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The Effect of Pretreatment of Organic Matter on the Outcomes of Dispersion Tests

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SYNOPSIS Internal erosion in clayey soils is associated to the identification of dispersion as this can be a major contributing factor in piping failure of earth embankment dams. For dams constructed without filters and of poor construction, it is critical to understand the nature of dispersive soils so they can be treated or appropriate remedial measures applied. This paper describes tests carried out using the Double Hydrometer Test, a type of physical dispersion test, on a representative core sample from a Pennine-type dam in Yorkshire. The determined potential for dispersion is compared for the soil tested with pretreatment using hydrogen peroxide to remove organic matter and without pretreatment. As well as highlighting the importance of pretreatment in determining the potential for dispersion, the results demonstrate that the amount of soil used in the hydrometer test should be carefully considered to avoid both hindered settling (using too much soil) at one extreme and poor hydrometer response (using too little soil) at the other.

INTRODUCTION

Internal erosion is defined as the detachment of soil particles within a soil mass due to the flow of subsurface water. This process is associated with seepage and leakage, which may pose a safety issue for small dams, levees and dikes and a more significant threat to the long-term safety of large embankment dams. However, the mechanisms and parameters involved in the progression of internal erosion in non-plastic and plastic soils are distinctive and therefore the methods of assessment for the potential for internal erosion for these two types of soils are different. For example, internal erosion via suffusion in non-plastic soils develops when an internally unstable soil with poor gradation (e.g. gap grading) and underfilled voids leads to highly stressed particle contacts in the coarser fraction and loose erodible fine-grained particles in the soil's finer fraction (Ronnqvist & Viklander, 2014). Similar associations of local packing and seepage flow are behind other forms of internal erosion in non-plastic soils, such as contact erosion and concentrated leak erosion. In contrast, the process of internal erosion in plastic or cohesive soils typically develops when water flowing through a crack removes material from the walls of the crack and transports it into the interstices of the downstream shoulder, foundations or drainage system; this process is closely linked to the identification of dispersive clays (Atkinson et al, 1990).

Dispersion

The presence of dispersive soil can be a major contributing factor to piping failure of earth embankment dams, particularly for dams constructed without filters and of poor construction (Jeyabalamoorthy, 2007). Dispersive clays are soils in which the physico-chemical state of the clay fraction of the soil is such as to cause individual clay particles to deflocculate / disperse and repel each other in the presence of relatively pure water and are therefore highly susceptible to erosion and piping (ICOLD, 1990). Granular soils can dislodge and move in water and may be highly erodible, but the internal erosion process is mechanical. Erosion in embankments constructed with dispersive soils occurs in areas of high crack potential such as around conduits, at the contacts between zones of incompatibilities of stresses, strains and deformations both within the embankments and at foundation and abutments or in areas of desiccation cracks, differential settlement cracks, saturation settlement cracks and / or during hydraulic fracture (ICOLD, 1990).

Several methods for identifying dispersive clays have been proposed, these include the following tests: Physical Tests including Crumb, Pinhole, Double Hydrometer (also known as Dispersion Test) and Chemical Tests including Sodium Adsorption Ratio (SAR) and Percentage of the Exchangeable Sodium Cation (ESP) and a number of different Auxiliary Tests (grading, Atterberg limits, pH, etc.). However, researches on identification of dispersive soils have not yet established a single test that will identify dispersive soils. Coupled with this, it has been observed that identification of dispersive clays by visual description and classification index tests (i.e., gradation, Atterberg limits) is not sufficient to conclude the potential of soils for dispersion (ICOLD, 1990). On the contrary, studies have shown that physical and chemical tests may indicate different dispersivity classes and dispersivity potential cannot be established accurately using a single test method. It has been concluded that the erodibility of materials having the same appearance and index properties can vary even at short distances and that the dispersiveness of susceptible materials may increase with time.

The aim of this paper is to provide some preliminary outcomes of on-going research on the identification of dispersive soils in the UK, with a focus on Double Hydrometer testing on a clay core sample from a Pennine-type dam. We compare the results of tests on clayey soil pretreated for organic matter with that not pretreated. We also compare with results of tests undertaken by a commercial contractor on samples from nearby in the same dam core. From the outcomes we suggest some changes to practice that may improve the outcomes from hydrometer dispersion tests.

