Measurement of density and porosity profiles within mixed sediment deposits using an electrical resistivity technique

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Introduction

Physical understanding of sedimentation processes in estuaries and nearshore coastal waters is economically important to port facility owners and operators requiring maintenance of navigable depths, and environmentally significant to those bodies charged with maintaining and enhancing these sensitive ecosystems. It is therefore essential that engineers and scientists have fundamental understanding of the physical behaviour of the mixed (sand-mud) sediments that are typically found in estuarine and coastal systems, as well as their role in large-scale morphodynamic evolution (e.g. Torfs *et al*., 1996; Cuthbertson *et al*., 2008). However, our ability to predict structural and compositional changes within mixed sediment beds, resulting from mobilisation, transport and deposition processes occurring under combined current and wave actions, remains severely limited by the inadequate knowledge base on the dynamic behaviour of sand-mud mixtures. Additionally, current limitations in the monitoring and characterization of these mixed sediment beds (and specifically the lack of simple, reliable, non-intrusive techniques for measuring bed layer structure and composition) have been identified as a major obstacle to improved understanding of mixed sedimentary environments (e.g. Ha *et al*., 2010). In this context, the current project has focused on developing an electrical resistivity measurement technique to characterise the spatial and temporal variation in bed structure and composition for saturated sand-clay deposits formed under idealised differential settling conditions. Ongoing development of the technique to test its applicability across a wider range of mixed sediment compositions and to monitor bed changes resulting from more natural erosion/deposition cycles (e.g. under cyclic tidal conditions) is also reported.

Settling column experiments

The resistivity technique was tested initially in a specially designed settling column with plan dimensions 15cm x 15cm and a total height of 50cm (Fig. 1). Two opposite walls of the column incorporated horizontally-aligned arrays of embedded stainless steel electrodes that allowed 4-point electrical measurements to be taken at a vertical resolution of 10mm throughout the column height. These electrode arrays were mounted flush with the inner wall surface to prevent interference with the sand-mud sedimentation process. The horizontal spacing of individual electrode sets was also set at 6mm and 20mm, respectively (Fig. 1), to determine the optimum spacing required for high-resolution characterization of the resulting bed deposits. Pure kaolin clay (D_{50} = 4μm; *SG* = 2.59) and fine-medium quartzite sand (*D* = 100 – 750μm; D_{50} = 250μm; *SG* = 2.64) were used as cohesive and non-cohesive fractions for the sediment mixtures. These fractions were combined into a slurry with 0.5M NaCl solution to obtain prescribed mixture compositions (% by dry weight) of 100S:0C; 75S:25C; 50S:50C; 25S:75C and 0S:100C. Each mixture was transferred, in turn, into the settling column as a "single shot", agitated by upturning of the column, and then left to settle over a period of 72 hours. The resulting settling and depositional behaviour of the sand-clay mixtures was observed through time-lapsed imaging (Fig. 2) and continuous profiling of the electrical resistivity within the developing bed deposit. Prior calibration for the sand-clay mixtures tested allowed conversion of measured resistivity profiles to more physically-relevant properties such as bulk density or porosity.

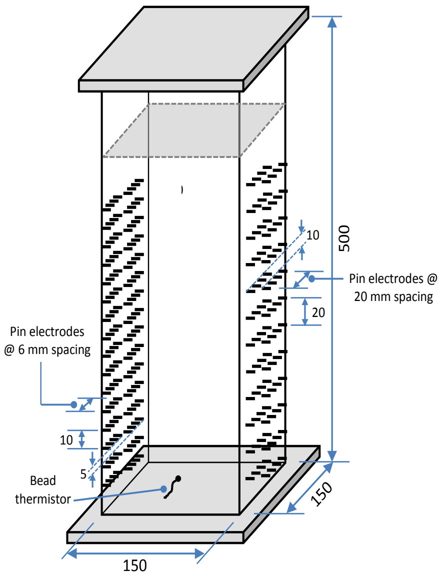

Fig. 1. Settling column arrangement showing 4-point electrode configuration (dimensions in mm).

