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A procedure to colour sand grains

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ABSTRACT: In physical modelling, it is beneficial for tracking of soil movement, like image processing, when the tested soil shows contrast in colour. When a sand does not have sufficient contrast or when displacements in a certain area are of special interest, artificially colouring of sand particles may provide an outcome. However, colouring sand also involves some challenges. When working with water saturated sand, the colour should be water resistance. Besides this, also the interaction between the grains (friction angle and cohesion) and the water permeability of the sand matrix should not be affected by the painting. In this paper a method for colouring sand particles with limited effects of the paint on the sand behaviour is presented. Finally, some examples in which coloured sand has been applied are given to illustrate its added value.

1 INTRODUCTION

It is usual in physical modelling to select a uniform sand and to prepare the entire soil model using a consistent method. In this way it is tried to create a model with uniform characteristics. This approach leads to a low contrast in particle size and matrix structure and density over the model volume. However, this also has a drawback. It is namely usually hard to observe or visualize discrete shear bands and/or displacement patterns during or after an experiment. A possible way out to overcome this issue is adding contrast by application of sand volumes having each its specific colour. In this way, the other soil characteristics, like particle size, matrix structure and density, can remain uniformly distributed over the model volume. However, as generally a specific natural sand shows low variety in colour, the volumes must be coloured artificially, what in turn also brings some challenges. It is especially important that the mechanical and, in case of water saturated samples, the hygroscopic properties of the sand matrix are not affected by the layer of the paint. Besides this, the durability and the water resistance are of importance.

This paper describes a method to paint sand particles with limited impact on the mechanical and hygroscopic properties of the sand. This method was developed about 30 years ago but was not shared with the outside world before. After presenting the procedure and the selected ingredients, some examples of tests are included showing the benefits of applying coloured sand. The paper ends with some final remarks.

2 PROCEDURE AND INGREDIENTS

2.1 Preparing the colouring fluid

As the artificial colour must be water resistant, a waterproof ink must be selected, like refill ink for a permanent marker. As long sufficient contrast is achieved, different colours can be selected. Mixing the ink first with ethanol (before bringing this in contact with the sand), enables further treatment to limit the effects of the ink on the mechanical and hygroscopic properties of the sand. The most favourable ratio between ink and ethanol differs per ink type. Therefore it has to be investigated what works most optimal. For the examples presented in this paper, ratios varying between 1/30 to 1/60 were applied. As ethanol is a volatile liquid, it is advised to use a closeable barrel. After pouring the ink into the ethanol, the barrel should be closed off and the mixture should be shaken or stirred thoroughly. After that, the ink should get at least 30 minutes to dissolve into the ethanol.

2.2 Colouring the sand

Now, dry sand (oven dried) can be poured into the mixture, see Figure 1. This must be done carefully and in small amounts, such that air inclusions are avoided. Sand should be poured into the fluid until the moment no “free fluid” is available any longer to fully use the mixture, see Figure 2. For sands, typically 200 to 250 ml of fluid is required per 1 kg of sand. It is advised to arrange sufficient time for the sand to absorb the fluid (at least 30 minutes).

Figure 1. Pouring of the sand in the colouring fluid.

Figure 2. Sand poured in the colouring fluid.

Figure 3. Washing the sand with hot water using a sieve.

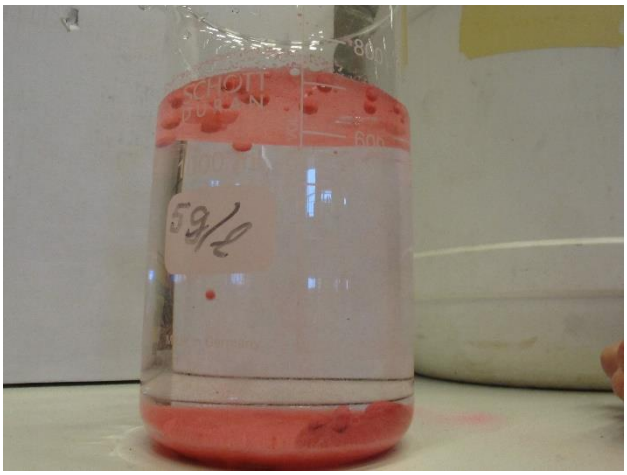

Figure 4. Example of greasy clumps of sand.