Investigation in the UK

The majority of the old Pennine-type dams in the UK were constructed with a puddle clay core and without the benefit of modern-day well-designed filters; selected fill however was placed next to the puddle clay core. This selected fill was more cohesive than the general embankment fill and might function as a filter (Tedd et al, 1987). Frequently the cut-off was a deep puddle clay filled trench excavated in an open jointed rock which might not offer any protection against erosion. Where the puddle clay in an embankment or its foundation is unprotected, the internal stability of the soil in the fill and foundations when subjected to drag forces from seepage and leakage is critical to the long-term performance of the dam. That is, while all clays will erode under severe conditions, in assessing the performance of existing structures it is important to determine the working erosion resistance of puddle clay core dams.

The specifications for the creation of puddle clay are indicated in the following criteria (Moffat, 1990), (it should be noted that this specification was developed in the 1940s but the general criteria prior to this generally remains the same):

- tenacious clay will not disintegrate when a well kneaded ball of 75mm diameter is immersed in water for at least 48 hours;
- sand content of 10% to 25% is considered desirable to control shrinkage;
- sand content of 40% to 50% is accepted if uniformly distributed in the clay matrix; and
- grading and consistency limits.

On this basis, it can be concluded that the cores of the Pennine-type dams may be clay rich or deficient and plastic or non-plastic, and as such, the cores could lie between the classic definitions of unstable due to low-plasticity granular instability or dispersion.

Within the UK, physical dispersion tests are the most common (and frequently only) type of laboratory test undertaken to assess the potential of soils for internal erosion and often the conclusions in the assessment are inconclusive. Physical dispersion tests such as Pinhole, Crumb and Double Hydrometer are scheduled for testing on soils undertaken during ground investigation across various numbers of samples. Often one type of testing dominates the others, while sometimes very limited testing is undertaken on an incorrect type of material (i.e. one that is granular) indicating that the understanding of both physical and chemical properties of dispersive soils is not strong. It should be noted that soil dispersivity tests do not measure the erodibility of soils per se, but measure dispersivity as an index of the likelihood of initiation of erosion.

DOUBLE HYDROMETER TESTING

Sample Location

The research undertaken by the authors includes collection of soil samples from various Pennine-type and Modern embankment dams in the Yorkshire and Northumbrian regions for both physical and chemical dispersion testing. In this paper, the soil sample considered was taken from the core of a reservoir which is dubbed here "Reservoir X", which is a typical "Pennine" type embankment of the mid-late Victorian era. This reservoir and its neighbouring reservoir were constructed in the 1870s. The embankment has a crest length of over 600m and a maximum height of 20m, with an overflow located at one end. The structure was zoned with a central puddle clay core. Selected clayey material was placed in inner zones on either side of the clay core with thicker layers of more stony material in the outer zones. The dam embankment was made watertight by the puddle clay core, which was carried down into a cut-off trench, with the depth of the cut-off trench varied along its length up to 18m deep. The deeper sections of the trench were partly infilled by concrete.

Superficial Deposits are shown to be absent across the reservoir, however peat is shown across the wider valley area in the western and southern regions. The solid geology comprises Millstone Grit Group bedrock that underlies the reservoir, and which is characterised by grits and sandstones, interbedded with siltstones, mudstones, marine shales, thin coal seams and seat-earth. There are no mapped faults passing beneath the reservoir basin or dam. Areas of landslip are shown on the geological mapping across the wider valley area, the closest area being approximately 150m away from the reservoir.

Managing Risks for Dams and Reservoirs

It is understood that there have been no serious reservoir safety incidents associated with the reservoir, however there is little information as to how the dam embankment performed in its first half-century. There is a variation in embankment settlement in some of the banks despite the relatively small difference in the height of the banks, with a maximum settlement of 117mm recorded over the last 27 years. The surface of the downstream shoulder is very irregular when compared to many nearby dams of similar age and recorded variable drainage flows indicate that leaks could initiate, develop, and enlarge through internal erosion and that flow may be by passing the measuring points. In the late 1990s a small cavity was discovered near the downstream toe of the embankment. This was subsequently investigated and the cavity was tentatively attributed to the possible presence of a timber post that had been incorporated into the face of the embankment which had subsequently rotted away.

