

CHAPTER 142

PIV Measurements of Oscillatory Flow over a Rippled Bed.

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This paper presents results of a study of the kinematics of planar oscillatory flow over a rippled sea bed. The flows are mapped using Particle Image Velocimetry (PIV), a flow measurement technique yielding accurate, full field maps of an instantaneous velocity field. The practical implementation of the PIV method for this study is described, and flow maps presented for amplitude of oscillation to ripple length ratios of 0.8, 1.2 and 1.8. The generation of vortices at the ripples and their subsequent trajectories is described. Finally, the vortex strengths for the three flow regimes are investigated.

Introduction

This paper presents detailed experimental velocity measurements of oscillatory flow over a rippled bed. The main motivations for the work are to validate numerical models (eg Block, 1993, Perrier, 1993) and eventually to help in the development of models for the prediction of sediment transport. Full field instantaneous velocity data is obtained using Particle Image Velocimetry (PIV). Existing studies using point measurement techniques (eg Sato et al, 1984 and Ranasoma and Sleath, 1992) have shown flow over a rippled bed to be very complex and turbulent but with coherent structures, primarily in the vortex shedding process (see fig. 1). By the very nature of these methods the details of this complex and constantly changing flow are lost. The numerical modelling of sediment transport over a rippled sandy bed requires accurate knowledge of the flow kinematics above the bed. Through the application of the PIV technique we hope to provide this information.

Experiments

The tests were carried out in a towing tank six metres long, a metre wide with a water depth of half a metre. Because of the way the PIV systems are set up

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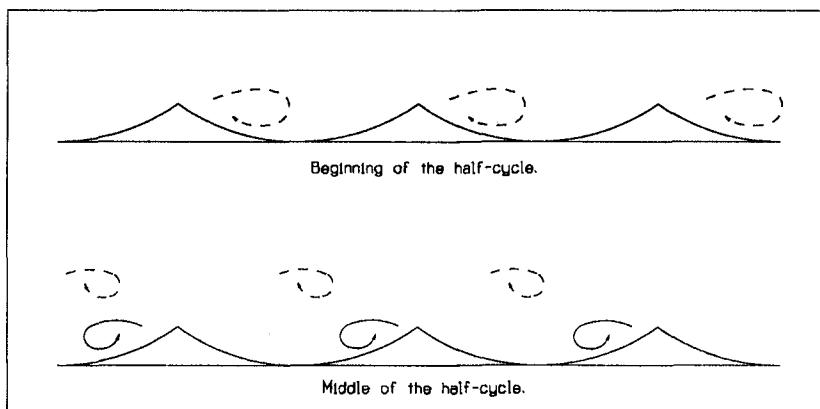


Figure 1: The vortices from the previous half-cycle are swept up and over the crests of the ripples as the flow accelerates from right to left and the new lee vortices form in the troughs.

in Edinburgh it is easier to have the light sheet coming in from underneath the tank and to suspend the ripples above, as shown in fig. 2. Rather than using an oscillatory flow over stationary ripples the ripple bed was oscillated in still water. There are several advantages to doing the experiment this way round: it allows a wider variation of amplitude of oscillation and ensures there is no externally imposed shear or turbulence as well as making the experiment physically easier. The ripples were attached upside down to a computer controlled trolley which could then oscillate them in initially still water. Three amplitudes of oscillation, a , corresponding to $a/L = 0.8, 1.2$ and 1.8 (where L is the ripple length) were used giving maximum velocities of $131, 196$ and 294 mm/s respectively. The time period, T , for all tests was $8.46s$ and pictures were taken of one of the central ripples at nine phases, ωt , of oscillation from 0° to 180° . Parameters were chosen within the EU MAST G8-M program to facilitate comparisons between the modellers and experimentalists in the group.

The ripples were solid and pre-formed from styrofoam. Again the EU MAST G8-M program decided on a 'standard' ripple shape and size. This is a sharp crested ripple (not as realistic as a rounded crest but generally easier for numerical work) 22 cm long from crest to crest and 35 mm high from crest to trough. The ripple shape was approximated to an arc of radius 19 cm.