Results and discussion

Fig. 2. shows the temporal development of the bed deposit for the 50S:50C sediment mixture. The initial rapid settlement of sand was shown to result in the formation of a bottom sand-rich layer, with near-vertical dewatering channels [Fig. 2.(a)]. Above this base layer, a patchier sand-clay layer was deposited [Fig. 2.(b)], followed by a thicker clay-rich layer containing discrete sand patches [Fig. 2.(c)]. The presence of these discrete sand patches suggests trapping within a clay matrix, which would form as the concentration in the clay layer reached the gelling point. Subsequent settlement of these sand patches [Figs. 2.(d) – (f)] also indicated that the clay matrix layer continued to compact (i.e. become denser) through ongoing settlement processes (note: this was also observed from the vertical displacement of the bed deposit surface interface, see Fig. 3). The degree of segregation observed in bed deposits was generally shown to increase with sand content in the settling mixture. Specifically, for the sand-rich 75S:25C mixture, a clearly defined sand-clay interface was shown to form between the lower sand and upper clay dominated layers [Fig. 2.(g)]. Normalised bulk density profiles, derived from electrical resistivity measurements, are shown in Fig. 3. for the 50S:50C and 75S:25C sediment mixtures at elapsed times of 10, 360 and 2880min. As expected, these profiles indicated a general increase in deposit density with elapsed time, due to settlement processes. For the 50S:50C sand-clay mixture [Fig. 3.(a)], the distinct layering structure observed within the deposit was identified by, and matched to, gradient changes within the corresponding measured bulk density profiles [i.e. 2880min, Fig. 3.(a)]. Similarly, the high degree of sand-clay segregation observed in the bed deposit formed by the 75S:25C mixture is also apparent from the sharp transition in bulk density values in the vicinity of the sand-clay layer interface [Fig. 3.(b)].

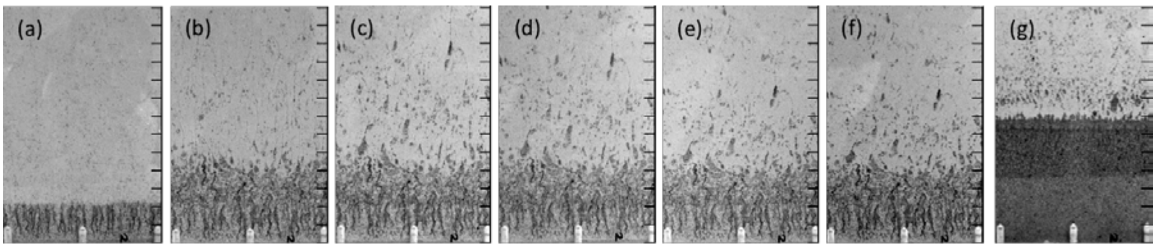

Fig. 2. Time-lapse images of bed deposit formation for the 50S:50C mixture at elapsed times (min.) of (a) 10, (b) 120, (c) 240, (d) 360, (e) 1440, (f) 1800. Fig. 2.(g) shows a corresponding deposit for the 75S:25C mixture after 1800min. (Note: scale divisions shown are 10mm).

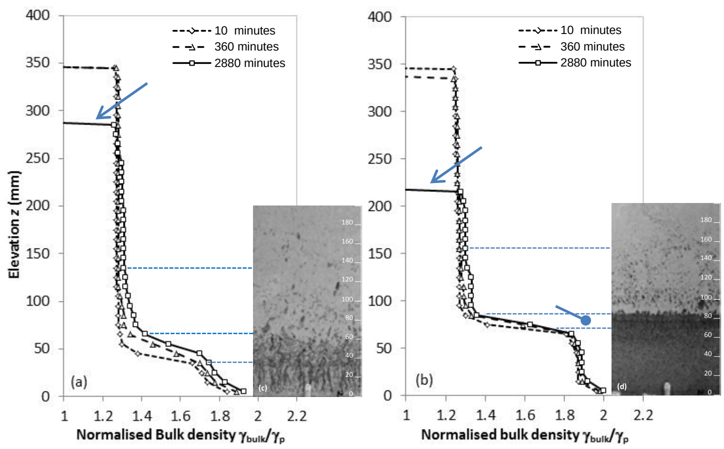

Fig. 3. Normalised bulk density profiles for (a) 50S:50C and (b) 75S:25C mixture deposits after 10, 360 and 2880min (corresponding scaled images also shown at 2880min). Deposit zones (i) – (iv) show sand-rich (>60% sand); sand-clay mix; sandy-clay (<10% sand) and clay layers, respectively.

Next steps

The resistivity technique is currently being utilised in further laboratory tests, employing a benthic annular flume (courtesy of Partrac Ltd.) to investigate sediment bed restructuring under more natural cyclic erosion and deposition events (i.e. more representative of cyclic tidal conditions). Ongoing development of the methodology is also underway to adapt it for a wider range of mixed sediment compositions (e.g. sand-silt-mud, organic matter) and for potential field applications. Preliminary findings from these additional studies will also be discussed in the paper.

References

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