2.3 Further treatment and checks

The first step of the further treatment consists of rinsing out of the colouring mixture. This can be done by (i) washing the sand with hot water using a sieve with a sufficient fine mesh (the fines should not be washed out), see Figure 3, or (ii) via thoroughly mixing the sand with clean water in a barrel and siphoning the fluid after settlement of the sand. This must be repeated until the pore fluid has become sufficiently clean. A procedure to assess this is given below.

To assess the coloured sand, its behaviour in water can be investigated. For that, it advised to first dry a small amount of the coloured sand in an oven (105 °C for 12 hours). After cooling down, a small amount of the coloured sand can be poured into a clean transparent beaker partly filled with clean water. Afterwards a larger amount can be poured into the beaker. During pouring, the settling process should be looked closely at. When clumps of sand (including air intrusions) are observed and/or the sand looks greasy, see Figure 4, the sand needs further treatment.

The treatment steps as described above can be repeated, but degreasing with washing soda or a soap product might be possibly necessary:

- When using a washing soda (about 4 teaspoons on 5 kg of sand), it is advised to boil the mixture for half an hour. The contaminations and residues will float to the surface and can be skimmed or poured off. After this the mixture must be rinsed thoroughly with hot water and a small sample can be assessed again.
- When using a soap product, it is advised to apply about 1% of the water volume and to thoroughly stir the coloured sand and the soapy water, preferably overnight. A strong pump might be a solution to keep the mixture in motion. However, it is important to check whether the entire mass is in motion. After this the mixture must be rinsed thoroughly with hot water and a small sample can be assessed again

When a satisfactory result is achieved when pouring the coloured sand into clean water, the entire coloured sand volume can be dried in the oven. No

greasy clumps of sand (including air intrusions) should be floating at the water surface, see Figure 5. An adequate check is to compare the settling behaviour of the coloured and the non-coloured sand.

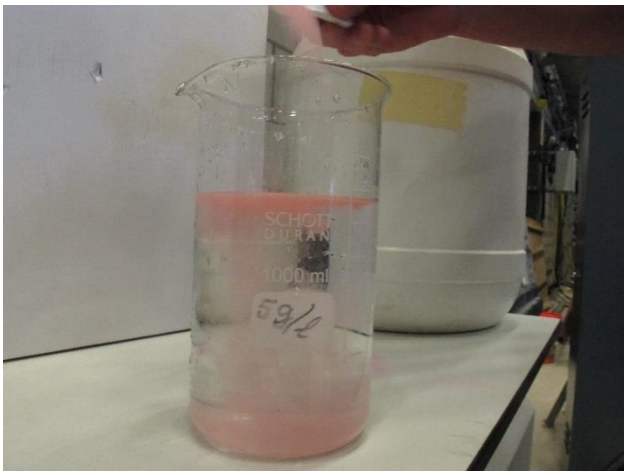

Figure 5. Example of adequately treated coloured sand.

3 IMPACT ON MATERIAL PROPERTIES AND DURABILITY OF THE COLOUR

3.1 Basic characterization tests

The effects of colouring of sand particles were assessed for sand from the Eastern Scheldt, The Netherlands. Figure 6 presents the particle size distribution of both the non-coloured sand (reference) and the sand after colouring (two colours). Besides assessing the effects on the grain size, also the minimum and maximum porosity (n_{min} and n_{max}) and the specific gravity (SG) were determined for both the non-coloured and the coloured sand, see Table 1. Based on these tests, it was concluded that the colouring procedure does not significantly affect one of these characteristics.

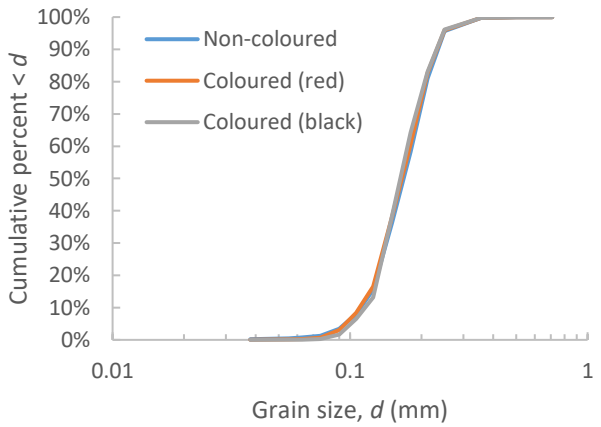

Figure 6. Particle size distribution of non-coloured and coloured sand.

Table 1. Maximum and minimum porosity and specific gravity of the non-coloured and the coloured sand.

