COMPRESSIBILITY OF MIXTURES OF MINE WASTE ROCK AND TAILINGS

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ABSTRACT
A laboratory program was undertaken to investigate the compressibility of mine waste rock, tailings, and mixtures of waste rock and tailings. Traditional methods of mine waste disposal include waste rock dumps, and tailings impoundments. The porous nature of waste rock dumps allows free flow of oxygen and water, which may promote acid rock drainage. Tailings pumped to impoundments remain semi-fluid and unconsolidated, and are subject to long-term liability due to the potential for geotechnical instability including catastrophic liquefaction failure. Mixing waste rock and tailings for disposal is examined here as an alternative mine waste disposal technique that may avoid the above problems inherent to current methods. Samples of waste rock, tailings, and a mixture of waste rock and tailings were tested in a 300-mm diameter consolidometer under double drainage conditions at applied vertical stresses of 0 kPa to 320 kPa. The mixture experienced a total strain of 8% at 350 kPa applied total stress, while the strains developed in waste rock and tailings samples for the same stress level were 5% and 50%, respectively. The waste rock and the mixture had similar values of Modified Compression Index ($C_{c\varepsilon}$) at higher applied stresses. It is concluded that the waste rock in the mixture acts to limit compressibility, and that the compressibility of the mixture was similar to that of waste rock alone due to the dominant effect of the "waste rock skeleton".

RÉSUMÉ
Lors d'une étude en laboratoire, des essais de consolidation ont été effectues sur des stériles, des résidus miniers et sur le mélange des deux. Les méthodes traditionnelles de déposition des rejets miniers, sous forme de haldes et sous forme de parcs à résidus miniers, présentent toutes les deux des problèmes structuraux. La nature poreuse des haldes de stériles favorise un libre écoulement d'oxygène et d'eau, ce qui peut provoque un drainage rocheux acide. Les résidus transportés par pompages sont semi fluide et non consolidés. À long terme, ils sont potentiellement exposés au risque d'une liquéfaction catastrophique. Le mélange des stériles et des résidus miniers est examiné ici comme une alternative de déposition des rejets miniers. Cette technique à l'avantage de palier aux faiblesses des méthodes couramment utilisées. Le changement de volume a été examine à l'aide d'essais de consolidation effectués sur des échantillons de 300 mm de diamètre sous des charges allant de 0 à 320 kPa, avec un double drainage. À une charge totale de 350 kPa, la déformation totale a été de 8 % pour le mélange, de 5 % pour les stériles et de 50 % pour les résidus miniers. Les stériles et le mélange présentent des index de compression modifiés (Cc_{ε}) semblables. Il a été conclu que les stériles réduisent le degré de consolidation dans le mélange, au point de le rendre similaire à celui des stériles seuls. Ceci est du à l'effet 'squelette' créé par les roches stériles.

1. INTRODUCTION

The current paper examines an alternative mine waste disposal technique, where waste rock and tailings are combined as a mixture. Mixing mine wastes for disposal is a form of "co-disposal", where waste rock and tailings are disposed together. Current practice of mine waste disposal typically involves segregation of waste rock and tailings into waste rock dumps and tailings impoundments. By combining waste rock and tailings as mixtures, it may be possible to avoid the problems inherent to waste rock dumps and tailings impoundments.

The largest environmental issue associated with waste rock dumps is arguably acid rock drainage, or ARD. Waste rock dumps are typically porous, with large void spaces that allow rapid infiltration of water, and the flow of air. The porous nature of waste rock dumps promotes weathering of rock that was once intact underground. Where sulphide minerals are present, waste rock may weather to produce acid rock drainage (ARD). The ARD reaction is catalysed by bacteria, and is well known. By introducing tailings to the voids of the waste rock, it may be possible to significantly reduce the rates of transport of oxygen and of water to the rock, and thereby inhibit the production of ARD.

Tailings in impoundments are subject to geotechnical instability including the potential for catastrophic liquefaction failure. Tailings are typically slurried and pumped to impoundments for disposal. Slurried tailings are initially in a fluid state that allows hydraulic transport and pumping. Tailings deposited in a fluid state may be described as low density mineral suspensions that are slow to consolidate and gain strength. Tailings in impoundments can remain semi-fluid and unconsolidated for years. By adding rock to the tailings, it may be possible to increase the rate of consolidation. Mixtures of tailings and waste rock may reduce the probability of liquefaction failure due to increased strength and stability over tailings alone.

