

TESTING PROCEDURES TO CHARACTERISE TUNNELLING RISK ON SPOIL MATERIALS

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Abstract

Many factors affect the success or failure of attempts to stabilise and rehabilitate waste rock dumps on mines. Major erosion causing waste rock dump “failure” is often associated with unstable materials prone to tunnelling, including dispersive spoils. The presence of these materials commonly results in the failure of berms at points where tunnels develop, creation of relatively unsafe landforms with widespread tunnels immediately below the soil surface, development of large gullies when tunnels collapse, and instability of rock drains. Although tunnel erosion is commonly considered to be associated with dispersion, some non-dispersive mine spoil materials have been shown to be highly susceptible to tunnelling. Similarly, materials that are initially stable often undergo chemical and physical changes over time that lead to subsequent tunnel formation. Hence, there is a need for the development of more comprehensive testing procedures to identify materials at risk of tunnel erosion. This paper reports on the development of a laboratory based testing procedure to characterise the risk of tunnelling failure on the basis of soil properties and failure mechanisms. The test procedure also provides information on the impact of leaching on the potential for tunnel formation over time.

Additional Keywords: mine rehabilitation, erosion, sodic soil, gullies, waste rock dump.

Introduction

Open-cut mining activities typically excavate large quantities of overburden or spoil to gain access to the mineral that is sought. Overburden is usually placed in above-ground waste rock dumps, which are commonly 10-40 m high, and may have outer batter slopes at gradients of 25-40%. Stabilisation of such constructed landforms is a major component of mine site rehabilitation works. The presence of materials susceptible to tunnelling or piping has large impacts on landform stability and rehabilitation, as tunnel erosion tends to specifically impact on important structural elements of dumps such as berms and drains. Damage can then result either directly from the failure of those structural elements and the discharge of concentrated flows onto slopes below, or from the expansion of tunnels and their eventual collapse to form large gullies.

In general, the development of tunnel erosion is associated with the presence of dispersive materials. These materials are typically sodic (containing relatively high quantities of exchangeable sodium) causing them to break down when wet and release clay particles into solution – the process of dispersion. There are a number of tests widely used to identify dispersive materials including the Emerson dispersion test and the pinhole test. These tests of dispersion do have their specific applications but they do not provide a quantitative result of tunnelling potential. As tunnelling potential is influenced by more factors than the dispersive nature of a material, a thorough testing procedure is necessary to identify the potential risk of tunnelling for a spoil material, extracted by mining operations, and the impact on waste rock dump design.

Materials and Methods

Materials tested

Spoil materials were collected from five Australian mine sites with a total of 5 materials from each site tested (Table 1). Measurements of electrolyte content (EC), exchangeable cations, particle size distribution (clay, silt, fine and coarse sand) and clay mineralogy (using X-ray diffraction) were taken on each spoil material for classification purposes. Materials susceptible to tunnel erosion can be broadly categorised into three groups: (a) non-saline sodic, (b) saline sodic and (c) non-saline, non-sodic, silty materials. These groups have distinctly different patterns of tunnel erosion under field conditions and thus have quite different management requirements.

The Coppabella (central Queensland coalmine) and Jundee (central Western Australia gold mine) materials are largely non-saline, sodic, dispersive and mostly sandy.

The Higginsville and St Ives (both from Western Australia Goldfields near Kalgoorlie) materials are largely saline and sodic. This is to be expected for paleochannel materials in an environment where high salt levels are common in subsoils. The predominantly clay materials from Higginsville contain various levels of quartz, kaolinite and

smectite minerals. The smectitic component in some of these materials caused high levels of swelling during testing followed by shrinkage upon drying. This swelling and shrinking cycle forms cracks, which appear to be a major pathway for water to move through these materials and initiate tunnels. (Dispersive clays, when wet, can be highly impermeable, and without water movement, tunnel formation is impossible.) The St Ives materials are highly sodic and saline, with salinity levels varying considerably. The St Ives materials showed greater variation than the Higginsville materials with one sample markedly different from the other materials, being a non-dispersive, sandy material.

