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EVALUATION OF CAUSES OF BLEEDING OF FREE WATER FROM A BENTONITE SLURRY

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This paper describes an investigation into the bleeding behaviour of bentonite slurry observed on a trial diaphragm wall panel. The bleeding is thought to be due to the bentonite experiencing a chemical reaction leading to settlement of the solids within the fluid, possibly as a self-weight consolidation process. The trial panel was constructed in a busy airport environment where many different chemical products are used for de-icing the aeroplanes, runways, apron areas, vehicle access and pedestrian routes. The relationships between slurry contamination, bleeding, bentonite hydration time and filter loss behaviour were examined as no relevant published literature could be found. The results show that the amount of bleed strongly depends on both the degree of contamination and the hydration time. It is concluded that bentonite fluids should be allowed to sit in the storage tank for at least 24 hours after mixing, and that the filter loss test is a quick and effective method to determine the potential for bleeding of contaminated slurries.

INTRODUCTION

Balfour Beatty Ground Engineering (BBGE) completed the construction of a trial diaphragm wall panel at a busy airport site located west of London during December 2010. Since the trial panel was not to be incorporated into the permanent works, BBGE decided to take the opportunity to assess the effects of various site scenarios such as the impact of a long trench open time.

To achieve this, the trial panel was excavated on a Friday and was left open over a weekend. On the following Monday morning BBGE personnel observed that approximately 800 mm (32 in) of free water had collected at the surface of the slurry most probably as a result of bleeding, i. e. separation of free water from the bentonite slurry.

Figures 1 and 2 are photographs of the panel trench showing the clear bleed water region at the top of the slurry column. Figure 3 shows the diaphragm wall rig used and Appendix A briefly summarises the chronology of construction events.

Since the bottom of the bleed water region was lying close to the base level of the concrete guide wall, this raised concerns within BBGE that if this reoccurred during the construction of the working panels then their stability would be compromised. This is because if the bleed water region fell below the base of the guide walls, it would drain relatively freely into the underlying ground as little filter cake may have formed. This would reduce the hydrostatic pressure from the slurry which is essential to the stability of the panels.

The trial panel founded in London Clay at 15 m (50 ft) below ground level and the ground profile is as follows:

Made Ground: 0 m to 1.7 m (0 ft to 5.6 ft)

Sand and Gravel: 1.7 m to 6 m (5.6 ft to 20 ft)

London Clay: 6 m to >20 m (20 ft to > 66 ft)

Shallow groundwater table: 3 m (10 ft)

Figure 1 Bleed water in trial panel
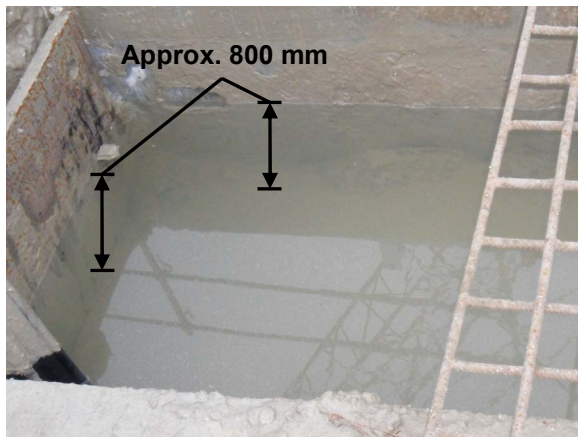

Approx. 800 mm

Figure 2 Close-up view of bleed water in trial panel

Figure 3 Diaphragm wall rig

As noted before, the trial panel was constructed in a busy airport environment. Therefore, during the winter many different chemical products were used for de-icing the aeroplanes, runways, apron areas, vehicle access, and pedestrian routes. Specialist chemicals are normally used rather than salt grit in order to withstand much lower temperatures and to prevent potential damage to the aeroplanes. Since the airport owner and the airlines are responsible for different parts of the airport's activities, they also tend to use many different de-icing products. Also due to their long history of use on the site, these chemicals may be present in the soil, groundwater or on the ground surface.

