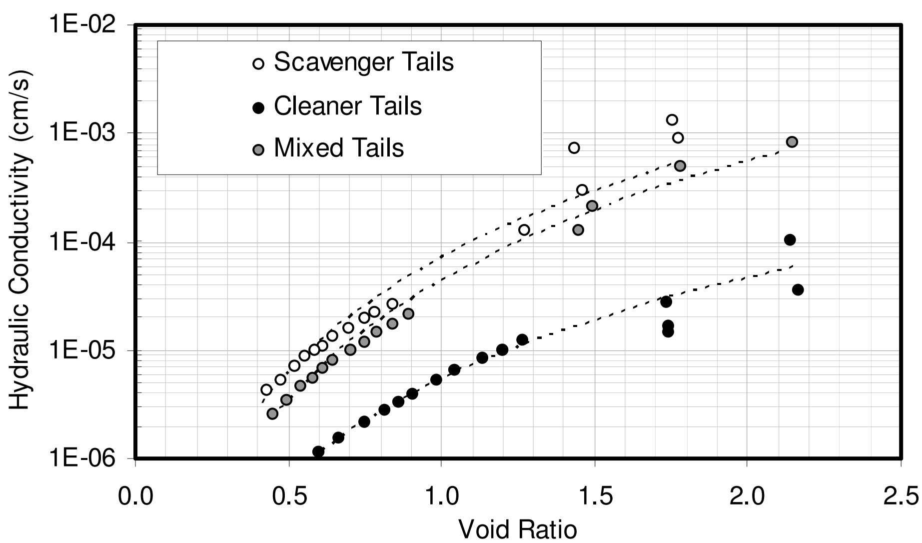

Figure 31 Hydraulic conductivity of Scavenger, Cleaner and Mixed tails

APPENDIX:
Large Strain Consolidation Test, Equipment and Numerical Modeling

Geotechnical Centre, University of Alberta

1. Test Procedure

1.1 LARGE STRAIN CONSOLIDATION TEST

A large strain consolidation test is performed on slurried materials which are too soft and undergo too much volume change for testing in a standard consolidation apparatus. As well, materials that undergo large strains do not follow the Terzaghi consolidation equations. Specifically, the coefficient of permeability or hydraulic conductivity can not be calculated from volumetric strain-time measurements and must be directly measured.

The large strain consolidation apparatus used in the University of Alberta Geotechnical Centre Laboratory confines the slurried material so it can be tested at any water content. As large volume changes take place with very small stress changes at high water contents, the first applied stress, including the self-weight of the slurry, can be about 1 kPa.

Cells to confine the sample are of various sizes and a typical cell is 140 mm inside diameter and can accommodate samples up to 200 mm high. The initial height of the sample is chosen so that the diameter-height ratio is approximately 2.5, to minimize wall friction, when effective stresses become significant above 10 kPa applied vertical stress. For a sample with an initial water content of about 75% (void ratio of 2.0), it is estimated that an initial height of 80 mm to 90 mm would result in a height of about 50 mm at effective stresses over 10 kPa, based on consolidation tests previously performed in our laboratory. The height should be as large as possible, keeping in mind the diameter-height ratio, to obtain accuracy in the permeability test. An initial height of 80 mm to 90 mm appears to satisfy both requirements. The diameter-height ratio under these conditions has been found to be approximately 2.6 at a vertical effective stress of 10 kPa and over 3.0 at a vertical effective stress of 250 kPa. For samples with initial water contents greater than 75% a greater initial height is used.

The permeability is measured at the end of consolidation for each load step. An upwards flow constant head test is performed with the head loss being kept small enough so that seepage forces will not exceed the applied stress and cause further consolidation or sample fracturing during the permeability test. For example, for a 85 mm high specimen, consolidated under a vertical stress of 1 kPa, the head loss should not be greater than 200 mm, which results in a hydraulic gradient of 2.4. Generally, the head loss and hydraulic gradient are kept to less than half this maximum calculated value. Such small hydraulic gradients may require fairly long permeability tests. The inflow is monitored for at least 2 to 3 hours to ensure that steady state flow conditions are obtained.

The test results are presented in a plot of void ratio as a function of vertical effective stress and in a plot of hydraulic conductivity as a function of void ratio. Curve fits to these two plots define the material relationships to be used in large strain consolidation numerical modeling of tailings ponds, thickener vessels or slurry deposits.

1.2 PERMEABILITY AT HIGH VOID RATIO STANDPIPE TEST

The relationship between hydraulic conductivity and void ratio needs to be determined over the full range of water contents or void ratios that the field tailings deposit experiences. The initial volume change of high water content tailings (over 75% water content), however, is so large that this relationship cannot be measured at high void ratios over 2.0 in a step load consolidation test. As the initial volume change is a major part of the volume change during field deposition, the modeling parameters at low stresses must be determined by a different test procedure to allow field predictions to be made with confidence. The test procedure developed for this purpose uses a series of standpipes containing tailings at very high water contents.