Little research has been done on mixtures of waste rock and tailings as a disposal technique. Pumped co-disposal has been investigated (Williams and Kuganathan 1993), and implemented (Wilson 2001) for coal mine wastes, but particle sizes are limited by pump and pipe size. Mixing may accommodate larger sizes and has the potential to address issues such as ARD and tailings liquefaction failure associated with traditional methods (Wilson et al. 2000). As such, there is a need to characterize mixtures in terms of their geotechnical properties and behaviours. Theoretical developments indicate design of mixtures to obtain beneficial properties is possible (Wilson et al. 2003). The use of mixtures in soil covers has also been investigated (Fines et al. 2003). One of the fundamental behaviours studied by classical soil mechanics is volume change behaviour. The current paper presents results of a laboratory study of compressibility of waste rock, tailings, and a mixture of waste rock and tailings. The work is part of a larger program of research examining mixtures as a mine waste disposal technique.

2. EXPERIMENTAL METHOD

Waste rock, tailings, and a mixture of waste rock and tailings were examined in a large diameter slurry consolidometer. Each material was subjected to vertical effective stress increments ranging from 0 kPa to 320 kPa.

2.1 Materials

Materials tested included an altered sedimentary waste rock scalped of sizes greater than 50 mm. The rock was competent, angular with sharp edges, and is not known to be chemically reactive. The tailings used for the experiment were Carbon In Pulp (CIP) tailings taken from a gold extraction process. The tailings are autoclaved, a process that oxidizes sulphide minerals, and are assumed to be chemically unreactive for the work presented here. The tailings are fine grained, with 80% to 90% passing 75 μm. The waste rock sample was tested in an air-dry state, at approximately 0.2% water content. The CIP tailings sample was slurried at approximately 107% initial water content, or 48% Pulp Density (mass solids/mass total). The mixture tested was created from air dry waste rock, and CIP tailings at 48% Pulp Density, combined at a ratio of 4.8:1 waste rock to tailings by dry mass. The mixture was blended and placed by hand.

2.2 Testing Apparatus

A large diameter consolidometer originally constructed for testing slurries, shown in Figure 1, was used for the current testing program. The tester consists of a cylinder with upper and lower lids, and a plunger that divides the cylinder into upper and lower chambers. The inside cylinder wall is chrome-plated and polished to mate with an o-ring fitted to the outer diameter of the plunger. The inner dimensions of the cylinder allowed samples of approximately 300 mm in diameter.

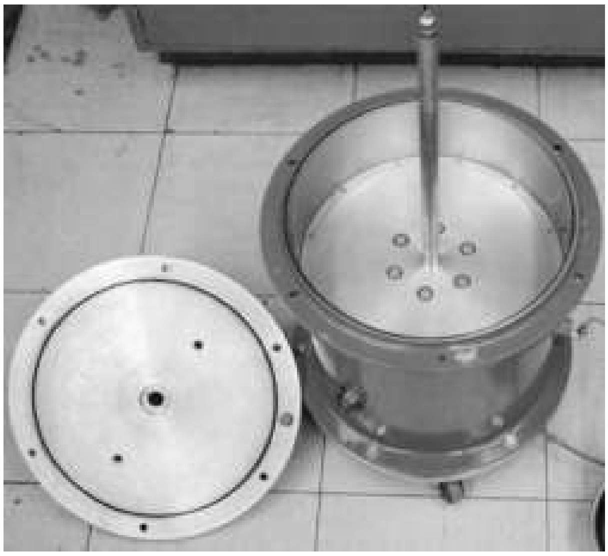

Figure 1. Large diameter slurry consolidometer, shown with upper lid removed.

In use, the lower lid of the tester was bolted to the cylinder, the test sample was placed in the cylinder, the plunger was placed on top of the sample, and then the upper lid was bolted to the cylinder. The upper chamber of the tester was pressurized with air, and movement of the plunger shaft was measured relative to the upper lid. The tester was plumbed to allow drainage from the upper and lower surfaces of the sample, with ports through the lower lid and through the shaft of the plunger. The upper and lower lids of the cylinder were fitted with o-rings to promote air and watertight seals. The upper lid also included an o-ring seal against the plunger shaft.
Approximately 10 kPa to 15 kPa of applied pressure was required to overcome the friction between the plunger o-ring and the wall of the tester.