Because of this rather unique site condition, the bleed water observed in the trial panel was thought to be caused by these de-icing chemicals, although other factors such as mixing effort, slurry hydration time, and the quality of the mix water may also played an important role. The effect of mixing has been shown by Jefferis (1982) to be an important factor and it can be affected by the type of mixer used, the shear rate in the mixer, and the duration of mixing.

This type of bleeding is usually only a concern for cement-bentonite slurries, typically used in cut-off walls. Hence very little information exists about the behaviour of bentonite slurries potentially affected by contaminants in the ground during the excavation process.

To investigate possible causes of the slurry bleeding phenomenon and to devise a quality control plan for the permanent works, BBGE invited Environmental Geotechnics Ltd and the University of Oxford to carry out a laboratory-based study using materials recovered from the site. The first part of this investigation considered several potential catalysts and identified a particular type of solid de-icer named Clearway 6S being used on site as the most harmful to the bentonite.

This paper presents the result of the second part of the investigation, which contains work carried out using this particular type of de-icer to assess the combined effect of slurry contamination and hydration time on bleeding behaviour. The filter loss property was also considered in order to assess its suitability as a control test method on site.

MATERIALS

The bentonite used for the trial panel and for the laboratory work was Berkbent 163 supplied by Tolsa UK (www.tolsa.com). According to Tolsa, this is a sodium carbonate activated bentonite specially formulated for civil engineering work. This material has a moisture content of about 13% and a cation exchange capacity (CEC) of 85 meq/100 g. Probably as a result of the sodium activation process, it also contains a small amount of residual sodium carbonate which was found to be useful for removing the hardness of the mix water. This product is commonly used in the UK for geotechnical works such as piling and diaphragm walling. A dosage of 40 kg/m^3 w/w was used for both the trial panel and the laboratory study.

The solid de-icer Clearway 6S was supplied by Kemira (www.kemira.com). According to the supplier, this de-icer is based on the chemistry of sodium acetate trihydrate and magnesium acetate. If it is allowed to intermix with the bentonite fluids, the free magnesium ions might prevent the swelling and hydration of the bentonite particles and convert some of the sodium activated bentonite into magnesium bentonite. This would change the properties of the slurry and so increase the likelihood of settlement of the solids within the slurry, i. e. bleeding. Figure 4 shows the de-icer in its dry as-supplied form.

Figure 4 Solid de-icer Clearway 6S

The mix water used for the laboratory work was Oxford tap water. This water was shown to have similar pH (7.5), water hardness (250 mg/L), and electrical conductivity (600 µS/cm) to the London site water. No additional soda ash was added to pre-treat the tap water since the residual sodium carbonate in the bentonite powder was capable of removing 90% of the water hardness, i. e. from 250 to 25 mg/L, as shown in the preliminary tests using hardness test papers.

METHOD, RESULT AND DISCUSSION OF LABORATORY TESTS

Bleed Water Tests

A total of ten bleed water tests were undertaken under laboratory conditions to assess the combined effects of contamination and hydration time. The test procedures were as follows: 1) mix the bentonite slurry at 40 kg/m^3 using a high-speed mixer for 5 minutes, 2) for the 5-min hydration case immediately add the required amount of contaminant (solid de-icer) into the slurry and mix for a further 5 minutes, but for the 24-hr hydration case the slurry is allowed to stand for 24 hours before the contaminant is added, 3) pour the slurry into a 1-litre glass cylinder and seal the top with a plastic film material, and 4) record the amount of free water at 24, 48 and 72 hours. All of the bleed tests were stopped after 72 hours since it is the longest time expected for a slurry column to be left undisturbed on site, i. e. over a weekend. For each hydration case, four different levels of de-icer contamination were used, i. e. 2.5, 5.0, 7.5 and 10.0 kg/m^3 of slurry.

