MIXTURES OF WASTE ROCK AND TAILINGS: RESISTANCE TO ACID ROCK DRAINAGE[1]

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Abstract. The potential for acid rock drainage (ARD) control is examined with respect to the geotechnical properties of mixtures of mine waste rock and tailings. Waste rock, tailings, and mixtures of the same waste rock and tailings were examined for hydraulic conductivity and soil-water characteristic curves through laboratory testing and a meso-scale column study. Both tailings and mixtures had low values of hydraulic conductivity that limit the flow of water and therefore limit the rate of the ARD reaction and the transport of reaction products. Mixtures and tailings were found to have high Air Entry Values (AEV's) that inhibit the flow of air by maintaining water saturation. In comparison, waste rock was found to have a high value of hydraulic conductivity and a low AEV. The findings demonstrate that mixtures of waste rock and tailings are resistant to acid rock drainage relative to waste rock alone.

Additional Key Words: hydraulic conductivity, soil-water characteristic curve, air entry value

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Introduction

Mixing mine waste rock and tailings for disposal is a relatively new idea with the potential to address mine waste disposal problems such as acid rock drainage and tailings liquefaction. Standard practice for mine waste disposal includes end-dumping of waste rock in large piles and also the impoundment of slurried tailings. Waste rock piles are typically unsaturated, made up of large particle sizes with an open void space that allows free flow of air and water, thereby promoting the formation of acid rock drainage. Tailings in impoundments have small particles and are typically saturated, with low density and the potential to liquefy. The purpose of the paper is summarize geotechnical investigations evaluating mixing of waste rock and tailings as a mine waste disposal technique that controls acid generation.

The work presented includes procedures and results from a laboratory investigation of hydraulic conductivity. Key findings from previous investigations are also summarized, and include soil-water characteristic curves (SWCCs) and the results from a meso-scale column study of self-weight consolidation.

Materials and Test Methods

Mixtures were tested for hydraulic conductivity by falling head test alternated with consolidation by a series of static loads. Brief descriptions of previous investigations of SWCC and behaviour under self-weight consolidation in a column study are included.

Materials

The materials investigated included one type of waste rock, one type of tailings, and mixtures thereof. The waste rock was an altered sedimentary rock collected from an open pit at an active gold mine, the Porgera Gold Mine in Papua New Guinea. The tailings were Carbon In Pulp (CIP) Au tailings diverted from a mill circuit and thickened using a flocculant. The particle size distribution of the materials was not changed aside from scalping of larger waste rock particle sizes. Laboratory mixture specimens were prepared by hand mixing. The column study specimens were prepared in a concrete transit mixer truck.

Hydraulic Conductivity Testing

The values of hydraulic conductivity, *k*, for two mixture specimens and one tailings-only specimen were measured by falling head tests alternated with static loading. Specimens were tested for *k*, then consolidated under a static load, unloaded, and retested for *k* to produce a void ratio versus *k* relationship. Hydraulic conductivity was measured in a 15.5 cm inner diameter aluminum walled permeameter with plastic end plates. The permeameter apparatus is shown in Fig. 1. Hydraulic conductivity was determined by the falling head test method, with water entering the top of the sample from a burette. Specimens were tested over a series of hydraulic gradients during a period of 24 hours, following ASTM standard D5868-95 to determine a value of *k*.

Specimens were subjected to static loads between successive falling head tests using free weights and a hydraulic press, as shown in Fig. 2. The upper and lower surfaces of each specimen were kept under a head of water during loading to prevent desaturation and desiccation. Each load was applied incrementally over a period of 5 to 10 minutes in order to prevent loss of material due to the failure of soft test specimens (i.e. "squeezing" of material out of the mold). The tailings sample was initially in slurry form and required special care. The time of loading was calculated to allow a minimum of 95% of consolidation to occur. The progress of consolidation was monitored by measuring sample height. The maximum time allowed for consolidation was typically less than 24 hours for each load increment.