The Telfer (northern Western Australia gold mine) materials are non-saline and have relatively low sodicity. Initial particle instability was only observed in samples with the highest ESP (only 7%). The mineralogy of these materials consisted primarily of quartz, kaolinite and illite, with no trace of swelling smectites. The tunnelling characteristics associated with this material are driven by liquefaction within the soil structure.

Table 1. Summary of material properties used in testing

Mine site	EC (mS/cm)	ESP (%)	Sand (%)	Silt (%)	Clay (%)	Mineralogy
Coppabella	0.1-1.9	20 - 36	51 - 90	6 - 21	5 - 34	Quartz, Kaolinite
Jundee	0.06 – 0.76	10 - 35	44 - 78	4 - 42	17 – 33	Quartz, Kaolinite
Higginsville	7.5 – 12.8	38 - 56	15 - 31	7 - 10	59 – 76	Quartz, Kaolinite, Smectite, Illite
St Ives	4.9 - 46	25 - 89	19 - 83	8 – 60	8 – 22	Quartz, Kaolinite, Smectite, Illite
Telfer	0.1 – 1.9	3 – 7.2	40 - 68	26 - 54	5 - 12	Quartz, Kaolinite, Illite

Testing methods

The Emerson test (AS 1289.3.8.1 – 1997) initially measures both slaking and spontaneous dispersion of an air-dry soil aggregate immersed in excess water (Emerson, 1967). If spontaneous dispersion is “slight to nil”, the soil is remoulded at near maximum field water content, and dispersion is again observed. Finally, if soil does not disperse after remoulding, the soil is shaken in water. Initially if the sample demonstrated no slaking, then any presence of swelling within the soil aggregate indicates the variation for these stable materials. High levels of gypsum or calcite also influence this test and need to be indicated if present.

The Pinhole Test (AS 1289.3.8.3) applies mechanical energy to sample via water flow through a pinhole of 1.07 mm diameter (Schafer, 1978) placed in a compacted soil specimen at its plastic limit moisture content. Distilled water is passed through the pinhole, with an initial mean velocity 0.4 to 0.8 m s⁻¹, and measurements are taken of the water turbidity and flow rates exiting the pinhole. Visual inspection of the pinhole is carried out after testing is complete (Schafer, 1978). Dispersive clay soils produce turbid water with a rapidly eroding hole, whereas non-dispersive clay soils result in clear water at the outlet and little change in pinhole size (Sherard *et al.*, 1976).

Short leaching columns were used to assess sample hydraulic conductivity and the extent to which leaching of soluble salts reduces the stability of the surface layer of each material. The short leaching columns used a soil layer 10mm deep with 40mm depth of water ponded above it. Leachate depth, leachate sediment loads and soil and leachate EC were measured at 50 to 100 mL leachate output intervals (intervals based on infiltration rates) to assess changes in infiltration rate through time and in response to amounts of leaching of soluble salts from the sample. Longer leaching columns (soil layer of 100 mm depth, with 300 mm depth of water ponded above it) were used to assess both sample hydraulic conductivity and potential for tunnel generation. Infiltration rates, leachate EC and total sediment in leachate were measured at 50 to 100 mL leachate output intervals. Soil layers for these columns typically formed a seal that reduced water movement through the soil layer. The impact of shrinkage cracks on the tunnel erosion potential of samples that formed strong surface seals were then assessed by drying samples and then ponding water on them again. Potential remediation techniques for various materials were assessed using leaching columns, particularly the use of gypsum and compaction levels.

Results and Discussion

The development of laboratory tests has typically relied on measured correlations between the test result and soil responses or behaviour in the field. For example, tests of soil fertility are commonly correlated with measured fertilizer responses. The assumption underpinning this approach is that a direct quantitative test result will have some mathematical relationship (neither necessarily linear nor precise) with a quantifiable field soil behaviour or response. However, the results of this work suggest that quantitative relationships between single parameters and the risk associated with tunnel formation under field conditions may not be readily identifiable nor appropriate for

spoil materials. Considerable difficulties associated with the development of a quantitative ranking of tunnel erosion potential on the basis of field observations became obvious early in the research. It was observed that:

- waste rock dump design strongly influenced the degree of tunnel development;
- differences in length of exposure to rainfall and runoff and in the quantities of spoil placed at given locations introduced enormous variations in observed response; and
- tunnel development is extremely difficult to assess in the short to medium term, as tunnels are not clearly visible until the roof of the tunnel collapses and the full magnitude of the underlying void becomes visible.

