

Rheological properties of cohesive sediments from Garonne Estuary

Janry Sébastien and Philippe Monnet

Pprime Institute, UPR 3346 CNRS-University of Poitiers-ISAIE ENSMA,
PO Box 30179, 86962 Futuroscope Chasseneuil Cedex, France
E-mail: sebastien.janry@univ-poitiers.fr

Natural cohesive sediments from the Garonne Estuary are taken and studied in order to determine their rheological properties. The Worall-Tuliani viscoplastic model is used to fit equilibrium flow curves and estimate yield stresses. Thixotropic properties are investigated by following build-up of internal structure of muds.

Introduction

Cohesive sediment behaves as viscoplastic fluids (Migniot, 1989; Van Kessel *et al.*, 1998), with thixotropic properties (Toorman, 1997). In this work, natural cohesive sediments from the Garonne Estuary are studied to determine their complex rheological properties. Equilibrium flow curves are obtained and present a typical double yield stresses evolution (Huang *et al.*, 2009). Moreover thixotropic effects are investigated using specific protocols to follow yield stress evolution as a function of rest time.

Materials

Natural cohesive sediments come from Cambes located in the Garonne Estuary, 15km upstream from Bordeaux. These materials have been taken directly from banks (low tide) for two depths: the first centimetre where muds are very fluid and not consolidated (cream muds) and from 1 to 5cm where muds present higher consistency (muds). Takings have been made manually and muds have been poured in boxes and directly put in an icebox for the travel. Each box has been stored in a refrigerator before measurements to prevent biota and bacterial development. Rheometrical tests have been made during the week following takings period.

Rheological protocols

The rheological characterisation of natural sediments is carried out with an AR1500ex rheometer (TA Instruments) using plate-plate geometry of 4cm diameter. Both surfaces are covered with sand paper with a mean roughness of 82 μ m to prevent slippage effects. Each measurement is realised for a 1mm gap. We check temperature of takings, let inside hermetically boxes to prevent evaporation, was 15°C to reach more quickly the temperature measurements. Muds are manually stirred for 2 minutes and poured within geometry gap. Before measurements and to ensure a reproducible proceeding a preshear is applied with a shear rate of 10s⁻¹ during 120s following by a 600s rest period.

Three protocols have been applied to characterize rheological properties of natural cohesive sediments. First, up and down flow curves are obtained applying shear rate steps ranging from 0.1 to 50s⁻¹ in a logarithmic repartition. Each curve is corrected using Rabinowitch formula to minimize existing error on the estimation of shear rate by using plate-plate geometry. Then two yield stress specific protocols are carried out varying the rest period after preshear to follow thixotropic effects. A shear stress ramp is applied during 60s leading to a parabolic curve of viscosity as a function of shear stress where maximum viscosity corresponds to the yield stress. A shear stress oscillating ramp is applied and averaged on 2 periods at 1Hz. The crossing point between storage and loss modulus is defined as the yield stress.

Rheological results

Down flow curves are fitted with the equilibrium Worall-Tuliani equation (Fig. 1a):

$$\tau = \tau_0 + \eta_\infty \dot{\gamma} + \frac{\eta_0 - \eta_\infty}{1 + \left(\frac{\eta_0 - \eta_\infty}{\tau_\infty - \tau_0} \right) \dot{\gamma}} \quad (1)$$

Where τ_0 is the true yield stress (the stress at $\dot{\gamma} = 0$), τ_∞ the Bingham yield stress, η_0 and η_∞ are the viscosities at low shear rate and high shear rate, respectively.

Worall-Tuliani model is well adapted to our measurements and permits to obtain the two specific yield stresses for equilibrium (Toorman, 1997). Cream muds present yield stresses two times lower

than muds. These differences can be explained by density (1442g/l for cream muds compared to 1493g/l for muds).

Direct measurements of materials yield stresses are plotted as a function of rest time (Fig. 1b). Yield stresses increase as a function of rest time that could be explained by build-up of internal structure of muds. This thixotropic effect seems to evolve for a same constant time for the two materials. Different thixotropic models are then applied to estimate this constant time (Coussot *et al.*, 2002; Cheng *et al.*, 1965). The kinetic of this phenomenon is governed by the same constant time around 2000s which is particularly short compared to tide period. So at the end of tide sediment build-up seems to be complete with a highest resistance to flow.

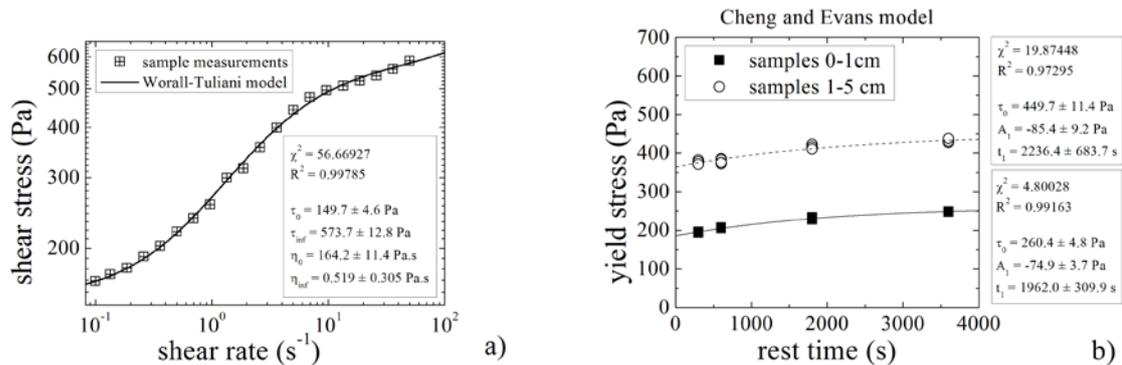


Fig. 1a. Rheogram of muds fitted with Worrall-Tuliani model. Fig. 1b. Yield stresses as a function of rest time for thixotropic Cheng and Evans model.

Conclusion

In this study rheological characterization of natural cohesive sediment is done. Cream muds and muds follow the same viscoplastic behaviour well described by Worrall-Tuliani model. Moreover thixotropic properties are present and a same kinetic is found for the two materials whereas values for cream muds are two times lower than muds linked to densities difference. This work takes place on a research project on tidal bore and these results must be associated to *in situ* measurements for describing erosion processes and sediment transport.

Acknowledgements

The authors acknowledge Pierre Lubin and David Reungoat for their help during muds taking and the Agence Nationale de la Recherche (Projet MASCARET 10-BLAN-0911-01) for financial assistance.

References

- Cheng D.H. and F. Evans. 1965. Phenomenological characterization of the rheological behaviour of inelastic reversible thixotropic and antithixotropic fluids. *British Journal of Applied Physics* 16:1599-1617.
- Coussot P., Q.D. Nguyen, H.T. Huynh and D. Bonn. 2002. Viscosity bifurcation in thixotropic, yielding fluids. *Journal of Rheology* 46:573-589.
- Huang Z. and H. Aode. 2009. A laboratory study of rheological properties of mudflows in Hangzhou Bay, China. *International Journal of Sediment Research* 24:410-424.
- Migniot C. 1989. Tassement et rhéologie des vases - Deuxième partie. *La Houille Blanche* 2 :95-111.
- Toorman E.A. 1997. Modelling the thixotropic behaviour of dense cohesive sediment suspensions. *Rheologica Acta* 36:56-65.
- Van Kessel T. and C. Blom. 1998. Rheology of cohesive sediments: comparison between a natural and an artificial mud. *Journal of Hydraulic Research* 36:591-612.