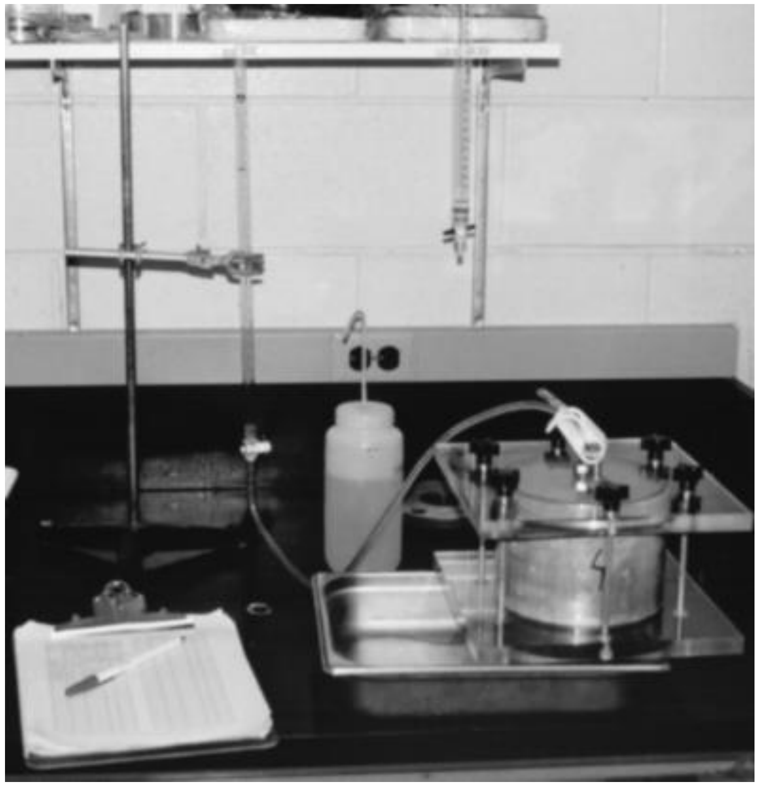

Figure 1. Rigid-walled falling head hydraulic conductivity test.

Specimens were unloaded in order to measure hydraulic conductivity, *k*. The height of each specimen was measured before and after static compaction, or before and after each *k* test, to ensure that the sample dimensions did not change significantly during the falling head tests.

Soil-Water Characteristic Curves

The soil-water characteristic curves (SWCC's) of a mixture, tailings alone, and a similar rock type are reproduced here from Wickland et al., (2006). SWCC's were determined for mixtures and waste rock in a large diameter Tempe cell. The SWCC for tailings was determined in a standard Tempe cell. The measured SWCC's provide a means of assessing the water retention ability of mixtures, tailings and waste rock.

Meso-Scale Column Study

Mixtures were placed in meso-scale columns in order to study self-weight consolidation. The methods and detailed results of the column study were reported in Wickland and Wilson (2005) and in Wickland et al., (2003). The column study involved placing three mixtures of waste rock and tailings in columns 1 m in diameter by 6 m in height, and observing settlement, drainage, and pore-water pressure response under self-weight consolidation. A fourth column of waste rock only was constructed as a reference column. The study was run for two years, and provided data on both the development of negative pore water pressures under free drainage and estimates of the hydraulic conductivity of mixtures at a larger scale than the laboratory studies described above.

Figure 2. Specimen compaction using free weights and in a hydraulic press.

Results and Analysis

Key results are summarized for the laboratory hydraulic conductivity testing and the column study. SWCC data were previously reported in Wickland et al., (2006) and are included here for comparison purposes.

Hydraulic Conductivity

Fig. 3 includes hydraulic conductivity data from laboratory testing as well as results from the column study. Hydraulic conductivity was back-calculated from the changes in measured pore-water pressures in the column mixture profiles using the conventional consolidation theory, and also from the time required for infiltration of water ponded on the surface of the column profiles. Fig. 3 includes the hydraulic conductivity of waste rock alone determined by constant head testing of the waste rock only column.

