Long-wave-induced flows of stratified cohesive sediments

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Introduction: Accurate parameterisations of wave dissipation mechanisms (i.e. dissipative seafloor effects and wave breaking) play key roles in large-scale coastal models (Liu & Park 2008). While it is well-known that propagating waves can be significantly dissipated by a soft deformable seabed (Gade, 1958), much is still unknown about the dynamic behaviour(s) of cohesive sediments as compared to the non-cohesive counterparts, where wave action is concerned. The usual practice is to classify the cohesive sedimentary material according to one of the simple models such as viscous, visco-plastic, visco-elastic or elastic with increasing sediment concentration (Winterwerp & van Kesteren 2004). Of course, real mud does not fit neatly into a single model, and the related material properties tend to change significantly in space and time. This behaviour results in extreme difficulty in making measurements of the response(s) of the sediments to external forcing (due, for example, to wave action).
Recently, Park & Liu (2010) have carried out a series of experiments with a visco-plastic (Bingham) material, which is characterized by a yield stress followed by a constant viscosity. Unexpectedly, however, the measured data showed some qualitative difference from the predictions of a numerical simulation using the visco-plastic constitutive relation. On the other hand, they found excellent agreement for all of the experimental cases when the elastic effect is added to the numerical simulation. More importantly, this elasto-viscoplastic model is fully described by constant material parameters (yield stress, viscosity and shear modulus) obtained from a simple, steady rheology measurement, and provides a single framework to study cohesive sediments, in the sense that the other aforementioned simpler models are subsets of this model.

Methods: In this paper, we extend Park & Liu (2010)'s model to a density-stratified environment. Considering that the material properties of the mud (density, yield stress, viscosity, shear modulus) are single-valued functions of the sediment concentration, a theory of wave-induced motion of the density-stratified, elasto-viscoplastic mud is being developed. Here, 2-dimensional motion is considered and breaking with the accompanying turbulent mixing at the water-mud interface is not included. This simplification is reasonable due to the very high viscosity of natural mud. Governing equations for the water and the mud are coupled via forcing terms and the unknown location of the water-mud interface. These are effectively decoupled using a perturbation approach, though the resulting equations at each order still need to be solved numerically due to the highly nonlinear nature of the constitutive relation.

Results and Discussion: Detailed results of analytical and numerical solutions will be reported in the full paper. In particular, vertical field in the sediment layer is of central interest, from which dissipation of free surface waves can be calculated. Time evolution of yield plane as well as that of strain in the sediment layer will also be presented. Finally, it will be discussed how this theory can help design field instrumentation of mechanical properties of cohesive sediment.

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