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- VOLÚMEN 1 -

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INVESTIGATION OF BED LIQUEFACTION IN HYDRAULIC EVOLUTION OF EXPERIMENTAL TURBIDITY CURRENTS

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Introduction

Turbidity currents are gravity flows established by the density difference between the flow and the ambient fluid, caused by sediments in suspension (Middleton & Hampton, 1973). These flows transport great amounts of sediments into the deep ocean and are associated to the generation of turbidites, potential hydrocarbon reservoirs (Talling et al., 2013).

Depending on the characteristics of the mobile bed over which turbidity currents flow, sediments from bed can be more easily eroded, entrained, and transported by these flows. Therefore, understanding the nature and the water content of the mobile beds over which turbidity currents flow, is relevant to investigate flow dynamics and their capacity and competence in transporting sediments.

Mobile beds, as well as turbidity currents, can be fluidized and/or liquefied. In fluidized beds/flows, the fluid moves upward through the particles, which are temporarily suspended without net downward movement (Lowe, 1976; Shanmugam, 2021). Liquefaction, on the other hand, can be interpreted as a temporary state of water-sediment organization in which particles settle downward through the fluid, while the fluid is expelled from the deposit (which becomes more compacted). Both liquefaction and fluidization may occur simultaneously within a bed (Lowe, 1976), and will be treated in this work as concurrent (coupled up) process.

Several mechanisms can trigger liquefaction and fluidization processes as earthquakes, excess pore-fluid pressures (related to tidal fluctuations or internal deposit seawater), volcanism, tsunamis, among others or by any stresses caused by waves or turbidity currents activities (Lowe, 1976). Rapidly deposited sand layers can also generate liquefied bed, by water squeezed out of underlying loaded sediment Lowe (1975).

Turbidity currents with fast and dense basal near-bed layers (c_v~ 10%) were observed in the Monterey Canyon (Paull et al., 2018) and their occurrence was attributed to the remobilization of the seafloor. These authors attribute this to the occurrence of disturbances and consequent fluidization/liquefaction of loose-packed canyon-floor sand, which would increase the particle lift force and, consequently, sustain dense near-bed layers in turbidity currents farther downstream.

Based on Paull et al. (2018) observations, the present study designed physical model of a liquefied/fluidized bed with the concomitant action of a turbidity current. Thus, it was possible to evaluate the influence of this type of bed on the current dynamics.

Experimental Setup and Data Analysis

Experiments were conducted at the NECOD hydraulic laboratory of the Universidade Federal do Rio Grande do Sul, Brazil, in a 4.20 m long and 14 cm wide acrylic-sided flume (Fig. 1 a), filled with fresh water before each run. At the end of the flume, turbidity currents expanded laterally and flowed towards the output valve, which was located at a lower level than the flume. The valve opening was adjusted to the inflow discharge, to stabilize the water level within the flume during the experiments.

Velocity and concentration measurements were performed at three stations of measurement located at 2, 3.3 and 4.3 m from the current inlet (Fig. 1 b) using Acoustic Doppler Velocimeter (ADV – Nortek at acquisitions rates of 100 Hz) and Ultrasonic High Concentration Meter probes (UHCM – Deltares, at acquisitions rates of 20 Hz). At all these three stations, velocity and concentration probes were installed close to the bed, to analyze the spatial variation of these parameters. At station 1, three additional probes were installed along the vertical, above the near-bed probe. This enabled the measurement of vertical profiles of concentration and velocity of turbidity currents and the calculation of their layer-averaged flow velocity (U), thickness (H) and concentration (C), by using Ellison and Turner (1959) equations. Using these parameters we calculate the Reynolds number ($Re = UH/\nu$) and the densimetric Froude number ($Fr_d = U/\sqrt{gH\,\Delta\rho/\rho}$), where g is the acceleration due to gravity (m s^{-2}), ν is the kinematic viscosity (ν, m s^{-2}) and $\Delta\rho/\rho$ is the density difference between flow and ambient water.

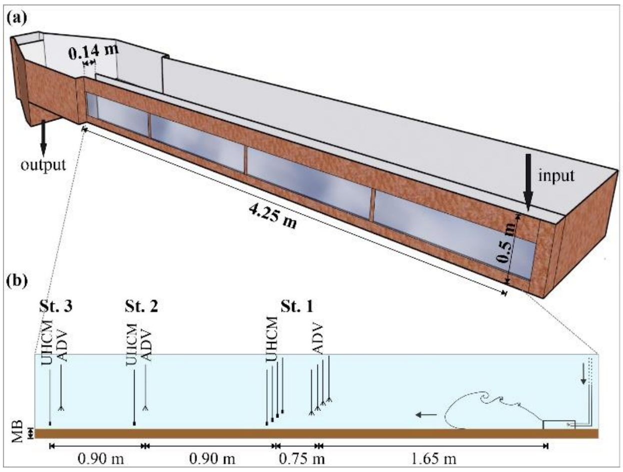

Figure 1.- (a) Experimental flume overview and (b) lateral view and experimental setup. Turbidity currents flowed from right to left.

Turbidity currents were prepared with coal-water mixtures with a volumetric concentration (c_v) of 8%. Three inflow discharges were tested: 20, 30 and 40 L min^{-1}. Finally, three mobile-bed setting were investigated using melamine (crushed plastic): (1) compact bed, (2) loose and (3) liquefied/fluidized bed.

