EXPERIMENTS ON THE STEADY STREAMING GENERATED BY A MONOCHROMATIC SURFACE WAVE OVER SMOOTH AND ROUGH BOTTOMS

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INTRODUCTION

The oscillating motion generated by a propagating surface wave over the bottom surface develops a bottom boundary layer whose dynamics is also of oscillating nature. The evaluation of the velocity field occurring close to the bottom is of particular importance, since it allows for a more accurate evaluation of the bottom shear stresses developing between the fluid and the bottom. Such stresses are relevant for, e.g., sediment mobilization and subsequent seabed modifications, as well as wave attenuation/dissipation over smooth and rough beds.

The flow in proximity of the bottom under progressive surface waves is studied since the seminal works of Stokes (1851) and Longuet-Higgins (1953). The former observed that waves generate a second-order, mass–transport steady velocity across the water column. The latter showed that, in the case of two-dimensional monochromatic, progressive waves in finite depths, the mass-transport velocity near the bottom, but outside the bottom boundary layer, is described by

$$\bar{U} = \frac{5\, a^2 \sigma k}{4 \sinh^2 kh} \tag{1}$$

where a is wave amplitude, $\sigma = 2\pi/T$ is wave angular frequency, $k = 2\pi/L$ is wave number, T is the wave period, L is the wavelength, and h is the finite water depth.

A recent contribution by Blondeaux and Vittori (2023) proposed a theoretical model for the description of the (linearized) flow in the bottom boundary layer close to a rough wall. In the companion abstract to this contribution (Vittori et al., 2024), the same model is extended to account for weak nonlinear effects.

The present contribution focuses on a suite of experimental tests performed at the Hydraulics and Maritime Engineering laboratory of Università Politecnica delle Marche (Ancona, Italy). In such experiments, Lagrangian and Eulerian velocity flow fields under progressive monochromatic surface waves over smooth and rough bottoms were obtained through particle tracking over the water column.

METHODS

Experimental measurements of flow velocity fields were performed in a wave channel (50 m x 1 m x 1.3 m) equipped with a piston-type wavemaker. The aim of the experiments was to evaluate the flow field induced by monochromatic surface waves, with particular attention to longitudinal velocity distributions across the water column and close to the bottom. To this purpose, the water was seeded with a neutral tracer and illuminated with a top-down light sheet. The fluid trajectories induced by a traveling wave were tracked using a high-resolution camera, i.e. a FLARE 12M125 CCD camera with 12Mpx resolution and 16-bit pixel depth. The setup is similar to that described in Brocchini et al. (2022) and is illustrated in Figure 1.

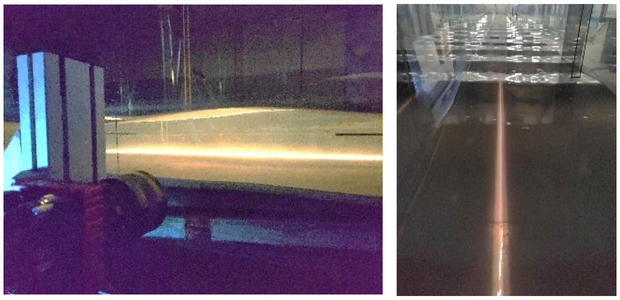

Figure 1 - Experimental setup: field of view and camera (left); top view of light sheet (right).

A monochromatic surface wave, of height H = 0.04 m and period T = 0.8 s, was generated at the wavemaker, run over a ramp and into the shallow measurement region (water depth h = 0.12 m). Particular care was given to the choice of the wave parameters and the water depth, so that the wave travels in deep/slightly intermediate waters. Guidance on the choice of wave parameters was given by Sleath (1970).

Both a smooth and a rough bottom were tested. In the smooth bottom test, the wave was run over a steel bottom. In the rough bottom test, the steel bottom was covered by 40 grit sandpaper, approximately corresponding to a bottom roughness D = 0.4 mm according to the conversion formula:

$$D = 11615\, (grit)^{-0.933} \tag{2}$$

with D expressed in microns and $grit$ being a rating of the size of the abrasive particles of the sandpaper.

The pictures taken by the camera were analyzed via the Particle Tracking Velocimetry (PTV) technique to obtain a representation of the oscillating flow field. Firstly, Lagrangian tracking of tracer particles was performed using the open-source suite Part2Track (Janke et al., 2020). Afterwards, Eulerian flow fields were reconstructed from the Lagrangian tracking, giving insight on the flow patterns at different wave phases.

An example of phase-averaged, profiles of the Eulerian horizontal velocity are plotted for a semi-period of the tested monochromatic wave: Figure 2 shows the cases of smooth (a) and rough (b) bottoms. Period-mean velocity profiles for both cases are given in Figure 3.

RESULTS AND DISCUSSION

The phase-mean profiles are rather consistent between the two cases (Figure 2), with velocities ranging between -6 cm/s and 6 cm/s. A velocity overshoot close to the bottom is more apparent for the rough bottom profiles at positive velocities, as also shown theoretically by Vittori et al. (2024; Figure 2b). Experimental investigation of flow features into the bottom boundary layer, however, was tricky due to the reduced thickness of the layer and size of tracer particles.