2.3 Testing Procedure

Samples of tailings, waste rock, and a mixture of waste rock and tailings were tested for volume change behaviour. Each sample was placed in the tester and loaded at pressures of 0 kPa, 10 kPa, 20 kPa, 40 kPa, 80 kPa, 160 kPa, and 320 kPa. Each pressure increment was applied overnight, and deflections of the plunger relative to the upper tester lid were recorded. Deflection versus log-time relationships were plotted and used to confirm that samples had completed primary consolidation. Occasionally, loads were applied over a weekend (for 3 days), including the 10 kPa and 320 kPa increments for the CIP tailings, the 320 kPa increment for the waste rock sample, and the 160 kPa increment (4 days) for the mixture. The 20 kPa increment for the waste rock sample was applied for approximately 18 minutes, with no deformations observed after the first 5 minutes of the test.

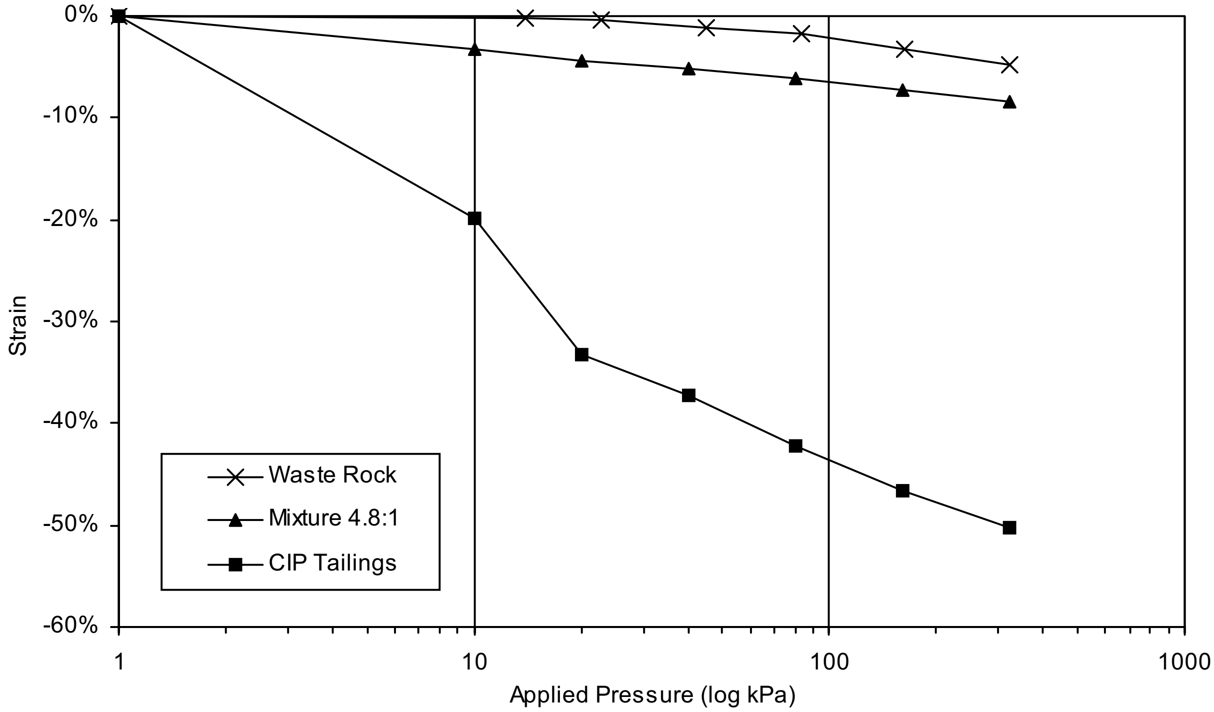

Figure 2. Strain versus Applied Pressure relationships for Waste Rock, Tailings, and Mixture.

An aluminium spacer was also tested using the same procedure with pressures applied for several minutes, rather than overnight. Deflections measured for the spacer were applied to the soil sample data as a correction for flexure of the consolidation testing apparatus. The waste rock sample was tested using 12 mm thick plastic discs above and below the sample, as well as a paper liner around the inside of the tester, in order to prevent damage to the tester. Corrections for deflection of the testing apparatus used for the waste rock sample are based on the same correction procedure described above, using the plastic discs, but no aluminium spacer.

3. RESULTS AND ANALYSIS

The waste rock was observed to exhibit creep behaviour, which is attributed to mechanisms of secondary settlement. It is expected that given more time, the waste rock would consolidate further, but loading times were generally limited to approximately 24 hours. Most deformation of the waste rock sample was observed to occur immediately upon loading. The plastic discs placed above and below the waste rock sample had minor scratches following testing, and the paper liner was observed to crumple evenly over the height of the sample. For the tailings and the mixture, the drainage lines from the tester were observed during testing, and a minor amount of fine material was observed to exit the tester during loading of the mixture.

