Erosion thresholds and rates for sand-mud mixtures

Smith S. Jarrell, David Perkey and Anthony Priestas

U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road; Vicksburg, Mississippi, USA 39180
E-mail: Jarrell.Smith@usace.army.mil

Background

The differences in erosion behaviour of non-cohesive (sand, gravel) and cohesive sediments (mud) are widely recognized (Mehta, 1989; Mitchener and Torfs, 1996; Jacobs *et al*., 2011). Erosion of non-cohesive sediments is dependent primarily upon the balance of weight, buoyancy, drag, and lift forces on the sediment grains, which in turn are associated with the size, density, and shape of the particles. Cohesive sediment erosion is largely influenced by electrochemical bonding between sediment particles. This cohesive bonding is influenced by clay mineralogy, pore water chemistry, organic content, biological cementation, and bed density (among others).

In many natural environments, sand and mud are not completely separated and occur as mixtures. Significantly less research has been conducted on the erosion behaviour of sand-mud mixtures compared to the separate treatment of sand erosion and mud erosion. Mitchener and Torfs (1996) found that adding sand to mud or mud to sand resulted in increased erosion resistance. Their study found that as little as 3-15 percent mud added to sand changed the erosion behaviour from non-cohesive to cohesive. The findings of van Ledden *et al*. (2004), Barry *et al*. (2006), and Jacobs *et al*. (2011) are similar to Mitchener and Torfs (1996); however each of these studies focus on the influence of mud fraction on the critical shear stress for initiation of erosion and very little on the effect of the mud fraction on the erosion rates. Additional research is required to define the effect of mud content on both the critical stress for erosion and erosion rate of mixed sediments (Jacobs *et al*., 2011).

Erosion experiments were conducted on sand-mud mixtures with varying mud content to define the relationships between mud content, critical stress for erosion, and erosion rate. These experiments aim to improve the general understanding of erosion of sand-mud mixtures and to inform development of mixed sediment algorithms for sediment transport models.

Methods

Erosion experiments were conducted with Sedflume (McNeil *et al*. 1996) on a suite of mixed sediment beds prepared in the laboratory. Sedflume consists of a 100-cm long, 2 x 10cm cross-section rectangular duct with a test section milled into the bottom of the flume for inserting 10-cm diameter sediment cores. The mixed sediments for this study were prepared by mixing varying fractions of mud with well-sorted quartz sand ranging in size from 250 to 500μm. Sand-mud mixtures were prepared with three mud sources: 1) non-swelling clay (kaolinite), 2) swelling clay (kaolinite/bentonite), and 3) a natural mud collected from the lower Mississippi River. The mud fraction (by sediment mass) ranged from 0 – 100 percent according to the schedule presented in Table I. The mud was prepared as a 1.40g/l slurry, which was mixed with the corresponding proportions of sand and placed into the sediment cores to a depth of approximately 30cm. The sediment mixtures were fully saturated with fresh water and allowed to consolidate for 30 days prior to erosion with Sedflume. Five log-distributed shear stresses were applied to the surface of the core in a sequence that was repeated five times for each sample. A least-squares fit of $E = A\tau^n$ was performed for each sample (where E is erosion rate in cm/s, A and n are the fit parameters, and τ is applied shear stress in N/m^2 (Pa)). The critical shear stress is defined by the erosion rate of 10^{-4}cm/s and was estimated for each sample from the least-squares fit.

Table I. Sand/mud mixtures for erosion experiments

	Weight % Mud														
Non-Swelling Clay	0	1	2	3	4	5	8	11	15	21	29	40	60	80	100
Swelling Clay	0	1	2	3	4	5	8	11	15	21	29	40	60	80	100
Natural Mud	0	1	2	3	4	5	8	11	15	21	29	40	60	80	100

Results

Similar to previous research of Mitchener and Torfs (1996) and Jacobs *et al.* (2011), the critical shear stress of the mixed sediments significantly departs from that of pure sand with mud fractions on the order of 2-10% (Fig. 1). The peak τ_{cr} for both mixtures occurs near 30% mud content, and the kaolinite/bentonite mud achieves a ten-fold increase in τ_{cr} whereas τ_{cr} for the kaolinite clay increases by a factor of five. At low mud content, erosion rates (Fig. 2) decrease by a factor of 10 to 100 with little change in the critical shear stress. Similar to the critical shear stress, minimum erosion corresponds to approximately 30% mud by mass. Erosion analysis for the natural mud mixture is in progress and will be available for presentation at the conference.