Figures 5 to 9 show the test samples for the 5-min hydration case after standing in the cylinders for 72 hours. Figure 10 also plots the relationship of bleed volume with time for these samples. The photographs of the 24-h hydration case samples are not shown since none of them showed any bleed.
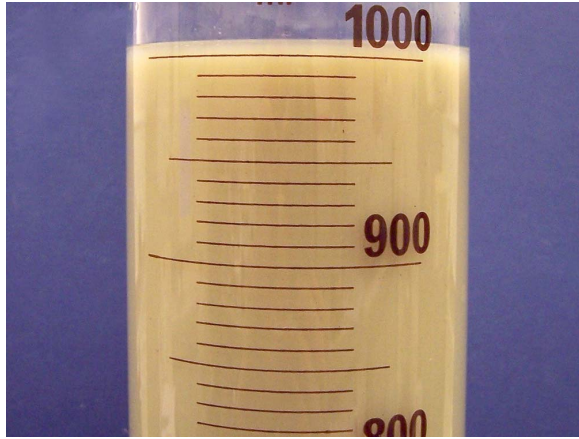
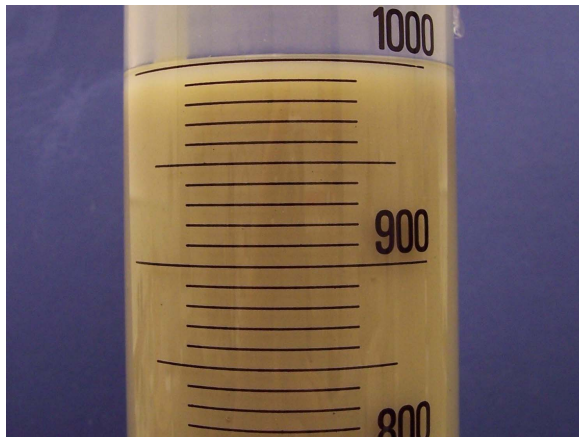Figure 5 Bleed test result - 5-min hydration and no contamination

Figure 6 Bleed test result - 5-min hydration and 2.5 g/L de-icer

As can be seen in these figures, the amount of bleed volume increases with the de-icer concentration, and at the end of the 72-h period the bleed was still continuing especially in the highly contaminated samples. This sort of behaviour is actually expected since high concentrations of magnesium ions have been associated with high bleed (Jefferis, 1992). However, what is unexpected is the complete absence of bleed shown by the 24-hr hydration samples. This is probably because the extra waiting time allowed the bentonite particles to swell and hydrate producing a slurry of finely dispersed bentonite platelets. Therefore if viscometer tests were also carried out, we would expect to see higher gel strength in the samples

with 24-hr hydration than those with only 5 minutes.

Figure 7 Bleed test result - 5-min hydration and 5.0 g/L de-icer

The findings from this series of tests basically mean that to minimize the bleeding of bentonite fluids (and other damage to the fluids) on a contaminated site, the best approach is to simply let the fluids to remain in the storage tank for at least 24 hours after mixing, preferably with some re-circulation of the fluid to promote dispersion of the bentonite, so that if they later become contaminated through use the adverse effect are minimised. The test results also seem to suggest that the young age of the bentonite fluid used for the trial panel, less than 24 hours, was part of the reason why bleed was found.

