A rheological lab measurement protocol for cohesive sediment

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Flanders Hydraulics, together with Antea Group, DOTOcean and KU Leuven, executed a long-term research project to obtain the necessarily tools and method to map the (true) yield stress, dynamic viscosity and thixotropy of cohesive sediments for nautical and dredging applications.

This paper describes a method to map the rheological behaviour of cohesive sediment. The protocol is designed to give a minimum set of rheological parameters to characterize a mud sample. It should be practical (can be completed in a limited amount of time) and robust (give reproducible results). This should allow for comparative research, in which the rheological characteristics of mud samples at different stages of consolidation, or mud samples of different origin or composition can be compared.

The protocol is designed to be used with a vane-type rotational rheometer that can perform both shear stress and shear rate controlled experiments. It is important to note that the proposed type of rheometer is not equipped with a spring, but with air or magnetic bearings instead.

The full measurement protocol with its different stages is illustrated in Fig. 1. In the first stage of the experiment, the undisturbed sample is subjected to a stress growth test [1], applying a constantly increasing strain at a constant shear rate, and monitoring the stress build-up over time. Shear stress at a deformation rate of 1 rev/min is recorded for 30 seconds, and the maximum stress value is recorded. This value is reported as the 'peak yield stress at x rev/min', which is related to the undrained shear strength.

Before executing any other tests, the mud sample has to be fully sheared, which is done by shearing the mud sample at the highest possible speed (1000 rev/min) for 15 seconds [2]. This step creates a fully homogenised disturbed sample. A structural equilibrium is obtained and can be used as a reproducible reference stage to execute the next steps.

This is followed by an applied rotation speed for 100 seconds to reach an equilibrium 'instrument' shear stress (or torque) [3]. The necessary time trajectory of the instrument shear stress (calculated out of the measured torque and the dimensions of the vane) to maintain the applied rotational speed leading to an equilibrium is recorded. The shear stress equilibrium values will be used for dynamic viscosity modelling (see below) and the time-trajectory for thixotropic modelling.

Directly after an equilibrium is obtained in the previous stage, a 'Dullaert test' (Dullaert, 2005) is applied [4]. During this test a minimal rotation speed of 0,001 rev/sec is applied for 6 seconds. A very quick sampling rate of 200 samples/second is recorded. Hereafter, the sample is pre-sheared again and a lower rotation speed is applied for 100 seconds. Nine cycles of decreasing rotation speeds are used. The equilibrium shear stress values will be used to construct the Equilibrium Flow Curve (EFC). This EFC describes the dynamic viscosity behaviour of the cohesive sediment at structural equilibrium.

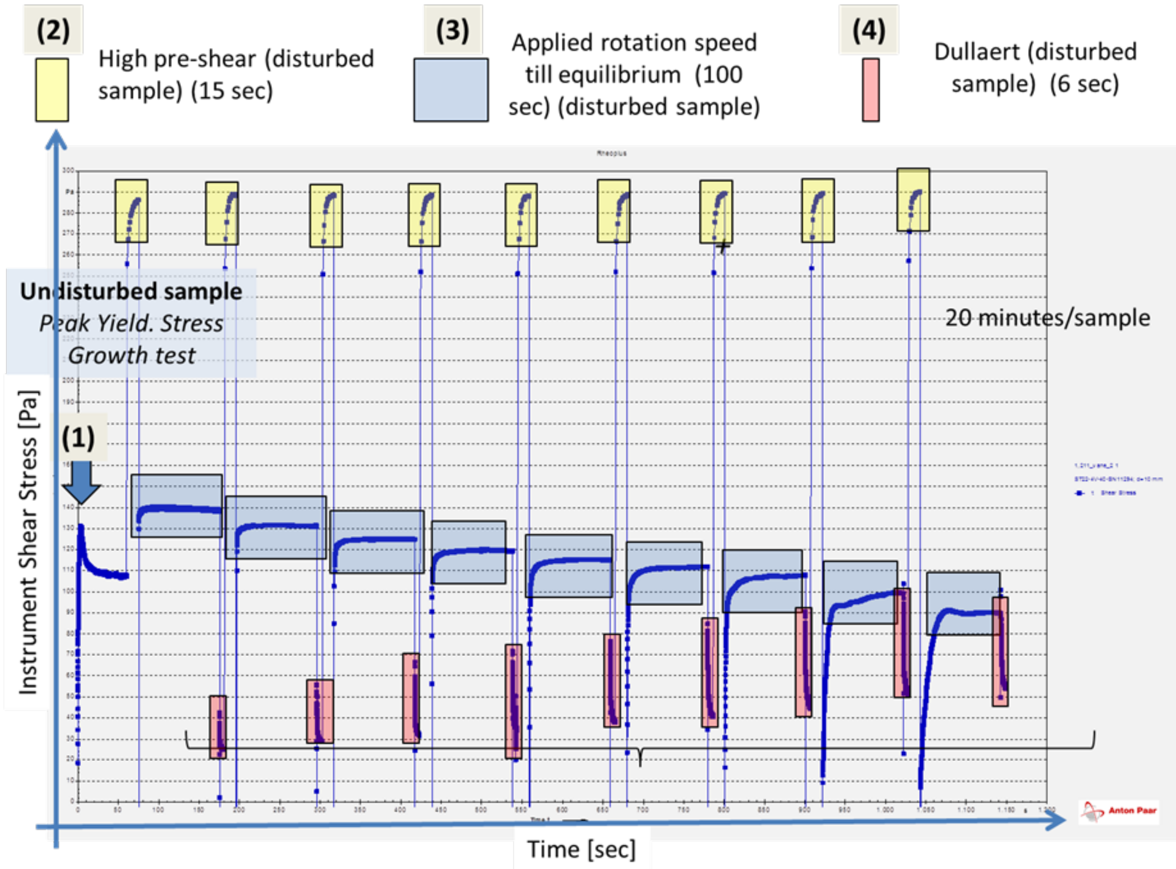

Fig. 1. Full measurement protocol.

Based on the iterative procedure to build an EFC described by Toorman (1994), a Matlab Toolbox is developed for automatic processing of vane test measurements. It is important to note that the shear rate distribution in the cup of the rheometer is non-linear and unknown, because it is dependent on the unknown EFC and because the yield radius (i.e. the distance, relative to the rotating surface, where the flow stagnates when the stress falls below the yield stress) is not known a priory. An iterative procedure is used to obtain the corrected shear rate and the resulting shear stress.

References

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