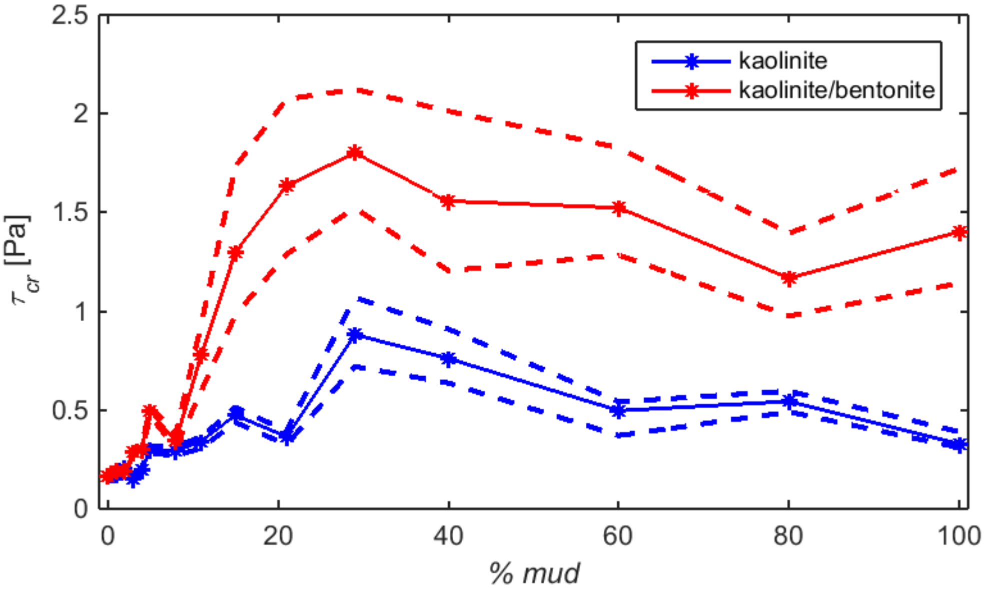

Fig. 1. Critical shear stress versus mud content for two (of three) mixed sediments. The solid lines and markers indicate the best estimate of τ_{cr} and the dashed lines indicate the 95% confidence interval.

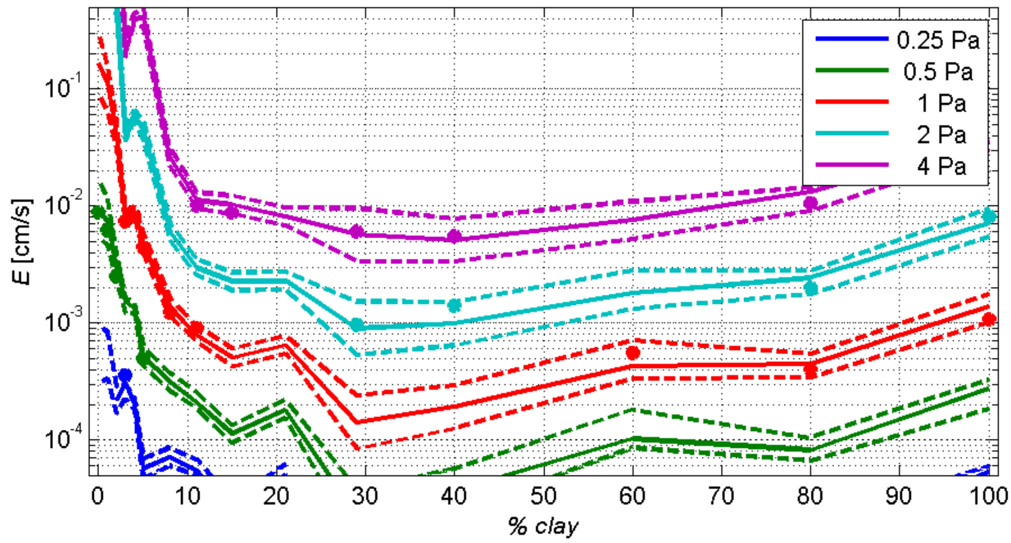

Fig. 2. Erosion rate versus mud content for the mixed sediment prepared with kaolinite. Markers indicate data from the experiments, solid lines are derived from the fit of $E = A\tau^n$ to the data, and dashed lines indicate the 95% confidence interval on the estimates.

References

Barry K.M., R.J. Thieke and A.J. Mehta. 2006. Quasi-hydrodynamic lubrication effect of clay particles on sand grain erosion. Estuarine Coastal and Shelf Science 67:161-169.

Jacobs W., P. Le Hir, W. Van Kesteren and P. Cann. 2011. Erosion thresholds of sand-mud mixtures. Continental Shelf Research 31(10):S14-S25.

McNeil J., C. Taylor and W. Lick. 1996. Measurements of erosion of undisturbed bottom sediments with depth. Journal of Hydraulic Engineering 122(6):316-324.

Mehta A.J. 1989. On estuarine cohesive sediment suspension behaviour. Journal of Geophysical Research 94(C10):14303-14314.

Mitchener H. and H. Torfs. 1996. Erosion of mud/sand mixtures. Coastal Engineering 29:1-25.

Van Ledden M., G.G.M. van Kesteren and J.C. Winterwerp. 2004. A conceptual framework for the erosion behaviour of sand-mud mixtures. Continental Shelf Research 24:1-11.