Sample Description

A ground investigation (GI) was undertaken on Reservoir X in 2022 as recommended in a Section 10 report for the reservoir, under Section 10(2) of the Reservoirs Act, 1975. A bulk sample of the clay core was taken from 11.5m depth in a borehole (denoted “BHA”) located on the crest of Reservoir X; this sample was tested using the Double Hydrometer method with the results presented in this paper. This sample is described as very soft to firm, greyish black, slightly gravelly, slightly sandy, very silty CLAY.

It should be noted that a Double Hydrometer test was also undertaken by the GI Contractor on another clay core sample at 6.5m depth in borehole (“BHB”) located approx. 60m from BHA, as scheduled by the Consulting Engineer.

Sample Preparation and Testing

The Double Hydrometer test for BHA 11.5m was undertaken with reference to BS1377 (Head, 2011). This test is based on the degree of dispersion of clay particles achieved during a hydrometer test. The test compares the percentage of clay in a sample that has been artificially dispersed to that of another sample which has no artificial dispersing agent added. The dispersion is taken as the ratio of the percentage of clay (particle diameter 2 microns in BS standards and 5 microns in other standards i.e. ASTM) of Sample A to Sample B (see description below). Common criteria for evaluating the results are outlined in USBR 5405 (Umesh et al, 2011) with a value of <30 taken for non-dispersive soils, a value of >50 for highly dispersive soils and anything between 30 and 50 indicating moderately dispersive soils.

Double Hydrometer Testing in BHA 11.5m

The recommended mass of test specimen was approximately 100g, which is the amount recommended for soils with particle diameter up to 2mm with any gravel size particles comprising <10% of the sample. The Wet Sieving method was used for the silty clay soil samples (for sizes less than 2mm) down to a particle size of 63 microns. Sedimentation by hydrometer test was subsequently undertaken on the remaining soil with at least 15% of fines passing the 63 micron sieve. For clay, Head (2006) recommends a mass of soil used for sedimentation (i.e. using hydrometer) of 30g, but he also notes that the mass may depend on the type of soil, stating that too much soil can prolong a test unnecessarily and too little soil can provide unreliable results. Hence, it is recommended that if in doubt, trial tests should be undertaken. Prior to testing the 20g of soil sample (as discussed below in Test 2), hydrometer testing on other core samples from other boreholes in Reservoir X was undertaken on a 30g soil sample, however, hindered settling was still observed using this mass of sample.

In this paper, the first set-up includes 100g for the original sample (Test 1), with the sample being pretreated for organic matter. It should be noted that the BS standard (BSI, 2016) indicates that organic matter present must be removed by chemical treatment (known as the pretreatment stage) prior to the sedimentation test (either via pipette or hydrometer test). The set-up includes the following:

- Sample A: Pretreated main specimen (after drying) and hydrometer test without mechanical stirring and using distilled water only.
- Sample B: Pretreated main specimen (after drying) with standard hydrometer sedimentation test with mechanical stirring and dispersant solution (33g of sodium hexametaphosphate and 7g of sodium carbonate in distilled water for a 1L dispersant solution).

It was also noted in Head (2006) that for inorganic soils, pretreatment is not necessary, however where the effects of pretreatment on the results are uncertain, parallel tests should be carried out (with and without pretreatment on two similar specimens). To check the effect of removing organic matter on the dispersivity of soil, the recommended parallel tests were also prepared for the same sample as above, again using 100g as the initial soil quantity.

- Sample C: as sample A but not pretreated.
- Sample D: as sample B but not pretreated.

A second set-up (Test 2) was undertaken using a 20g mass of main specimen after it was observed that 'hindered settling' had affected Sample B in Test 1. Hindered settling is further discussed in the Results section below.

