Rheological Properties of a Natural Estuarine Mud

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Abstract:
In this paper, the linear and non-linear rheological properties of estuarine cohesive sediments were investigated. The density of the sediments has been determined by pycnometry. Creep and oscillatory shear measurements have been performed in order to determine i) the transitions in mechanical response to creep and oscillatory shear and ii) the material properties of these natural fluids as a function of their density. For all samples tested, four different rheological transitions have been determined and all material properties have been shown to be satisfactorily fitted by exponential functions of the density.

Zusammenfassung:
In diesem Artikel werden die linearen und nicht-linearen rheologischen Eigenschaften kohaesiver Sedimente, die aus Flussmuendungen stammen, untersucht. Die Dichte der Sedimente wurde mit Hilfe der Pycnometrie bestimmt. Kriech- und oszillatorische Schermessungen wurden durchgeführt, um i) den Übergang in der mechanischen Antwortfunktion zum Kriechverhalten und zum oszillatorischen Scherverhalten und ii) die Materialeigenschaften dieser natürlich vorkommenden Fluide als Funktion ihrer Dichte zu bestimmen. Für alle untersuchten Proben wurden vier verschiedene rheologische Phasenuebergaenge bestimmt und alle Materialeigenschaften konnten befriedigend mit einer exponentiellen Dichteabhaengigkeit angepasst werden.

Résumé:
Dans cet article, les propriétés rhéologiques linéaires et non-linéaires de sédiments cohésifs estuariens ont été étudiées. La densité des sédiments a été déterminée par pycnométrie. Des mesures en fluage et en cisaillement oscillatoire ont été menées afin de déterminer i) les transitions dans la réponse mécanique en fluage et cisaillement oscillatoire et ii) les propriétés matérielles de ces fluides naturels en fonction de leur densité. Pour tous les échantillons testés, quatre transitions rhéologiques différentes ont été déterminées et on a montré que les grandeurs matérielles étaient décrites, de manière satisfaisante, par des fonctions exponentielles de la densité.

Key Words: cohesive sediments, mud rheology, viscoelasticity, non-Newtonian behavior

1 INTRODUCTION

Cohesive sediments are commonly found in estuaries. They are natural suspensions, mainly composed of clay mineral particles (plus sand and organic matter), with variable physical and mechanical properties depending on numerous parameters : density, mineral and organic content, pH and ionic strength of the medium, temperature [1]. The study of the transport of these natural complex fluids, when subjected to oscillatory shear by water waves, or simple shear by current, is of great interest from both an economical and an ecological point of view. Indeed their accumulation in estuaries may not only hinder navigation but also induce environmental pollution by the presence of contaminants held in sediments. Thus, for coastal management, it is of great importance to know whether planned projects will diminish or increase siltation. In order to make such predictions, hydro-sedimentary models are being used as current tools; IFREMER, in France, has been working on such models for many years. Still getting good predictions from such modeling needs both relevant constitutive laws, and accurate quantitative description of the rheological parameters of these equations, as a function of physical or physico-chemical parameters (e.g. density).

Hydrodynamic, mainly oscillatory, forcing of cohesive sediments was studied in numerous modeling research works, but with sediment rheological properties assumed rather than measured. In these works, the behavior of the sedi-

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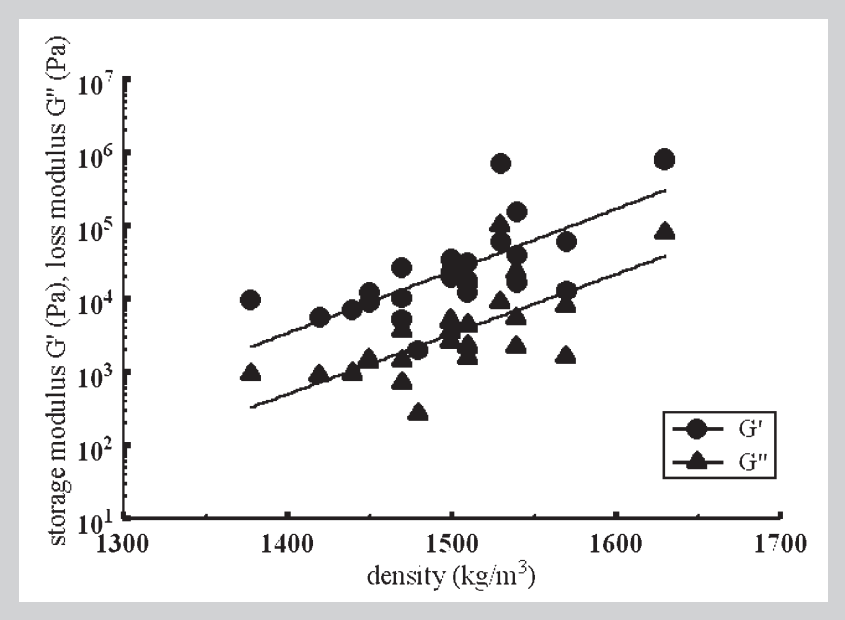

Figure 8: The linear viscoelastic moduli, at a frequency of 1Hz, as a function of the density of the mud.

turation of the mud above critical relative displacements of neighboring particles. This destructuration process finally leads to a liquefaction ($G'' > G'$) of the mud at a strain amplitude γ_{liquif} of about 100%, above which the sediments progressively lose their cohesive character. The transitions $\gamma_{destruct}$ and γ_{liquif} are certainly the most relevant one regarding the rheological response of natural muds. Indeed strain amplitudes of a few % are commonly encountered in natural hydrodynamic forcing [12], therefore liquefaction is expected to occur quite frequently, even for sediments which are very dense and cohesive at rest. At last, it is worth noticing that the order of magnitude of γ_{liquif} was found for another type of estuarine sediments, namely Seine estuary muds [12].

The mechanical transitions defined above mainly concern non-linear rheological behaviors of the mud. As far as linear rheological properties of this material are concerned, this work shows that the density dependence of the Newtonian viscosity η_O, and the linear viscoelastic moduli G'_O and G''_O can be satisfactorily fitted by an exponential function. Such exponential dependence of material properties with density, or volume fraction, was observed for other natural estuarine muds [12] and, more generally, for many other clay-water systems [13], even though the microstructural interpretation of such an exponential increase is not yet clear.

The qualitative and quantitative rheological results presented and discussed in the paper will be compared with those obtained on many different natural estuarine cohesive sediments in a near future in order to study the influence of mineral and organic content, granulometry and sea water properties on the rheological transitions and material properties studied in this work.

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