A standpipe test on a high water content slurry progresses through three stages. When the standpipe is filled with the slurry, a flocculation period or induction time may elapse during which no measurable settlement takes place. Following this period, settlement in the form of hindered sedimentation may occur for a short time and then long term consolidation settlement continues until the excess pore pressures are fully dissipated. During hindered sedimentation the tailings remain at the initial void ratio and little or no effective stress exists in the settling material. The settlement rate during this period can be used to calculate the hydraulic conductivity and, therefore, a relationship between the tailings initial void ratio and hydraulic conductivity can be determined. Performing such tests with different initial water contents (void ratios) allows the determination of the hydraulic conductivity relationship for large initial void ratios. The values can then be added to the data from consolidation tests to give the relationship between void ratio and hydraulic conductivity over the complete water content range that will occur in field deposits.

At large void ratios the hydraulic conductivity dominates large strain consolidation numerical modeling of tailings pond deposits and the effective stress relationship is not as important. Therefore, the effective stress-void ratio relationship determined from the step load consolidation test can be extrapolated to large void ratios with little error.

1.3 COMPRESSIBILITY STANDPIPE TEST

If the effective stress-void ratio relationship is required at large void ratios, a compressibility standpipe test can be performed. Void ratios at vertical stresses from a fraction of a kPa up to 1 kPa can be measured with this test and added to the data from consolidation tests.

2. Test Apparatus

2.1 CONSOLIDATION TEST

The vertical stress in the large strain consolidation apparatus is applied by dead load acting on the loading ram up to 8 kPa and by compressed air in a bellofram acting on the loading ram up to the maximum stress of 750 kPa to about 1300 kPa. The initial set up of the apparatus before any load is applied is shown in Figure A1. Only self-weight of the sample exists at this stage. Immediately after the cell is set up the submerged piston dead load is applied. The total effective stress at this stage at mid-height of the sample is about 0.93 kPa which is composed of 0.24 kPa from the mass of the sample and 0.69 kPa from the submerged mass of the piston. After the consolidation is complete from this effective stress, an upward flow constant head permeability test is conducted. Subsequent loads are approximately doubled for each load step. Effective stresses up to 8 kPa are applied by dead loads acting on the piston as shown in Figure A2. Effective stresses over 8 kPa are applied in a loading frame by an air pressure bellofram as shown in Figure A3.

Vertical strain is measured with a LVDT. The samples are usually drained from the top and bottom to conduct the test as rapidly as possible. For special cases only top drainage is used and pore pressures at the base of the sample are measured as shown in the figures. The load is maintained until the vertical strain and/or base pore pressure dissipation are significantly completed before adding the next load. The horizontal tube for inflow to the bottom of the sample during permeability testing is positioned at a height to give the required head across the sample as shown in Figures A2 and A3. All measurements are continuously recorded manually and on a data logger, downloaded and plotted.

2.2 PERMEABILITY STANDPIPE TESTS

The hydraulic conductivity standpipe tests only have to run for a few hours to the end of the hindered sedimentation phase and, during this time, effective stresses will be close to zero. The diameter-height ratio of the standpipes, therefore, is not important and standpipes with a height of 35 cm and a diameter of 6 cm are used. The only measurement taken is the slurry-water interface settlement with time.

Care must be taken to ensure that the slurry material in standpipe tests at large void ratios or high water contents does not segregate during the test. That is, the material remains homogeneous and the larger particles do not settle preferentially. If in doubt, segregation standpipe tests can be performed to determine the segregation boundary for the material. Segregation depends on the grain size distribution of the tailings material, the addition of flocculants or coagulants as well as the void ratio.

2.3 COMPRESSIBILITY STANDPIPE TEST

To determine the effective stress-void ratio relationship at very low effective stresses, a large diameter standpipe is filled with tailings at the initial water content, allowed to consolidate under self-weight and when consolidation is complete, sampled in layers to determine the effective stress and void ratio with depth. The test standpipe used is 20 cm in diameter and is filled to a height of 26 cm. At large void ratios the effective stress is small even after consolidation and the diameter-height ratio is satisfactory to prevent significant wall friction. The sample is allowed to settle under self-weight and pore pressures are monitored at the base. Consolidation is considered complete when the excess pore pressure at the base has fully dissipated.

2.4 PROCESS WATER

To prevent changes to the clay mineral bonding and structure in the tailings samples which may affect settlement, compressibility and hydraulic conductivity during the tests, all water added to the tailings must have the same water chemistry as the pore water in the tailings. The best source of such water is fresh process decant or runoff water from the tailings deposit. If necessary, the water chemistry of the tailings pore water can be determined and artificial process water can be made.

3. Numerical Modeling

In order to manage a containment pond or design a thickener for slurry materials, geotechnical engineers have to be able to predict interface settlement and the effective stress-void ratio profiles with time for the material. To achieve this, there are several models in the geotechnical field that can be used. There are a number of finite strain consolidation theories but these do not include sedimentation. The importance of combining sedimentation and consolidation into one analysis has led to many developments which can be generally divided into two categories which are geotechnical and fluid dynamic approaches. Both approaches, however, are theoretically similar. One valuable alternative approach to these models that enables the theory to predict sedimentation and consolidation is to include an interaction coefficient which takes advantage of the similarity of both phenomenon and connects them together. The result is a governing equation that can handle both the sedimentation and consolidation phases. The Geotechnical Centre at the University of Alberta has developed such a numerical model that is user friendly, simple to operate and available free online. The Geotechnical Centre will perform numerical modelling if requested or advise others on how to use the model.

