Fine sediment properties: determination, interpretation and use

Winterwerp Johan C.[1,2], Claire Chassagne[2], Maria Ibanez[2], Miguel de Lucas Pardo[1], Thijs van Kessel[1], Walther van Kesteren[1] and Bram van Prooijen[2]

[1] Marine and Coastal Management, Deltares, PO Box 177, 2600 MH, Delft, the Netherlands
E-mail: han.winterwerp@deltares.nl

[2] Section of Fluid Mechanics, Civil Engineering and Geosciences, Delft University of Technology, PO Box 5048, 2600 GA, Delft, the Netherlands

This paper describes the methods and protocols developed over the last decades at Deltares and Delft University of Technology to determine the chemo-physical properties of fine sediments, the interpretation of the results, and their application in research, consultancy studies and numerical models.

Our methods are based on laboratory analyses of grab samples collected from the sediment bed. These samples may have been disturbed/moulded. However, it is crucial that the water content of these samples is not altered, i.e. we require the in-situ bulk density of the samples. The first series of analyses comprise determination of the sample's dry density, and the organic and carbonate content, and the salinity of the ore water. Generally, we use Dutch standard protocols, or differently when requested by our client.

One of the key parameters for fine sediment charaterization is the particle size distribution. A crucial step in this determination is sample preparation. For use in empirical soil mechanical formulations, samples are depleted of organic components and carbonates, dried, and ground again in a mortar. Assessment of the unflocculated particle size distribution requires removal of organics and carbonates (using H_2O_2 and HCl), whereas these components should be maintained if the distribution of the flocculated sediment is required. It is widely known that different instruments can yield very different particle size distributions, for the same material. Infamous are the differences between optical methods (Malvern) and methods based on Stokes' law, such as Sedigraph, Hydrograph, sedimentation balance and Pipette method. We show that by a proper separation of the samples in sub-samples (through sieving and sedimentation), these instruments however do yield almost identical results (Chassagne, in prep.). By plotting the results in a triangular diagram (sand-silt-clay) we get a first impression on whether the sediments at the study site are of one origin only, or whether sources containing sediment with different composition/properties play a role.

Next, we determine the Atterberg Limits determining Plastic Limit (PL), Liquid Limit (LL) and Plasticity Index (PI). From the Plasticity Chart (PI vs LL) we get a first idea on the relevant clay minerals (by comparing with literature values for individual clay minerals), and whether the Atterberg Limits have been measured properly. From the Activity Chart (PI vs clay content) we establish whether the bed from which the sample was taken depicts cohesive or non-cohesive behaviour.

More insight into the sediment properties and clay minerals is obtained from determining the zeta potential, for which we remove the organic fraction and carbonates. We always measure the zeta-potential at a variety of pH-values (by adding HCl), and sometimes also the salinity is varied (mono- and divalent salts, Chassagne *et al.*, 2009, Tsujimoto *et al.*, 2013; Ibanez *et al.*, 2014). By comparing with literature values for individual clay minerals, we get more information on the mixture of minerals in the sample. Moreover, these analyses yield qualitative information on flocculation behaviour of the sediments, and the size and strength of the flocs to be expected in the water column, of course assuming that sediments in the bed and in the water column are of the same origin.

The undrained strength of the sediment, as a function of its dry density (water content) is determined with undrained vane measurements. Done properly, the peak and undrained strength of these measurements should not differ too much (~10%), and both values can be used in further interpretation. We assume self-similar properties of the sediment, which implies power-law behaviour. When plotted against the content of fines (<64μm), we obtain the fractal dimension of the soil, which is a measure for its structure.

Small-scale consolidation experiments are done with the CST-instrument (Capillary Suction Time). Diluted and pre-consolidated sub-samples are put in a small container (few cm^3) upon which the CST

is measured. These analyses provide parameters describing the permeability and effective stress of the soil as a function of bulk density. Again assuming self-similar behaviour, we obtain a second value for the fractal dimension, which in general proves to be identical to the one obtained from the vane tests.

We also carry out meso-scale consolidation experiments in settling columns of 0.5 – 1m height. We prepare three mixtures at concentrations below the gelling concentration, and follow the interface over time. Ideally we measure the vertical dry density distribution in the consolidated bed at equilibrium. From analysis of the hindered settling phase, we obtain the undisturbed settling velocity of the sediment and its gelling concentration. From the consolidation phase, we obtain again the parameters for permeability and effective stress, again assuming self-similar behaviour (Merckelbach and Kranenburg, 2004; Winterwerp and van Kesteren, 2004).

When all these analyses have been performed properly, we obtain identical/similar values for the various parameters. As some of these analyses are more laborious than others (in particular zeta-potential, vane test and CST-measurements are fast and very cheap), we set up a hierarchy in these experiments, which allows for a space covering picture of the open water body to be studied at relatively small costs. This picture adds to our system understanding of a specific site, helping to set up numerical models for assessing fine sediment dynamics. Moreover, the information on the fractal dimension yields the ratio between mass and volume concentration of the soil, an indispensable parameter when assessing maintenance dredging needs.

Also we deploy the Gust micro-cosm for erosion experiments on undisturbed cores from the field to compare with erosion parameters obtained from the soil mechanical analyses. As this instrument is accurate up to stresses of about 0.8Pa only, the micro-cosm is applicable for soft soils only. Finally, we developed an in-situ floc camera obtaining direct information on floc size and settling velocity.

The parameters obtained give us direct information on the erodibility of the soil, as described in previous publications of the authors (Winterwerp *et al.*, 2012).

Finally, in our full paper we will show some application of the method through elaboration of two case studies in which our method provided valuable data for setting up our numerical models. In fact, without these analyses, we would not have been able to obtain any credible model result at all.

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