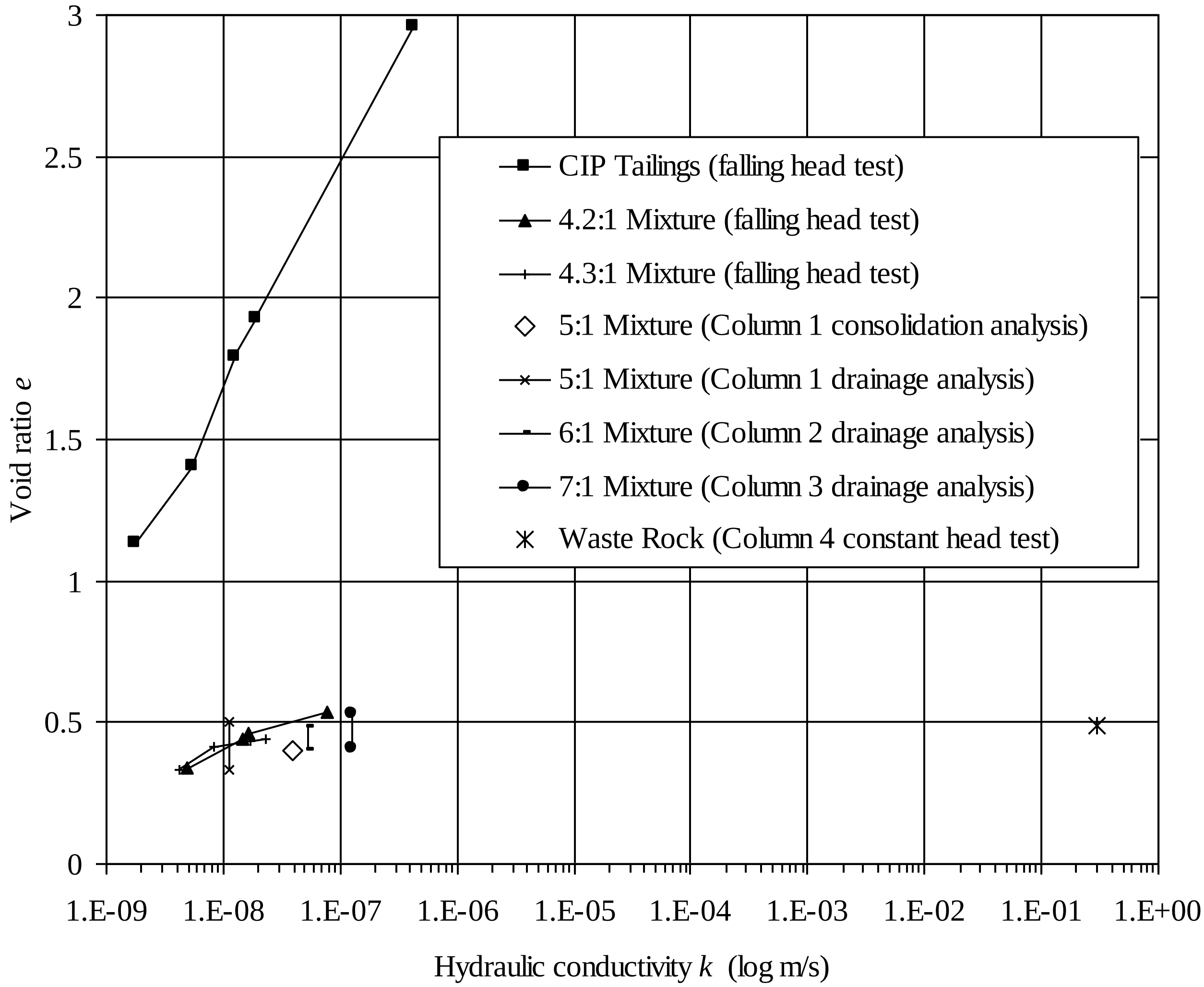

Figure 3. Hydraulic conductivity for mixtures, tailings, and waste rock

The data in Fig. 3 indicate that mixtures had hydraulic conductivities that were generally similar to those of tailings alone. The mixtures had void ratios that were similar to and slightly lower than waste rock alone. Clearly, the hydraulic conductivity of mixtures was much lower than that of waste rock alone.