The design and operation of a containment pond or a gravity thickener, however, are complicated by the mixing mechanism, complex material behaviour and the effects of chemical additives. The most important task for geotechnical engineers is to be able to define the appropriate geotechnical constitutive relationships of the material through laboratory and field experiments. It is also necessary to recognize changes in material behaviour and adapt the use of a thickener during production for maximum performance both during thickening and deposition stages.

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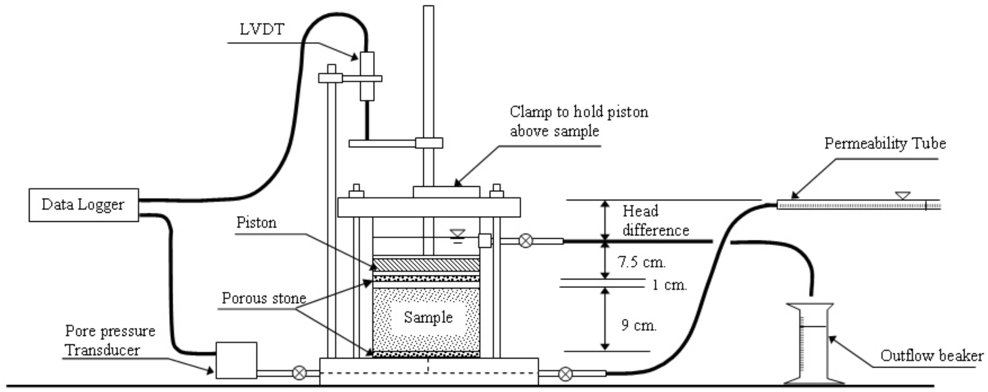
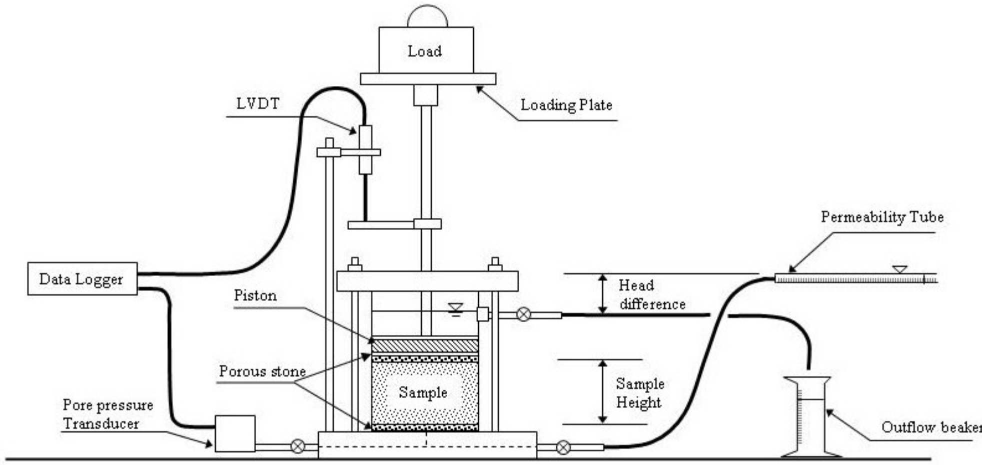


Figure A1 Initial set up of the large strain consolidation test before loading sample



FigureA2 Sample loaded with piston and dead loads up to about 8 kPa

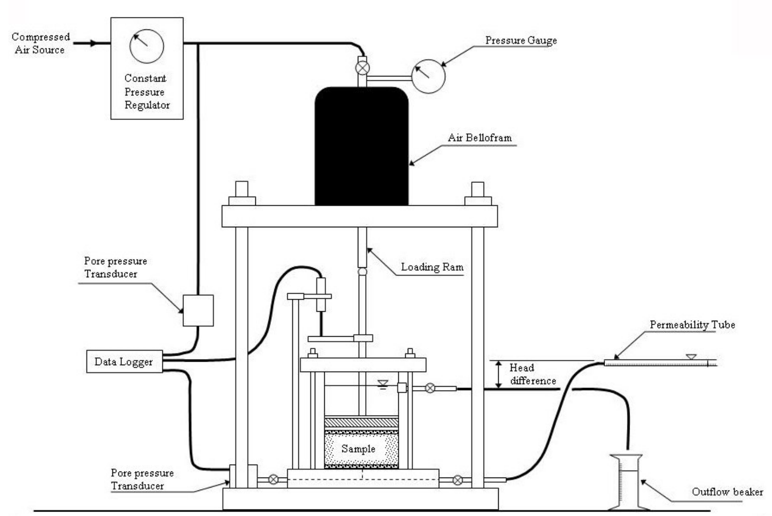


Figure A3 Sample in loading frame and loaded by bellofram up to 1000 kPa.