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Stabilisation of mine tailings deposits using electro-kinetic geotextiles

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ABSTRACT: Dewatering soft soils by electro-osmosis is a well-recognised technique. However, problems associated with corrosio electrodes, build-up of gas at electrodes and excessive energy costs have limited the utilisation of this technique to all but the most pres problems. With the recent development of electrically conductive geosynthetics, the potential for electro-osmotic stabilisation of a rang problem materials is now extremely promising. This paper describes results of tests that were carried out to determine the potential for elec osmotic dewatering of four different mine tailings using these new generation geosynthetics. Processes of both electrophoresis and elec osmosis were both studied, with varying degrees of success. It is clearly essential to develop techniques for characterising mine tailings other soft soils in such a way that their response to electrically-induced consolidation can be more accurately predicted.

1 INTRODUCTION

The legacy of the mining industry in South Africa includes some of the largest man-made structures in the world, in the form of tailings dams. Due to the nature of most tailings disposal operations, which incorporate the preparation, transportation and deposition of very large volumes of low-density slurries, many of our tailings disposal facilities present severe environmental and safety hazards. The large quantities of water stored on the surface and in the voids of these tailings impoundments can make them potentially unstable on the one hand and a potential risk to underlying groundwater on the other. Many tailings disposal facilities contain material that undergoes extremely slow self-weight consolidation. Examples include the fine tailings produced in the Oil Sands industry (Morgenstern and Scott, 1995) and the waste products from the phosphate mining industry (Martin et al, 1977).

Aside from the obvious dangers posed by such poorly consolidated material (eg the potential for flowslides or mudrushes in the event a breach of the impoundment occurs), there are problems of rehabilitation of the facility once it is closed. The extremely low undrained shear strength of such deposits means that earthmoving machinery cannot operate on the surface and placement of cover material and a growing medium is extremely difficult.

2 ELECTRO-OSMOTIC DEWATERING AS A STABILISATION OPTION

Electro-osmotic dewatering of soft clay deposits is a recognised, although seldom-used technique that may prove viable for the above application. In the conventional application of this technique, an electrical potential is established between two metal electrodes. This induces a hydraulic flow between the electrodes thus facilitating dewatering and consolidation. However, significant problems of corrosion of the metal electrodes as well as decreases in system efficiency due to the buildup of hydrogen gas is common. Problems of this type have led to the procedure not being widely adopted.

Recent research at the University of Newcastle in the United Kingdom has included the development and testing of conductive geotextiles - so-called electrically conductive geosynthetics (ekg's). Before discussing the ekg's developed to date, it is worth reviewing briefly the fundamental aspects of electro-osmotic dewatering that are relevant to the present study.

2.1 Electoosmotic dewatering of soils

The application of an electrical field across a soil sample results in the attraction of cations to the cathode and anions to the anode. As these ions migrate, they drag their water of hydration with them, resulting in a force on interstitial water that causes free water to migrate to one of the electrodes. As most clayey soils tend to be negatively charged and thus surrounded by an outer cloud of positively charged water molecules, water migrates towards the cathode during electro-osmotic dewatering. The rate of this water movement is independent of the pore size of the soil and rather depends on the applied voltage gradient and certain characteristics of the particles, only some of which are fully understood at present. The relative independence of electro-osmotic dewatering with respect to pore size, means that the technique is far more effective in fine grained soils than in sands and other coarse grained materials, where the hydraulic conductivity is relatively large.

In the application envisaged in this paper, electroosmosis would be used to dewater deep deposits of mine tailings. The depth of this material may be many tens of meters and for dewatering to be effective it will probably be necessary to instal some form of vertical drain into which pore water may be discharged for subsequent extraction. It is clear that having a porous material such as a geotextile that is also electrically conductive will be extremely valuable in this application.

2.2 Development of electrically conductive geosynthetics (ekg's)

As discussed by Jones et al (1997), these new generation materials can take the form of single materials, that are electrically conductive, or composite materials, in which at least one element is electrically conductive. A number of different configurations have been tested at the University of Newcastle, with varying levels of success. This paper illustrates how stabilisation of a deep deposit of soft tailings may be achieved through the use of a combination of ekg's.