Both tested cases show a slight dominance of backward-directed mean current along the water column, which is smaller than 5 mm/s (Figure 3), i.e. one order of magnitude smaller than the maximum measured velocities. Such mean currents are slightly more intense for the smooth bottom. Further investigations are underway to ascertain the role of wave non-linearities and ambient parameters on the steady velocity component. The flow-bottom interaction will also be investigated analyzing the vorticity patterns generated in the lower part of the water column.

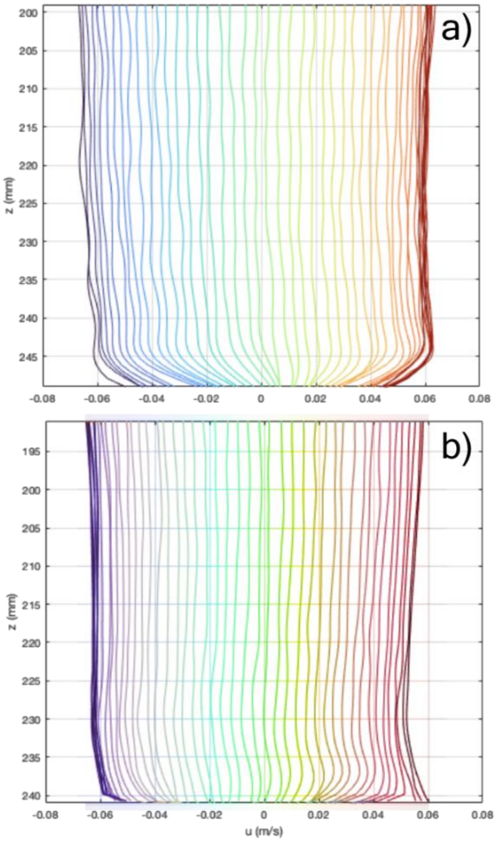

Figure 2 - Time development of the experimental phase-mean velocity profile generated by a progressive monochromatic surface wave above the bottom, over a) a smooth bottom, and b) a rough bottom.

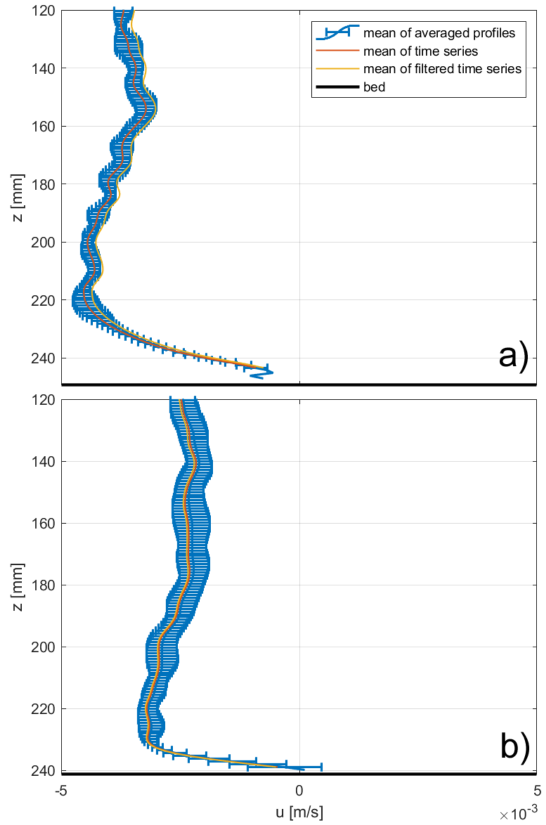

Figure 3 - Experimental period-mean velocity profiles generated by a progressive monochromatic wave over a) a smooth bottom, and b) a rough bottom.

REFERENCES

Blondeaux & Vittori (2023): Wave Boundary Layer over a Rough Bottom at Moderate Reynolds Numbers. Journal of Hydraulic Engineering, vol. 149, number 6, 040223013.

Brocchini, Marini, Postacchini, Zitti, Falchi & Xie (2022). Interaction between breaking-induced vortices and near-bed structures. Part 1. Experimental and theoretical investigation. Journal of Fluid Mechanics, 940, A44.

Janek et al. (2020): Part2Track: A MATLAB package for double frame and time resolved Particle Tracking Velocimetry. SoftwareX, vol. 11, 100413.

Longuet-Higgins (1953): Mass transport in water waves. The Royal Society of London, vol. 245, number 903, pp. 535-581.

Sleath (1970): Velocity measurements close to the bed in a wave tank. Journal of Fluid Mechanics, vol. 42, pp. 111-123.

Stokes (1851): On the effect of the internal friction of fluids on the motion of pendulums. Pitt Press Cambridge,

Vittori et al. (submitted to ICCE 2024): Steady streaming generated by a monochromatic surface wave close to a rough bottom. Proceedings of ICCE 2024.