Sample	n_{max} (%)	n_{min} (%)	SG (-)
Non-coloured	46.2	34.3	2.6475
Coloured (red)	46.2	34.5	2.6495
Coloured (black)	45.7	34.1	2.6495

The effect of the colouring on the sand permeability was not investigated. However, as neither the settlement behaviour in water nor the grain size distribution are affected, the permeability will be most likely not affected either. This can be further investigated.

3.2 Triaxial tests

Besides some basic sand characterisation tests, also consolidated drained triaxial compression tests were performed. The non-coloured and the coloured sand, all with initial porosity, $n = 41.4\% \pm 0{,}1\%$, were tested at two cell stress levels. The peak friction angles from these tests are presented in Figure 7. Here, a significant difference was observed in between the reference material (non-coloured) and the black coloured sand (almost 4°), while only a small difference was observed for the red coloured sand (< 1°). This difference in between the red and the black coloured sand shows the importance of the further threatening (rinsing). While the black coloured sand was only partly rinsed (not sufficiently), the red coloured sand was rinsed to a higher degree.

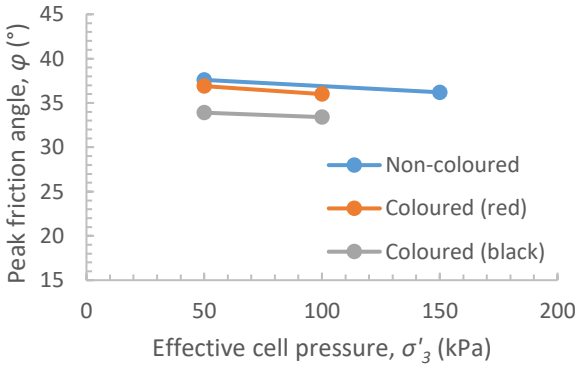

Figure 7. Peak friction angles derived from consolidated drained triaxial compression tests.

3.3 Durability tests

The durability of the paint was tested by (i) pouring the coloured sand in boiling water and (ii) keeping the coloured sand in water and in a viscous fluid for six months. No deterioration of the colour was observed in any of these tests.

Figure 8. Tunnelling (Bezuijen & Brassinga, 2005).

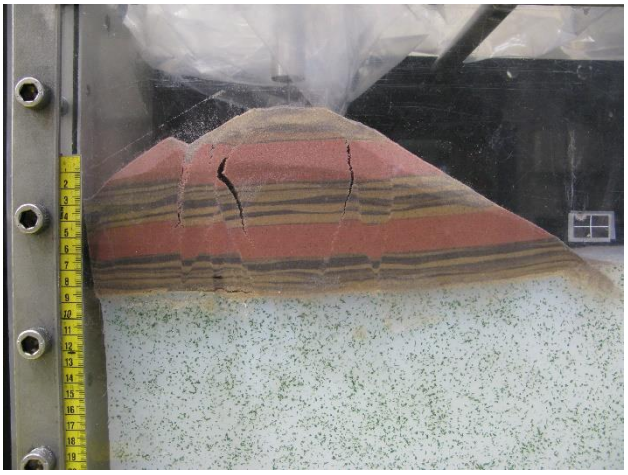

Figure 9. Dyke failure (Fern et al., 2017).

Figure 10. Cone penetration testing (after extraction of the penetrometer, the hole was filled with red sand).

4 EXAMPLES

Some examples of the application of coloured sand in physical modelling tests are given in Figure 8, Figure 9, and Figure 10. Coloured sand has been also successfully applied in combination with viscous pore fluids and for centrifuge testing.

5 HEALTH, SAFETY AND ENVIRONMENT

When considering applying the presented procedure, one should also consider health and environment. As ethanol is a volatile and flammable liquid, open fire should be avoided, and sufficient ventilation is of importance. It is also advised to wear safety glasses and gloves. Further, the residual products should not end up in the sewage, the surface water, or the groundwater.

6 CONCLUDING REMARKS

Colouring of sand particles can be very useful to visualize discrete shear bands and/or displacement patterns during or after an experiment. However, it has been observed and measured that water resistance ink, when applied directly to the sand particles without further treatment, affects both the mechanical and the hygroscopic characteristics of the sand. Therefore, a procedure has been developed to colour sand particles with only limited implications on the mechanical and the hygroscopic characteristics of the sand. The authors hope that sharing their experiences and the methodology developed will be useful for future tests in other institutions.

ACKNOWLEDGEMENTS

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