Compacted bed was created by accommodation the melamine along the bed of the flume. Then, the tank was slowly filled with water. Loose beds were created with the tank already filled with water, by vigorous agitation of the material from mobile bed. The particles freely settled and the bed thickness was smoothed along the flume avoiding bed compaction. Then, the experiment was run as fast as possible (less than 40 min), after the installation of the above-mentioned equipment.

Liquefied/fluidized beds were created by injecting water beneath the mobile using four hoses (ϕ= 1 cm) installed along the entire flume, generating an excess of pore pressure inside the deposit. The fluid discharge was low enough (~ 3 L min^{-1}) so the fluid percolated upward between the grains without lifting them.

Results and Discussion

In this study, turbidity currents presented Reynolds numbers (Re) between 3654 and 5734, indicating that the physical model was able to represent the turbulent forces involved in natural-flow events. Moreover, from the nine turbidity-current runs of this study, five were supercritical flows and four subcritical flows.

Figure 2 shows that all turbidity currents decreased their near-bed concentrations (c_b) throughout the flume. Although turbidity currents were depositional flows, c_b values were always higher for those experiments performed over liquefied/fluidized beds (red lines in figure 2), when compared to compacted and loose ones. This indicates that this type of mobile bed allowed the development of turbidity currents of higher capacity of sediment transport. Moreover, the decrease in c_b was smoother between stations 1 and 2, when considering fluidized beds.

The results indicate the influence of the water movement from the mobile bed inside the base of these flows, in terms of sustaining the grains in suspension more effectively. This process added a vertical force on the grains, which acted against their weight and reduced the settling velocity of the grains transported close to the bed.

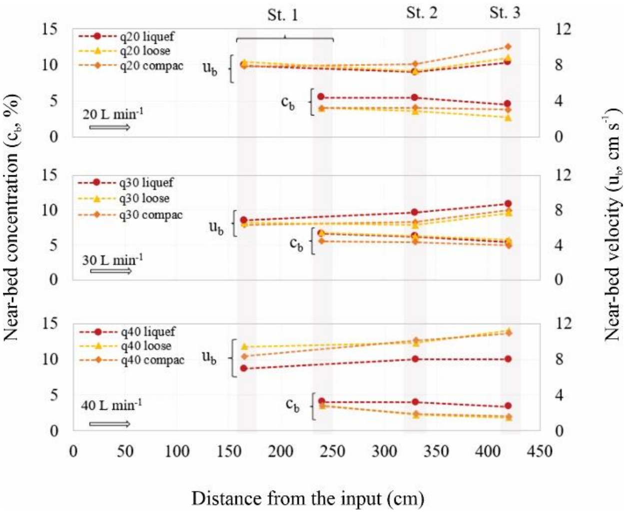

Figure 2.- Turbidity currents near-bed concentrations (c_b) and velocities (u_b). Flows from left to right.

Near-bed velocities (u_b, Fig. 2), on the other hand, were lower in turbidity currents that flowed over liquified/fluidized bed (except for discharge 30 L min^{-1}), in relation to those recorded in loose and compacted-bed runs. In fact, the experiments with higher u_b values were those that developed lower concentrations c_b. This is something new and needs further analysis, since turbidity currents with higher concentrations (higher driving force) are expected to develop higher velocities. However, we suggested that in the reported experiments there may have been processes of internal stratification at the base of the turbidity currents, reflecting lower turbulent velocities and, consequently, lower values of u_b. Furthermore, one should note that in all experiments there was an increment of u_b in Station 3. This station of measurement was installed close to the end of the flume, where there was a rapid flow deformation resulting from the loss of confinement (this is further described by Pohl et al., 2019).

In relation to the dimensionless thickness (δ) of the generated deposits (Fig. 3), all experiments presented similar values from the distance 250 cm to the end of the flume (Fig. 3). However, along the upstream part of the flume, experiments with liquefied/fluidized beds presented deposits with higher slope followed by a thin layer of deposit. We suggest that this caused flow acceleration and thus, a localized bed erosion, as observed in figure 3.

The grain size (d_{50}) of the sediments collected from the deposits (Fig. 3) were larger along the entire flume for experiments performed with fluidized/liquefied beds. This indicates that this type of mobile bed allowed the development of turbidity currents of higher competence, since larger particles were able to be transported further downstream.

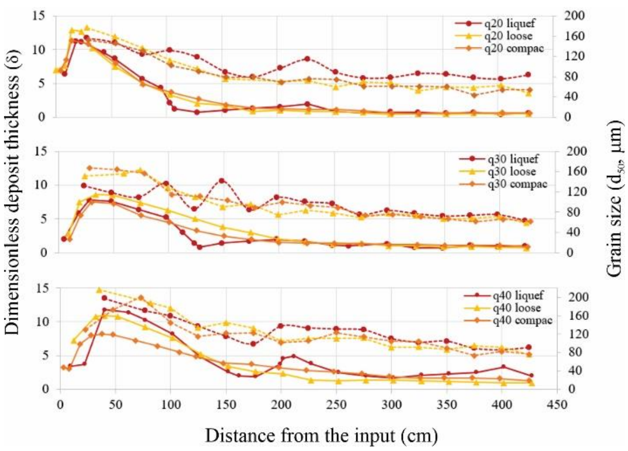

Figure 3.- Dimensionless thickness (δ) and median grain size (d_{50}) of the deposits generated by the tested turbidity currents.

This study showed that liquefied/fluidized beds are likely to improve the capacity and competence of turbidity currents. This supports the hypothesis that liquefaction of loose-packed canyon-floor sand is linked to dense basal-layer turbidity currents observed in nature.

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