The pretreatment of soils utilised the addition of 150ml of hydrogen peroxide on the dried mass specimen, allowing the sample to stand overnight, then heating and boiling the pretreated sample the following day until the volume of liquid was reduced to about 50ml. Simultaneous to the pretreatment for organic matter, a further check for the presence of calcareous matter was undertaken by adding HCl to a small portion of the sample to check if acid pretreatment was also required; the sample did not react with HCl. The samples pretreated for organic matter (Samples A and B) were then filtered and dried, with the pretreated dried mass subtracted from the untreated dried mass of the original specimen to derive the percentage loss of organic matter.

Double Hydrometer Testing in BHB 6.5m

The Double Hydrometer Test undertaken for a sample from BHB at 6.5m depth was undertaken by the GI Contractor with reference to BS 1377 (BSI, 2022) which refers to the hydrometer sedimentation test in BS EN ISO 17892-4 (BSI, 2016). In this updated standard, the use of hydrogen peroxide to remove organic matter is given as optional only (Clause 4.5.4) while pretreatment to remove organics prior to sieving, if required, should state the method on the test report together with the amount of material removed. Furthermore, Clause 5.3.2.4 indicates that pretreatment is recommended if organic material and/or carbonate compounds are present – but this statement is less strong than the recommendation by Head (2006) to check for the influence of organics and which makes reference to BS 1377 (BSI, 1990).

It is also noted in Clause 5.3.2.1 that the initial soil specimen, prior to preparation, should be large enough to give 20g to 30g of material smaller than 63 microns and that a suspension concentration of around 25g of sediment smaller than 63 microns per litre of solution is regarded as ideal.

For the GI report, no details of the amount of original mass specimen or mass that went in the hydrometer testing and details of pretreatment were provided. It is possible that 100g of soil specimen was used and / or that no pretreatment of soil was undertaken. This information is observed to be generally absent in all GI factual reports that the researchers have seen to date.

RESULTS AND DISCUSSION

Table 1 shows a summary of Double Hydrometer test results for Test 1 and Test 2.

Table 1. Double Hydrometer Test Results for Soil Sample taken from Reservoir X

Properties	**BHA 11.5m**			
	Pre-treated		**Not Pretreated**	
	A	**B**	**C**	**D**
Test 1 - Original mass of specimen approx. 100g (see Figure 1)				
Dry mass of specimen (g)	79.97	80.91	77.21	86.23
Moisture content (%)	21	21	23	23
Organic Matter lost after PT (g)	2.65	4.13	-	-
Organic Matter lost after PT (%)	3.31	5.1	-	-
Total dry mass ≥63μm (g)	6.94	10.14	37.50	14.13
Total mass for hydrometer test (g)	70.38	66.64	39.71	72.10
Percentage clay (passing 2μm) (%)	22	21	8	42
Dispersion (% clay A/B or C/D)	≈100		19	
Test 2 - Original mass of specimen approx. 20g (see Figure 2)				
Dry mass of specimen (g)	16.67	15.62	-	-
Moisture content (%)	21	23	-	-
Organic Matter lost after PT (g)	0.27	0.26		
Organic Matter lost after PT (%)	1.62	1.66	-	-
Total dry mass ≥63μm (g)	1.62	0.07	-	-
Total mass for hydrometer test (g)	14.78	15.29	-	-
Percentage clay (passing 2μm) (%)	37	53	-	-
Dispersion (% clay A/B)	70		-	

Notes:
Samples A and C – without mechanical shaking and dispersant
Samples B and D – with mechanical shaking and dispersant

Test 1 - Original mass of specimen approx. 100g

Figure 1 shows the PSD curves for BHA 11.5m Samples A to D, where samples A and B correspond to pretreated samples without dispersant and mechanical shaking and with dispersant and mechanical shaking, respectively. It can be seen that the curve flattens within the silt region for Sample B, indicating the occurrence of hindered settling of silt. Hindered settling is the reduction of sediment settling velocity at increasing sediment concentration due to grain interactions (Te Slaa et al, 2012). This was also observed on a localised level (within the medium silt region) in Sample A. The readings in Samples A and B are therefore considered inaccurate, as indicated by the estimated derived dispersion of 100.