The viability of these ekg's for dewatering applications has already been demonstrated for natural soft clay deposits. Jones et al (1997) describe laboratory tests in a purpose built electro-osmosis cell, which showed that similar electrical currents were generated in specimens of kaolin clay using copper disc electrodes and an ekg made of carbon fibre. These tests also showed an increase in vertical compressive strain from 9.7% without an ekg to 13% with an ekg. Surprisingly (see later) in these tests, the rate of settlement was relatively unaffected.

More recently, Lamont-Black (2001) reported the results of large scale laboratory tests using a test pit at the University of Newcastle. The pit was filled with kaolin clay at a moisture content of 85% to a depth of 2.4m. A number of electrically conductive prefabricated vertical drains (e-PVD's) were suspended in the clay. After allowing self-weight consolidation of the clay for 100 hours (with 20mm settlement), the e-PVD's were switched on for 500 hours, during which an additional 340mm of settlement occurred. As described by Lamont-Black (2001), to achieve an equivalent amount of settlement by surcharging would have needed the application of some 10m of fill. The method has thus been shown to have enormous potential for the dewatering of soft, natural clays. The remainder of this paper describes preliminary tests carried out to determine the applicability to a number of different mine tailings materials.

3 LABORATORY TESTING

3.1 Mine tailings tested

Four different tailings were evaluated for their susceptibility to electro-osmotic dewatering. These were the fine residue from a mineral sands operation, a coal washery waste, a kimberlite diamond tailings and an extremely acidic lead-zinc tailings. Properties of the various tailings are summarised in Table 1 and particle size distributions are shown in Figure 1.

Table 1. Properties of mine tailings tested.

Property	Mineral sands	Coal	Diamond	Lead-zinc
Specific gravity	2.76	1.72	2.72	3.28
Liquid limit (%)	66	38	38	41
Plasticity Index (%)	37	3	38	9
Linear Shrinkage (%)	12	2	15	40
pH	8	5	8.5	1.5

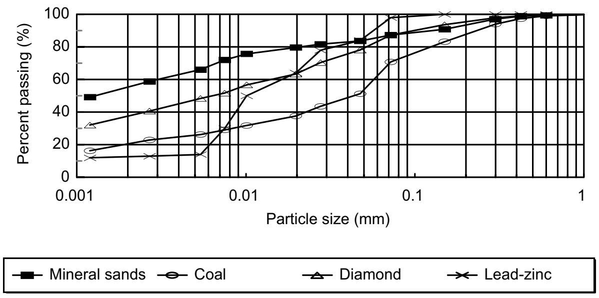

Figure 1. Particle size distributions of four mine tailings tested

Initial screening tests on the coal tailings showed virtually no difference in settlement rates between unaided self-weight consolidation and consolidation aided by electro-osmosis. This material was thus not used in any further testing, but it is interesting to speculate on why it did not respond to electro-osmosis despite having a relatively high proportion of clay-sized particles. X-ray diffraction tests showed the coal tailings minerals to be primarily quartz and kaolinite. The latter should have contributed positively to electro-osmotic dewatering potential. However, the loss on ignition (LOI) of these tailings was 69%, indicating that the greatest proportion of the solids were in fact of organic origin. It may be that the particle surface charge of this organic material was negligible, thus contributing to its relative immunity to electro-osmotic dewatering.

Aside from conventional consolidation testing (using a Rowe consolidation cell) to determine unaided consolidation rates, two different types of tests were carried out to evaluate the response of the three remaining tailings to electro-osmotic dewatering.

3.2 Bucket testing

Some of the tailings we obtained was at such a high moisture content that it was impossible to set up specimens in the consolidation apparatus (described in next section). As an indication, the diamond tailings had an initial moisture content of 400% and the mineral sands tailings 150%. Application of electro-kinetic dewatering to this kind of material is not so much electroosmosis as electrophoresis. In this case, application of an electrical field across a particulate suspension causes charged particles to be attracted to one of the electrodes whilst being repelled from the other.