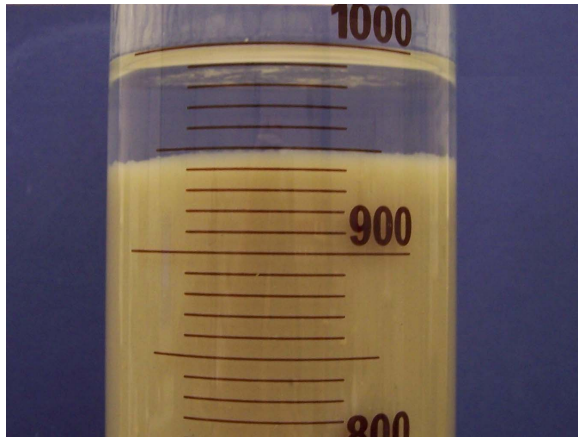Figure 8 Bleed test result - 5-min hydration and 7.5 g/L de-icer

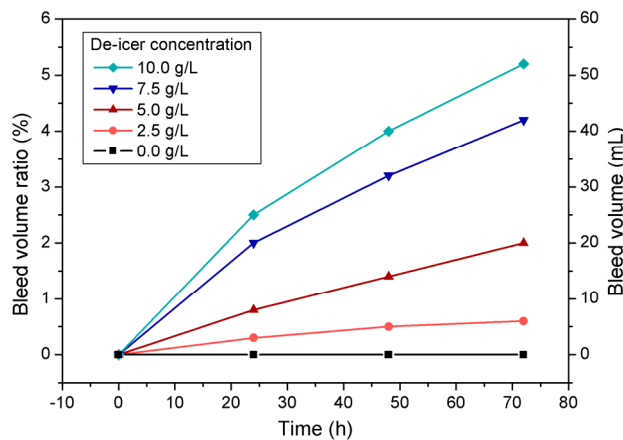Figure 9 Bleed test result - 5-min hydration and 10.0 g/L de-icer

Figure 10 Development of bleed volume for the 5-min hydration case

API Filter Loss Test

The bleed tests in the laboratory test cylinders showed that small scale bleeding is not a good indicator of the behaviour of bentonite fluids at site scale – as would be expected if bleed is a self-weight consolidation process.

The API (American Petroleum Institute) filter loss test, which has traditionally been used to assess the cake-building ability of bentonite fluids, was investigated as perhaps a better procedure than small-scale bleed tests to identify contaminant damage as bleed, fluid loss, and syneresis (expulsion of a liquid from a gel) are all results of a segregation process. Slurries which show high values for any one parameter may therefore show high values for the others.

For this reason, the filter loss test was included in the test programme to assess its ability to detect slurries which are likely to show bleed. To allow comparison with the bleed test results, the filter loss tests were carried out on the bleed test samples after their 72-hr readings had been taken.

The test measures the amount of filter loss when the slurry is subjected to a pressure of 100 psi (690 kPa) for 30 minutes in a standard API cell. Since the filtrate volume normally shows a linear relationship to the square root of time for which the sample is under pressure, the test can be terminated at 7.5 minutes and the filtrate loss reported as twice the 7.5-min value. This is a useful feature for sites with tight schedules although it does involve some potential inaccuracy as the filter loss versus square root time plot may not pass through the origin (see, for example, Figure 12). However, for this laboratory investigation the tests were run for the full 30 minutes and the amount of filtrate was logged continuously with an electronic balance. Figure 11 shows the exploded view of the API filter press.
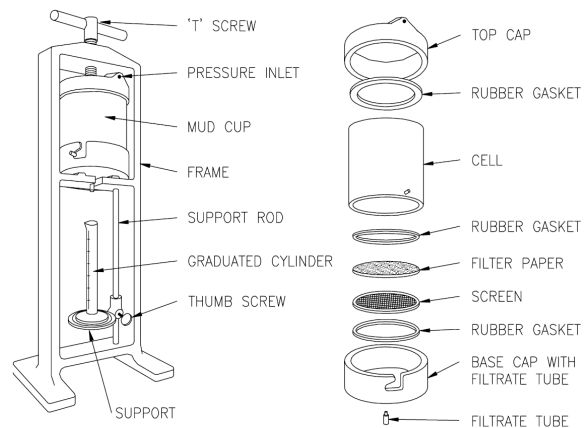

Figure 11 API filter press
(after Federation of Piling Specialists, 2006)

Figure 12 shows the effect of de-icer contamination and hydration time on the filtrate volume from the filter loss testing. As can be seen, all the samples showed the expected linear relationship to the square root of time but their filtrate volumes varied considerably. The 5-min hydration samples generally showed much higher fluid loss than the 24-h hydration samples and within each group the more contaminated samples also showed higher loss. The ability of the filter loss test to detect contaminated slurries

is very good indeed since it could even show the difference between the four 24-hr hydration samples when the bleed test could not (no bleed was found in any of them).