Soil-Water Characteristic Curves

The SWCC's of a mixture, tailings, and waste rock are shown in Fig. 4 (after Wickland et al., 2006).

The waste rock specimen had an air-entry value of less than 1 kPa and reached residual water content at matric suctions near 10 kPa. Mixtures maintained water saturation at significantly higher matric suctions than waste rock alone. The finding is attributed to the presence of a fine-grained tailings matrix. The air-entry values (AEV's) and residual matric suctions of the mixture and tailings specimens were not readily apparent from the data in Fig. 4, primarily due to the limited range of applied matric suctions. The AEV's of the tailings and the mixture are considered to be greater than 60 kPa. The curved shape of the SWCC's for mixtures and tailings are primarily the result of sample volume change during the Tempe Cell test. For a change in matric suction of 0 kPa to 100 kPa the tailings specimen shrank by slightly more than 50% and the mixture specimen shrank by 15%. The limited volume change of the mixtures was attributed to the presence of waste rock.

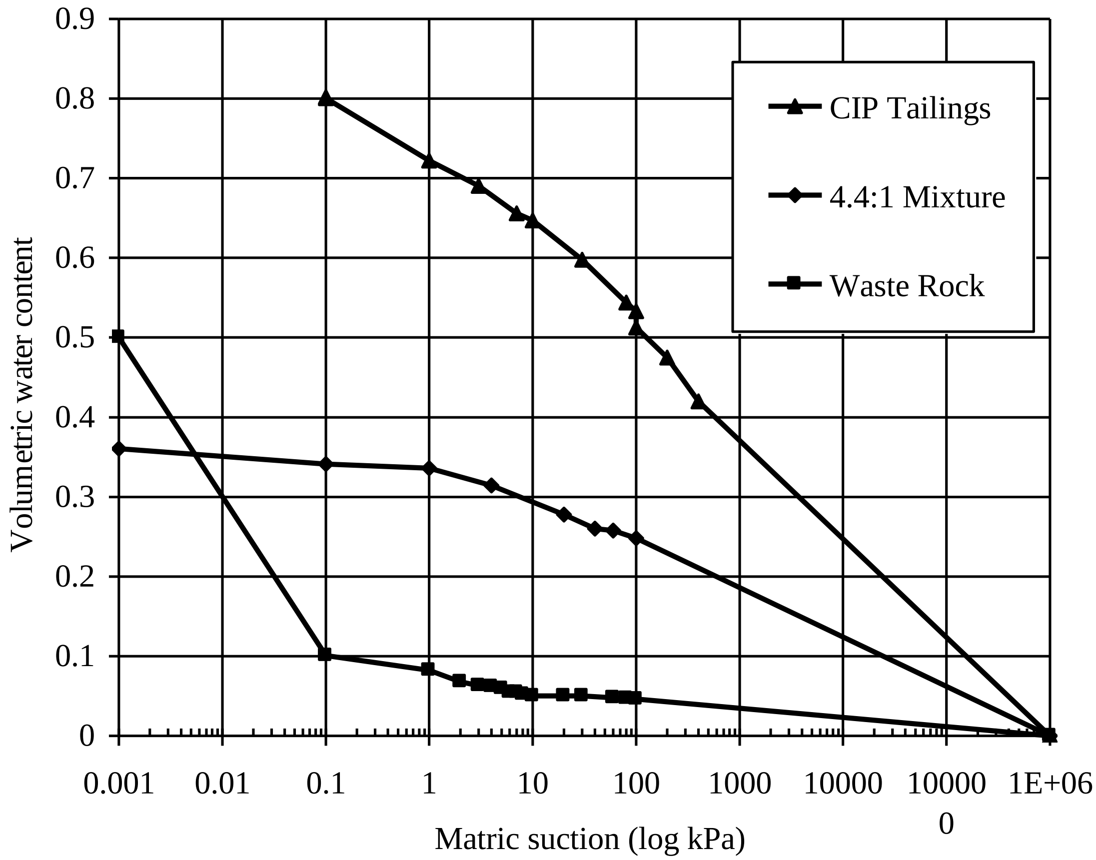

Figure 4. Soil-water characteristic curves for mixtures, tailings, and waste rock (after Wickland et al., 2006).

The maximum matric suctions measured after three months of free drainage in a 5.5 m high profile of mixture material in the column study were near 60 kPa. A matric suction of 60 kPa was not enough to desaturate the mixture material according to the SWCC in Fig. 4. Minor cracks in the tailings portion of mixtures were observed for both the column and laboratory tests at matric suctions greater than 40 kPa. Increases in air permeability due to cracks will depend on the size and connectivity of such cracks.

Discussion

Water acts as both a reactant and a transport mechanism for acid rock drainage, ARD. Materials with a low hydraulic conductivity are therefore more resistant to ARD than materials with high hydraulic conductivity. The data reported here indicates that saturated mixtures can be constructed so that the mixture retains the hydraulic conductivity of the tailings used to create the mixture. While waste rock alone has a high hydraulic conductivity it appears that addition of tailings to the waste rock void space will limit the flow of water through the waste material.