The pretreatment percentage loss of organic matter found for Samples A and B are 3.3% and 5.1%, respectively. Based on BS EN ISO 14688 (BSI, 2018), soils with organic content of <6% are considered to be "low" in organics.

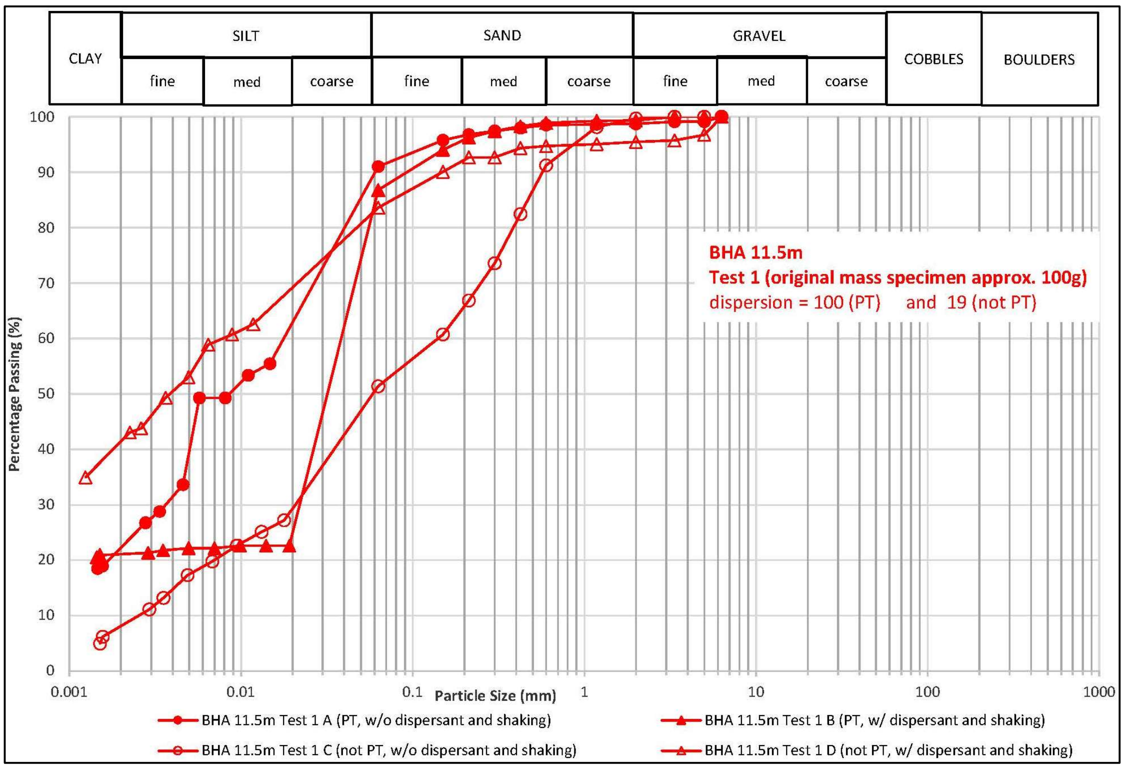

Figure 1. Plot of double hydrometer test results for BHA 11.5m Test 1 (original mass = 100g, mass for hydrometer test = 40 to 72g)

Test 2 - Original mass of specimen approx. 20g

To resolve the issue on hindered settling, various amounts of similar soil specimen were tested. It was observed that the hindered settling on Test 1 Sample B could only be avoided by using an original soil specimen mass of 20g (resulting in the mass of soil sample tested in the hydrometer being 15g, which is less than the baseline value recommended by Head, 2006). Figure 2 shows that the dispersion ratio from Samples A and B is 70 and an organic matter content of <2% was lost during the pretreatment. This test demonstrated that the degree of dispersion of soils determined using the Double Hydrometer Method is sensitive to both the amount of soil being tested and by pretreatment.

