CHARACTERIZATION OF FLUID-PARTICLE INTERFACE DEFORMATION USING 4D CT SCAN MEASUREMENTS

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Summary: This paper reports on the use of a cross-correlation algorithm using particle image velocimetry technique to compute the velocity vector fields of ripples displacement using the CT scan images. The experimental setup, composed of a high resolution imaging technique, promises a way to better understand the underlying mechanisms of fluid-particle interface dynamics within the boundary layer.

1. INTRODUCTION

The fluid-particle interface dynamics is important to understand the physical mechanisms involved in sediment transport. This thin boundary layer is however difficult to sample without disturbing the flow. The x-ray computed tomography (CT) technology is then a useful tool considering that it is a non-destructive method providing density and porosity of materials. This study attempts to characterize the relation between the sand bed roughnesses for different flow types. To achieve this, a physical model composed of a movable sand-bed is used. Different quasi-steady flows were generated to create distinguishable dynamic features. The deformation of the sand bed is quantified by 4D CT scan measurements.

2. EXPERIMENTAL METHOD

A movable sand-bed model was built in the Multidisciplinary Laboratory of CT Scan for Non-Medical at the Institut National de la Recherche Scientifique (Quebec, Canada). A rectangular flume (0.30 m x 0.30 m x 7.0 m) made with 0.025 m thick transparent acrylic material was inserted into a medical X-ray CT scanner (Siemens, Somatom Definition AS+ 128) as conducted by Brunelle *et al* (2016). The CT scanner moves on 2.6 meters rails along the flume. The water depth in the flume is 0.14 m. The sand bed is composed of quartz (SiO_2), Ottawa sand, with grain median diameter (d_{50}) of 217 μm and uniform density. The bed height is 0.05 m. A steady flow is created using a water pump joining the two water tanks placed at each extremity of the flume. The 3D fluid velocity is determined by a high-resolution acoustic Doppler profiler (ADP) Nortek Vectrino-II.

The CT scan measures 3D attenuation coefficients matrix obtained with a tube current of 287 mAs at a tube voltage of 140 kV. The cooling time between the scans are short enough to measure at least 4 times bed density at each velocity. The beam collimation is 1.2 mm. The pitch factor is 0.35. The field of view used in the cross-section for the reconstruction image is 0.30 m x 0.30 m. The reconstructed matrix is 512 x 512 pixels in the cross-section with a pixel size of 0.6 mm x 0.6 mm. In the longitudinal axis, the slice thickness is 2.0 mm. The sand bed elevation is determined by a threshold value on scan images. The LaVison cross-correlation algorithm for particle image velocimetry (PIV) was used to compute vector fields (Scarano, 2012). A decreasing interrogation window size from 128x128 to 32x32 pixels, with 25% overlap and 3 iterations each was used. The field of view is 280 x mm x 1180 mm resulting in a grid of 40 x 54 vectors. The outliers above 2 times the standard deviation with the neighbors are removed and only data within 4 times the standard deviation are kept.

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3. RESULTS

The 4D CT scan measurements characterize the sand bed deformation under the action of different steady flows (Fig. 1(a)). The main advantage is that the bed porosity can be calculated (Brunelle *et al*, 2016) which is a fundamental parameter for sediment transport. The wavelengths of ripples as well as the bed structures increase with flow velocity. The bed roughness (k_s), which is two times the standard deviation of bed elevation, increases until a certain point were the ripples are eroded by the high flow velocity. The ripples are not symmetric as the current increase. This shows that the use of variogram (i.e., spatial length analysis) could be more appropriate than the standard deviation method to quantify the k_s parameter. These structures were easily identified by the PIV algorithm to track the ripples displacement (see Fig. 1(b)). For instance, the mean velocity of ripples is 1.2 mm s^{-1} at fluid velocity of 0.3 m s^{-1}. This technic shows promising results to better quantify the overall particles movement for given bed roughness and fluid motion in order to review classical models of sediment transport.

References

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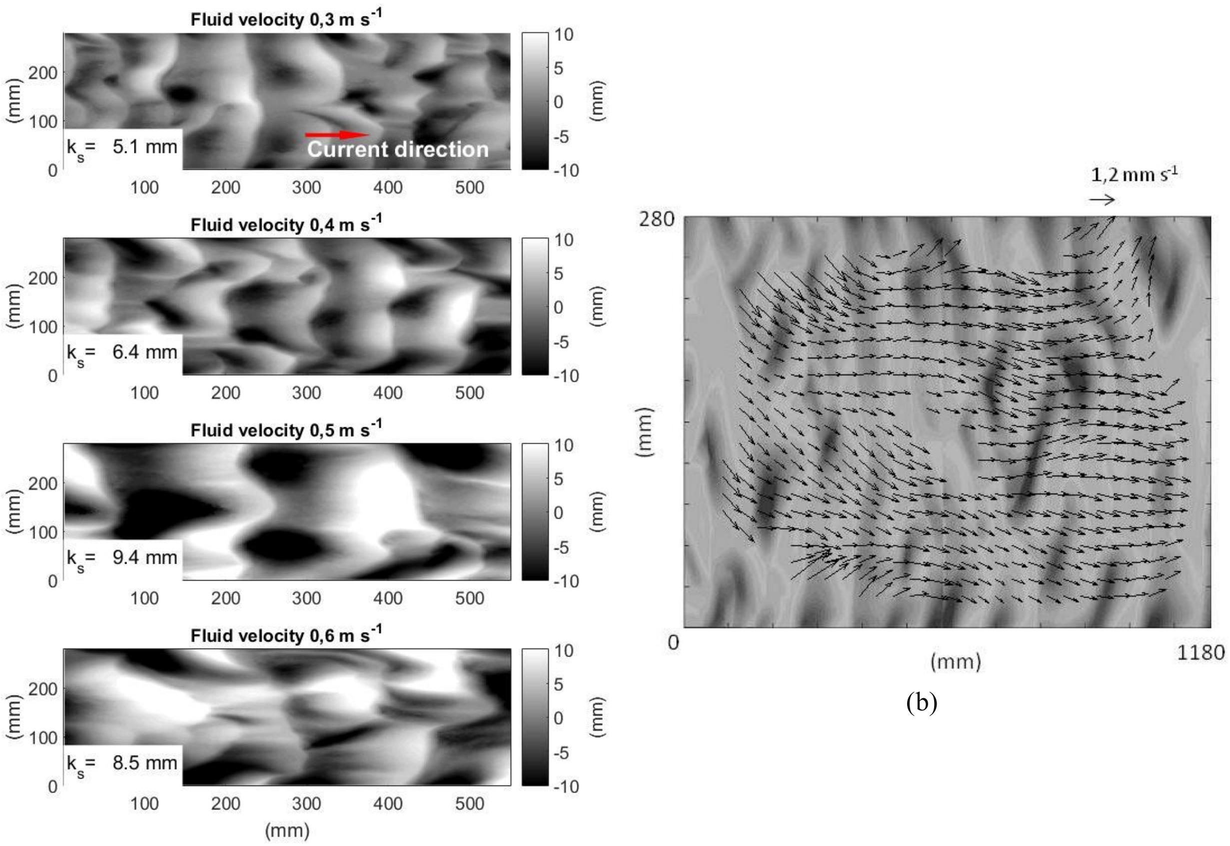

(b)

(a)

Figure 1: Top view (a) Topography of the sand bed elevation (mm) with increasing fluid velocity (m s^{-1}). (b) Velocity vectors field of ripples displacement at fluid velocity of 0.3 m s^{-1}. The background is the 2D topography of sand bed elevation as illustrated in (a). The images are distorted only for a better visualization.