When considering the bleed and filter loss results together (Figures 5 to 12), it would appear that the 30 mL limit specified by the Federation of Piling Specialists (FPS) on filtrate loss after 30 minutes is a good guideline for site use as those samples with > 30 mL are more likely to bleed – though the actual indicator figure may depend on the type of bentonite used. This finding suggests that the filter loss test is a quick and effective indicator of damage to a bentonite slurry and the potential for bleeding on site. To our knowledge, the usefulness of the filter loss test for this purpose is not thought to have been reported previously.

CONCLUSIONS

This paper describes an investigation into the observed bleeding of a bentonite slurry in a trial diaphragm wall trench on an airport site where de-icer products are used extensively. As part of the investigation, the combined effect of de-icer contamination and slurry hydration time has been investigated by a series of laboratory bleed and filter loss tests. The results show that if bleed occurs, the amount of bleed will depend on both the degree of contamination and the hydration time of the bentonite fluid.

The filter loss test has been found to be very useful indicator of contamination damage to a slurry – damage which may cause bleeding on site but which is not identifiable in small scale laboratory bleed tests.
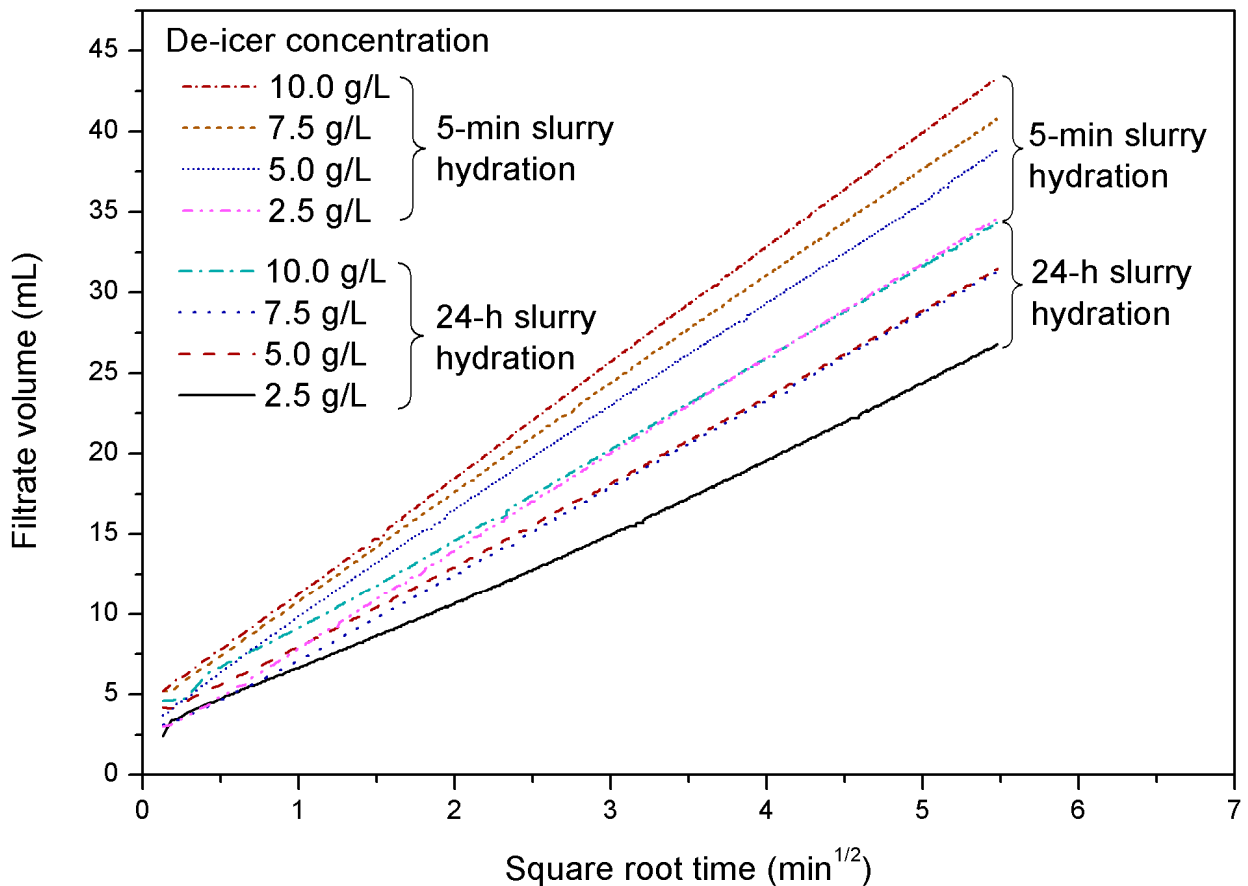