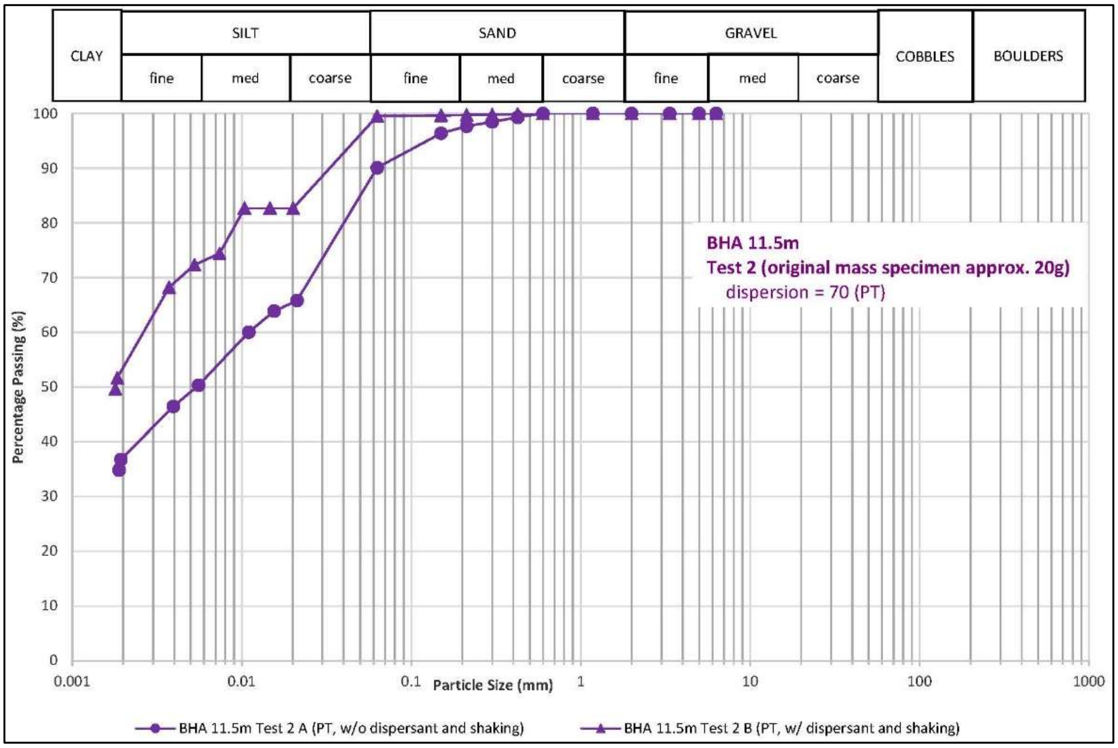

Figure 2. Plot of double hydrometer test result for BHA 11.5m Test 2 (original mass = 20g, mass for hydrometer test = 15g)

Test for BHB 6.5m

Table 2 and Figure 3 show a comparison of the amount of clay measured for the not pretreated samples in BHA 11.5m (Samples C and D) and BHB 6.5m (Data A and B). The amount of clay in Samples C and D are almost the same amount as those in Data A and B. Furthermore, the degree of dispersion measured (19 and 14) are also almost similar for both datasets with both results suggesting non dispersive soils.

Figure 4 shows that the samples with mechanical shaking and dispersant (Sample D and Data B) follow a similar trend. Although the other two samples, Sample C and Data A, do not show a similar trend, the amounts of clay measured in these samples are similar at 8% and 5%, respectively.

Table 2. Comparison of Double Hydrometer Test Results for BHA 11.5m and BHB 6.5m

Properties	**BHA 11.5m (Original mass of specimen approximately 100g, Not Pretreated)**		**BHB 6.5m (unknown mass, unknown if Pretreated or Not Pretreated)**	
	C	**D**	**Data A**	**Data B**
Percentage clay (passing 2 μm) (%)	**8**	**42**	**5**	**37**
Dispersion (% clay A/B or C/D)	**19**		**14**	