Air (or oxygen) is generally required for the ARD to occur. If air flow can be reduced, then the rate of the ARD reaction can be limited. One way to reduce the coefficient of air permeability is to increase the water content of a soil (Fredlund and Rahardjo, 1993). Completely saturating the pore space of a porous media with water can limit convection and reduce air flow. The waste rock in Fig. 4 desaturated at low matric suctions, and will likely have a high value of air permeability associated with convective flow. The tailings and mixtures in Fig. 4 did not appear to desaturate at the range of matric suctions tested (excluding the oven dry condition of 1,000,000 kPa).

The results of the column study indicated that mixtures can undergo prolonged periods of drainage and drought without desaturation. In contrast, the waste rock desaturated at low matric suctions and remained unsaturated. Mixtures are expected to have much lower values of air permeability than waste rock alone due to the presence of water saturated fine-grained tailings in the mixture waste rock void space.

Summary and Conclusions

The hydraulic conductivity and soil-water characteristic curves of one type of waste rock, one type of tailings, and saturated homogenous mixtures were examined at the laboratory scale and in a meso-scale column study. Findings from the column study generally confirmed laboratory results. The results presented are specific to one type of waste rock and one type of tailings but provide a means for evaluating the concept of mixing mine waste rock and tailings for disposal. Key findings included:

1. Falling head hydraulic conductivity testing indicated that mixtures of waste rock and tailings had values of the hydraulic conductivity that were similar to those of tailings alone and orders of magnitude lower than those of waste rock alone. The low hydraulic conductivity of a mixture was attributed to the presence of a fine-grained tailings matrix.
2. The hydraulic conductivity of both tailings and mixtures decreased with compaction. Mixtures that are compacted in the field under self-weight are expected to have lower values of hydraulic conductivity with depth.
3. Mixtures can remain water-saturated for prolonged periods of time under free drainage. Soil-water characteristic curves indicate that mixtures will remain water-saturated at higher suctions than waste rock. In contrast, waste rock has a low air entry value and is unsaturated under field conditions. The water retention properties of mixtures are attributed to the presence of fine-grained tailings in the void space of the waste rock.

In general, the results presented indicate that the addition of tailings to the void space of waste rock reduces both air permeability and hydraulic conductivity, and will thereby limit the production of acid drainage relative to waste rock alone.

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