Figure 12 Filtrate loss of bleed test samples

Overall, the key issue is that contaminants such as calcium and magnesium, if at sufficient concentration, can effectively inhibit the swelling and dispersion of sodium bentonites. Short hydration times may be acceptable on sites where there is no contamination so that hydration can continue whilst the slurry is in use. However, on contaminated sites short hydration times may lead to only partial hydration of the bentonite and hence effectively the wasting of some of the bentonite. This also can occur when preparing cement-bentonite slurries as the calcium from Portland cement effectively prevents the swelling of the bentonite.

The results of this laboratory investigation helped BBGE to decide to revise their quality control plan such as to strictly enforce a minimum 24 hour hydration period, with slurry re-circulation, after mixing of fresh bentonite fluid (the slurry used in the first bite of the trial panel was about 12 hours old but was over 3 days old for the subsequent bites), and to include the filter loss test as a routine control test. This experience should also help other contractors to determine any future strategy to manage similar bleeding of bentonite slurries on contaminated sites.

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APPENDIX A : CHRONOLOGY OF TRIAL PANEL CONSTRUCTION EVENTS

Thursday – bentonite slurry was mixed at a concentration of 40 kg/m^3 using water delivered by a tanker.

Friday – excavated the first bite of trial panel of 3.1 m x 1 m x 15 m depth (10.2 ft x 3.3 ft x 49.5 ft) introducing the bentonite slurry during excavation. At the end of excavation for the day the slurry level was left 200 mm (8 in) below the top of the guide wall. The bentonite fluid was less than 24 hours old when it was used, being about 12 hours old.

Saturday and Sunday – panel and bentonite slurry left undisturbed.

Monday – upon returning to work it was observed that up to 800 mm (32 in) of water had separated with the bottom of the bleed water region lying close to the base level of the concrete guide wall. The surface of the fluid in the trench remained 200 mm below the top of the guide wall. The second bite at the opposite end of the panel was then excavated, again 3.1m x 1m x 15m depth, with the bleed water from the first bite intermixing with the bentonite slurry within the second bite as the slurry surged over the intervening soil column between the two bites.

Tuesday – about 100mm of bleed water was observed at the top of the slurry in the first and second bites. The unused slurry in the holding tanks was inspected and no excessive bleed was observed. The central third bite was then excavated.

Wednesday – about 50mm of bleed water was observed at the top of the slurry in the panel which was now fully excavated. The panel was then concreted.