Similarly, this research suggests that there are two distinctly different mechanisms by which tunnel erosion develops. Hence, a single quantitative measure of tunnel erosion potential may not, on its own, be useful. It seems more reasonable to expect that evaluations of tunnel erosion risk will need to include an assessment of both the spoil material properties and the waste dump design characteristics which influence each of the failure mechanisms. For these reasons, data analysis has relied heavily on understanding both soil and field level processes influencing tunnelling.

Emerson testing does not allow for high salinity materials, encountered in measurements on some mine spoils, particularly those of marine origin. If the salt content of a material is very high, then spontaneous dispersion may not occur, even when immersed in excess deionised water. Re-assessing Emerson test ratings may be necessary following leaching of saline materials to determine the impact of the decreased salinity and potential dispersive behaviour on tunnel formation over time. This test is not effective in identifying materials susceptible to liquefaction failures.

The pinhole test was originally designed to assess dispersion and failure of clay-rich materials. The main mode of failure was expected to be clay dispersion, allowing soil around the pinhole to be removed by flow through it. However, pinhole testing of materials with low cohesive strength (sandy and silty materials) demonstrated the importance of liquefaction as a mechanism for tunnel formation in these materials. All materials with low clay contents and/or low cohesive strength (Coppabella, Jundee and Telfer samples and 1 from St Ives) resulted in rapid failures, producing predominantly highly dispersive (D1) ratings. The highly saline clay-rich materials from Higginsville and St Ives mines provided the greatest variations in pinhole test results. The localised leaching around the pinhole during testing reduces the influence of initial salt levels on the dispersion/failure of the samples during testing.

Conclusions

This research suggests that no single test will provide an adequate predictive capability across the range of potential tunnelling materials and mechanisms by which tunnel erosion develops. Rather, it appears that initial assessment of soil chemical and physical data is required, followed by a range of tests to assess the specific tunnel erosion mechanism. Initial soil/spoil parameters that provide information on tunnel erosion potential are:

- i) EC (to assess potential salinity impacts on dispersion);
- ii) cations, with particular emphasis on exchangeable sodium percentage (ESP) to assess dispersive potential (calcium content is also of interest if it is in the form of gypsum or calcite as per Emerson testing procedures);
- iii) particle size distribution (to provide an indication of soil cohesion and liquefaction contributions to tunnel formation/failure); and
- iv) clay mineralogy (due to the effect on swelling).

These data are required before a judgment can be made on which of the following tests is most appropriate. The occurrence of tunnel erosion on a site containing a potential tunnel generating material will depend on preferential flow path development, with contributions from waste dump design, material particle size distribution, clay mineralogy and site seasonality.

The Emerson dispersion test will provide a quick assessment of the presence of spontaneously dispersive material, and is most appropriate for samples of high ESP and low EC. The influence of EC must be taken into account for material that does not test as spontaneously dispersive, especially hyper-saline materials. Leaching is critical for any material that may have water ponded on it at some point in the landscape. Material that is spontaneously dispersive without leaching applied will be prone to tunnel formation. Tunnel formation on material that spontaneously disperses only after leaching will be a function of the potential for localised leaching of salts out of

the profile. Hence, designs and management practices that minimise localised surface ponding and/or maintain higher salt levels would be expected to delay and minimise tunnel formation.

Pinhole tests provide a very good indication of tunnelling following the development of preferential flow paths. The test provides data on a material's resistance to tunnel development. In materials with high salinity levels that naturally inhibit clay dispersion, the area of soil surrounding the pinhole is exposed to accelerated leaching inducing dispersion. The pinhole test is suitable for dispersive materials with both high and low salt levels, and also for samples that tunnel by liquefaction, though these latter materials will create some difficulties during analysis.

Leaching columns provide an indication of the rate of flow through materials and the formation of surface seals. The value of columns in assessing tunnelling potential is limited by the comparatively long period over which leaching occurs and the variability between replicates. However, leaching columns tests have been used to effectively discriminate between alternative remediation practices (eg. gypsum applications, compaction impacts).

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