Final deformations for each pressure step were corrected for flexure of the apparatus and then converted to strains relative to the initial height of each sample. The relationship of strain versus applied pressure for each material is shown in Figure 2. Waste rock showed the least deformation of the three materials tested, followed by the mixture, and then by the CIP tailings sample. The maximum strain calculated for the waste rock sample was 4.8% at 320 kPa. The maximum strains calculated for the same stress level for the mixture and the CIP tailings samples were 8.5% and 50.3%, respectively. The data indicate that the strain for the CIP tailings sample was an order of magnitude greater than that of the waste rock sample. As expected, the strain for the mixture was between the strain for the waste rock and tailings samples. The mixture follows a stress versus strain relationship that is more similar to the waste rock than to the tailings.

Modified Compression Index, $C_{c\varepsilon}$, was calculated for each material for each pressure interval, as shown in Table 1. Modified Compression index $C_{c\varepsilon}$ is defined as:

$$C_{c\varepsilon} = \Delta\varepsilon_v / \log(\sigma_2' / \sigma_1') \quad [1]$$

Where $\Delta\varepsilon_v$ is vertical strain, and σ_2' and σ_1' are applied vertical effective stresses (Holtz and Kovacs 1981).

Table 1. Modified Compression Index $C_{c\varepsilon}$

Pressure Interval (kPa)	Waste Rock[1]	CIP Tailings	Mixture
0- 10	0.0021	0.20	0.033
10-20	0.0029	0.44	0.035
20-40	0.031	0.13	0.028
40-80	0.021	0.17	0.033
80-160	0.053	0.14	0.037
160-320	0.050	0.12	0.040

[1] Maximum recorded pressures for waste rock were 7.7 kPa and 14 kPa, rather than 0 kPa and 10 kPa, respectively for the first two pressure intervals.

The values of $C_{c\varepsilon}$ for the waste rock ranged from 0.0021 to 0.05. The low values of $C_{c\varepsilon}$ of the waste rock for the first two pressure intervals may be due to wall/plunger friction in the testing device, resistance from the paper liner, or overstepping the loading increment. The values of $C_{c\varepsilon}$ for the mixture ranged from 0.028 to 0.040, and appear to increase slightly with pressure. The value of $C_{c\varepsilon}$ for the CIP tailings sample ranged between 0.12 and 0.44, and appeared to decrease with increase in pressure. The decrease in $C_{c\varepsilon}$ for the CIP tailings is expected due to the high compressibility of slurried tailings at low stress levels.

4. DISCUSSION AND CONCLUSIONS

The volume change of waste rock, CIP tailings, and a mixture of waste rock and tailings were examined in the laboratory using a large diameter consolidometer. For a given stress level, waste rock and tailings experienced strains that varied by an order of magnitude. The strains developed in the mixture were more similar to those for waste rock than for tailings. In terms of compressibility parameters, the CIP tailings had values of $C_{c\varepsilon}$ that were an order of magnitude greater than those of the waste rock. The mixture had values of $C_{c\varepsilon}$ that were more similar to those of waste rock.

The similarity of strains and values of $C_{c\varepsilon}$ indicate that the mixture behaved more like waste rock, and less like tailings. It is concluded that, amidst the presence of fine-grained tailings, contact between waste rock particles still occurs in the mixture considered for the present study. The resulting “waste rock skeleton”, acts as the primary participant in resisting applied stresses, and effectively limits the strain experienced by the mixture under a given load. It is of interest to note that this is conceptually similar to the role of the coarser-particle skeleton in resisting applied loads that has been observed previously for mixtures of sand and silt (Kuerbis et al. 1988, Thevanayagam and Mohan 2000).

From a field applications point of view, the amount of settlement observed for waste rock deposited by end dumping is typically in the order of 1% to 2%, which is much smaller than the strain of near 5% observed for the laboratory sample. The difference between field and laboratory strains may be attributed to the differences in particle arrangement and packing created by method of placement. While the void space in waste rock is mainly determined by the method of placement, the void space in a saturated mixture is governed by the volume and water content of the tailings in the mixture. Consequently, strains experienced by mixtures placed in the field are not expected to differ significantly from laboratory values.

The results presented here are preliminary to a comprehensive study investigating the technique of mixing waste rock and tailings for disposal. Other work completed to date includes a meso-scale column study examining self-weight consolidation of mixtures described by Wickland and Wilson (submitted 2003), and Wickland et al. (2003). The authors are currently working on a theoretical model to describe the behaviour of mixtures.

5. ACKNOWLEDGEMENTS

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