Testing the lead-zinc tailings in this way resulted in a reduction of moisture content from an initial value of 95% to 63% in two days. The control sample experienced a decrease to 77% in the same time, illustrating the benefit of electrophoresis. In a similar way, the diamond tailings reduced from an initial water content of 400% to 142% with electrophoresis but to only 260% in the control test. Based on the success of this procedure, an additional sample of diamond tailings was obtained for testing. This came from a different mining operation to the first sample and was the overflow from a thickener that was found to remain in suspension interminably. The initial moisture content of this sample was

7500%. After 2 days electrophoretic testing at a voltage of 10V DC, the material settled out completely and the moisture content was reduced to 1600%. Comparative tests on a control sample showed no discernible settlement of material after 3 weeks. Clearly there is tremendous scope for treating these problematic mine tailings using ekg's.

3.3 Electro-osmotic cell tests.

A drawback with the bucket testing system discussed above is that consolidation takes place under only self-weight conditions, ie there is no applied vertical stress. To evaluate the potential for electro-osmotic consolidation of mine tailings beyond the range achievable in the bucket tests, an electro-osmotic testing cell was built. This is similar to the device described by Hamir et al (2001), except that there was no provision for the hypodermic syringe monitoring probes that were developed by the above authors. The cell was made of perspex, with no metal components that could cause short-circuiting of electric currents within the cell. The cell had an internal diameter of 145mm and samples with an initial height of up to 150mm could be tested. Drainage was allowed at both ends, with the end plates consisting of perforated copper discs (the electrodes) covered with a few layers of filter paper. In this phase of the testing, no ekg's were tested in the cell. The tests were only aimed at proving the benefits of electro-osmotic dewatering, with a view to carrying out cell tests with ekg electrodes at a later date.

The lead-zinc tailings was not tested in this phase of the programme and only results for the mineral sands and the diamond tailings are reported here. Tests on each of these two materials were firstly carried out without the application of an electrical potential across the specimen, ie these tests served as control tests (duplicate control tests were carried out in a 150mm diameter Rowe cell and very similar results obtained to the electro-osmotic cell). Thereafter specimens at moisture contents equal to those used for the control tests were set up and tests run under conditions of a voltage of 10V DC applied across the specimen height.

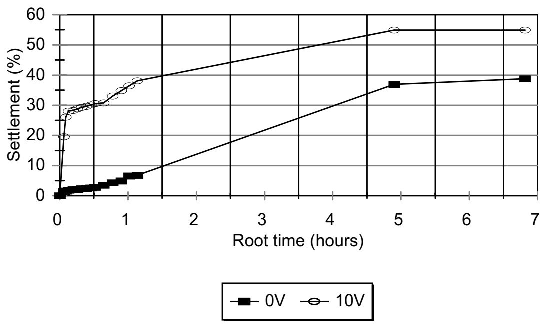

Figure 2. Time - settlement curves for mineral sands tailings

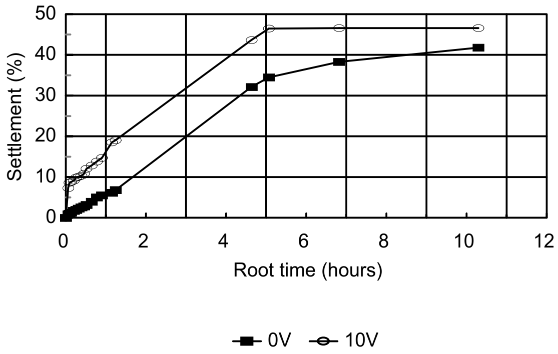

Figure 3. Time - settlement curves for diamond tailings

Results are presented in Figures 2 and 3 in terms of the settlement (as a percentage of initial specimen height) versus square root of time for the two tailings tested under an applied vertical total stress of 25kPa. The first thing to note is that similar percent settlements were achieved in the two control tests and the two electro-osmosis tests even though the initial water contents were different (about 180% for the mineral sands specimens and from 203 to 268 for the diamond tailings control test and electro-osmosis test respectively). The major differences are the rates of consolidation, in particular in the early stages of a test. It is difficult, if not meaningless, to calculate coefficient of consolidation (c_v) values for the electro-osmosis tests because the time-settlement curves differ so markedly from classical soil mechanics consolidation curves. In particular, note that for the diamond tailings about half the total consolidation settlement occurs within 30 seconds of the start of the test (the 30 second consolidation proportion for the mineral sands was a still-substantial 19% of the total amount). After this very rapid period of electrically-induced consolidation, the root-time vs settlement curve becomes relatively linear until the final settlement is reached after which time the settlement values level off abruptly.