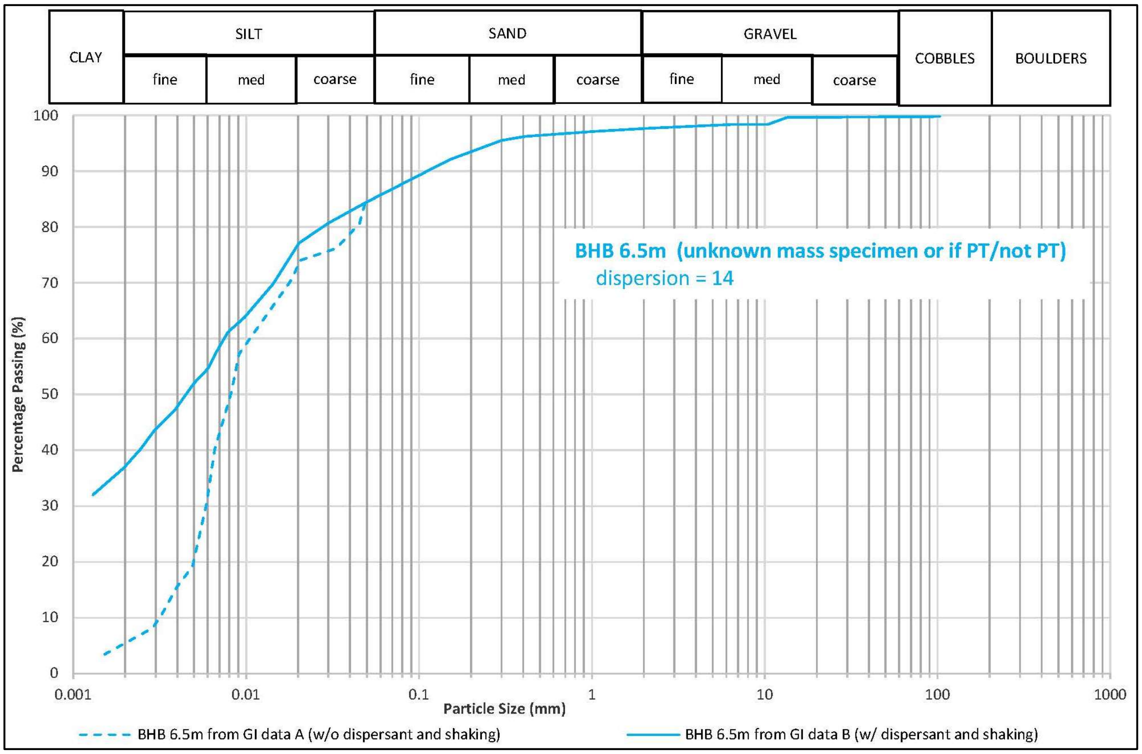

Figure 3. Plot of double hydrometer test results for BHB 6.5m (unknown mass of specimen and unknown if sample was pretreated for organic matter content)