It is thus not so much the amount of final settlement that is achieved (which does not differ significantly between the control tests and the equivalent electro-osmosis tests), but rather the speed with which the settlement is achieved, that is so impressive in the latter tests. Considering that up to 50% of the final settlement occurred in less than one minute, it may be that it will only be necessary to apply a voltage to a specimen of super-soft tailings for a short period and then allow natural self-weight consolidation processes to occur. In this case the primary function of the geosynthetic will be to filter fine particles, allowing only relatively clean process water to enter the e-PVD. An evaluation of these possibilities will form the core of future work in regard to dewatering of mine tailings.

A measure of the efficiency of the ekg's is provided by the time taken to reach 90% of final consolidation. For the mineral sands and the diamond tailings, there was a reduction in this time relative to conventional (ie unaided) consolidation of factors of 4 and 3.6 respectively.

4 DISCUSSION

The results described in this paper have clearly shown that there is a role for the use of electro-kinetic geotextiles in the dewatering and stabilisation of a range of mine tailings. It is also evident that there are some materials (eg the coal tailings) that do not respond well to dewatering by these techniques. What is now needed is a range of characterisation techniques that will provide an accurate indication of whether or not a particular soil or tailings is likely to respond favourably to electro-osmotic dewatering. Factors such as particle surface charge, pH and electrical conductivity are all likely to play a role in this regard and it will probably be necessary to include more than one test in order to appropriately characterise any material.

The ability of ekg's to obviate some of the problems traditionally associated with electro-osmotic dewatering of soft soils (ie corrosion of electrodes and build-up of gas at the electrodes) has been demonstrated in the laboratory by Hamir et al (2001). What is now needed is a number of large scale field tests, potentially on problematic materials such as mine tailings, similar to those carried out by Lo et al (1991) on soft marine clays in Canada. Only then will the true energy requirements of the technology become known.

There is also likely to be a great deal of work necessary to determine the filtration characteristics required of a geosynthetic in this type of application. The material being consolidated will have a fairly wet consistency and problems of blinding and clogging of the geosynthetic may become very pronounced.

Based on the results presented in this paper, it is possible to conceive of a range of strategies for stabilisation of mine tailings deposits using ekg's. Taking the extremely high water content diamond tailings thickener overflow as an example, a first phase of treatment could include the use of conductive geogrids suspended in the tailings to cause electrophoresis-induced settling out of solid particles from the slurry. Once a matrix of particles had developed, the geogrids could be removed and replaced by conductive geotextiles in the form of prefabricated drains (e-PVD's). Accelerated consolidation of the deposit could be initiated by applying an electrical potential between e-PVD's and it may only be necessary to maintain this potential for short periods of time until self-weight consolidation was well underway.

There are a number of problems to be overcome before a programme such as that envisaged above might come to fruition, but the potential benefits to be derived from being able to stabilise and rehabilitate potentially hazardous mine waste deposits make it certainly worth pursuing further.

5 CONCLUSIONS

The development of new generation geosynthetics that are electrically conductive has made it possible to envisage the dewatering and stabilisation of previously intransigent mine waste deposits. In this paper, two different techniques are discussed, both of which are aimed at addressing the above application. Firstly, electrophoretic sedimentation of extremely high moisture content slurries using conductive geogrids were shown to be extremely successful with a lead-zinc tailings and with a diamond tailings. In a separate programme of tests using a purpose-built electro-osmotic cell, specimens of diamond and mineral sands tailings tested under an imposed vertical stress of 25kPa showed a very large increase in initial settlement rates compared with control specimens.

While there is still a great deal of development work required before electro-kinetic stabilisation of large deposits of mine tailings becomes a reality, it seems that the introduction of electro-kinetic geosynthetics has a huge role to play in this regard.

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