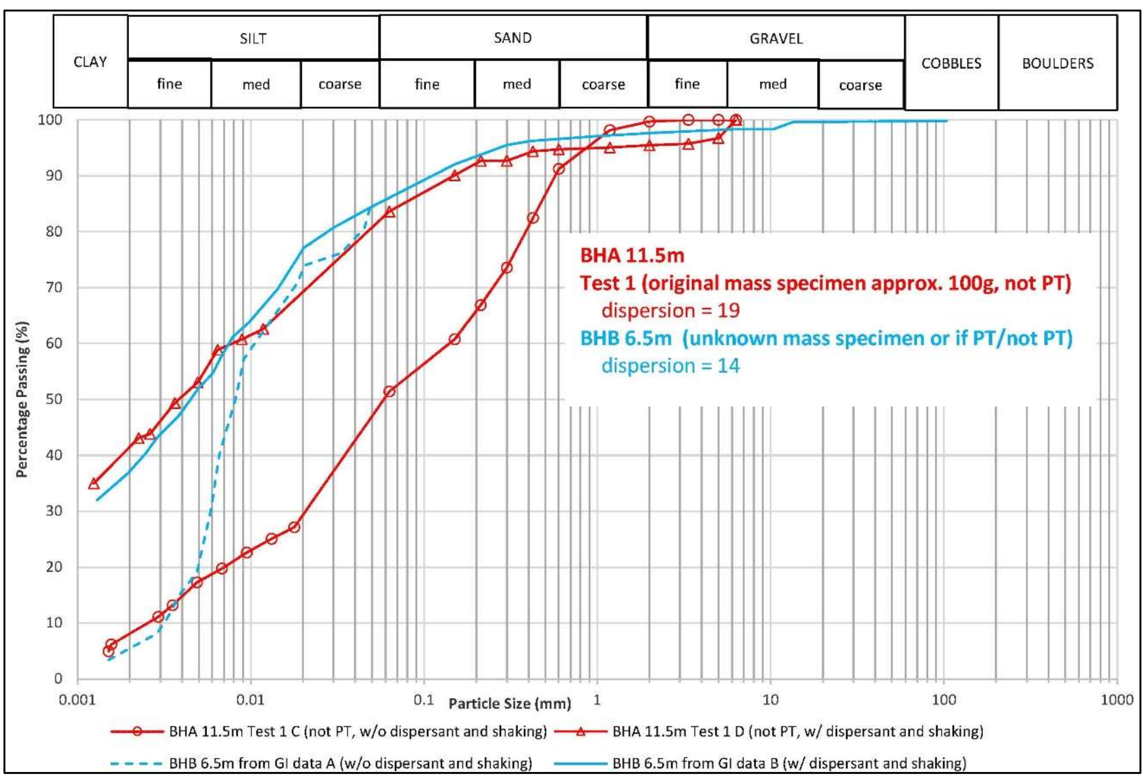

Figure 4. Comparison of plots of double hydrometer test results for BHA 11.5m and BHB 6.5m

DISCUSSION

On the basis of the above, it can be assumed that the Hydrometer Testing on BHB 6.5m undertaken by the others during the Ground Investigation in Reservoir X did not undergo pretreatment of organics, showing a degree of dispersion of 14 that indicates the soil tested is non dispersive (Degree of Dispersion <30). In contrast, where soil tested is pretreated for organics (BHA 11.5m Samples A and B using 20g original mass specimen or 15g soil for hydrometer testing), the degree of dispersion was found to be 70, classifying the soil as highly dispersive (Degree of Dispersion >50).

Organics may act to inhibit dispersion, but their presence can be highly variable within a dam. The treatment of soil to remove organics in the clay prior to hydrometer testing ensures that the underlying nature of the soil is revealed. It should be noted that six organic content tests (test standard not specified) were undertaken by the GI contractor on clay cores taken from other boreholes on the crest of Reservoir X, ranging from 1.4 to 4.8%. The measured organic content in BHA 11.5m for the 100g soil specimen ranged from 3.3% to 5.1% and about 1.7% using the 20g soil specimen. The variation in the percentage loss can be attributed to the heterogeneity of the soil, such that sampling a larger amount of soil will possibly include more organics from the bulk sample, while soil with smaller samples may be highly variable in general.

CONCLUSIONS AND ONGOING RESEARCH

The amount of soil tested for Double Hydrometer Testing should be sufficient enough (not too high and not too low) in order to provide the best dispersion test results. It may be necessary to conduct several hydrometer tests in order to establish what the most appropriate amount of soil is, in order to avoid hindered settling on the one hand, and a generally poor result through lack of soil on the other. The use of pretreatment should be routine, even where soil organics are found to be low. This is because, while the presence of organic material may reduce the dispersivity of a clay, its presence may be highly variable within a dam.

Further investigations are currently being undertaken by the authors on core samples, shoulder fill and natural soil samples from various reservoirs, predominantly in Yorkshire and Northumbrian regions, to better establish the criteria for dispersion; these include physical dispersion tests (Crumb, Pinhole and Double Hydrometer) and chemical dispersion tests comprising X-Ray Diffraction (XRD) and determination of Total Dissolved Solids (TDS). The erosion properties of soils that will be identified using these various methods will be further investigated through a Hole Erosion Test (HET) apparatus currently being constructed in the university where the authors are affiliated. The erosion rate index obtained from HET will give a guide to how quickly a pipe will develop in a dam.

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