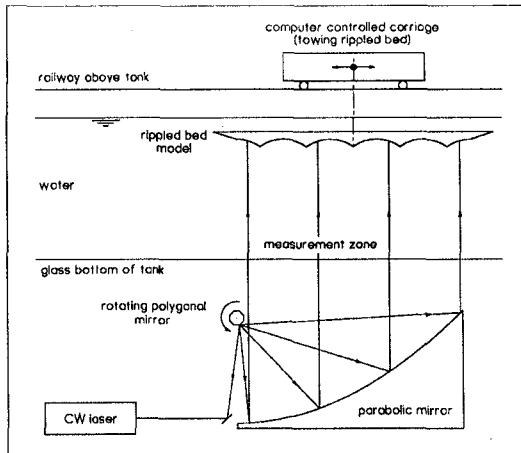


Figure 2: Ripple bed attached to the trolley above the wave tank with a scanning beam system under it

Particle Image Velocimetry

Particle Image Velocimetry (PIV) is well documented; for a general overview see Adrian, 1991, and for applications in the field of coastal engineering see Greated et al, 1992 and Quinn et al, 1993. The advantages of PIV are that it is a non-intrusive technique and therefore does not in any way interfere with the flow and that it provides simultaneous full field data. Briefly, the flow is seeded with small, neutrally buoyant particles which scatter light and follow the flow accurately. A light-sheet is generated to illuminate the flow stroboscopically using a scanning beam system as shown in figure 2 (see also Gray et al, 1991). Typical scan rates are of the order of a millisecond. The area of interest is then photographed with a long enough camera exposure time to ensure that multiple images of each of the seeding particles are captured on the same negative. By looking at the separation of successive images of each particle a full picture of the magnitude and direction of velocity at each point in the flow can be built up.

In oscillating flows two difficulties are encountered when applying PIV. Directional ambiguity occurs because there is no way of telling which of the multiple images came first and zero and near-zero velocities cannot be measured as the images are too close together to be discriminated by the analysis system. To overcome these two problems a known shift velocity was superimposed onto the flow field such that the multiple images always occurred on the same side of the original particle thus resolving both the above problems. This technique is analogous to frequency shifting in LDA. The simplest way of including a shift velocity is to move the camera during the exposure, achieved here by mounting the cam-

era on a computer controlled turntable; the shutter is triggered when the camera is perpendicular to the tank (Bruce & Easson, 1992). The shift velocity is later subtracted from the analysed negative to reveal the true flow field.

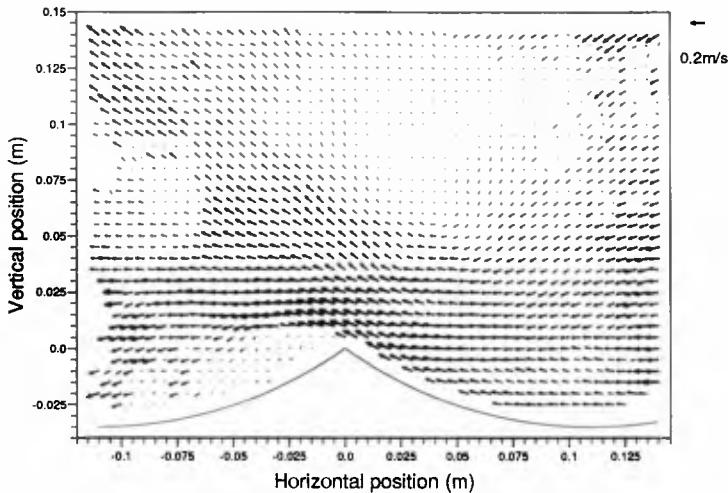


Figure 3: Velocity map for $a/L=0.8$, $T=8.46s$ and $\omega t=30^\circ$.

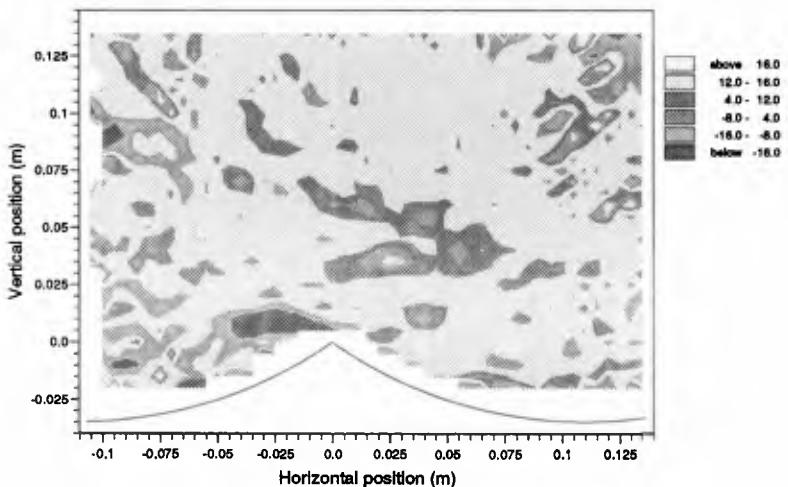


Figure 4: Vorticity plot for $a/L=0.8$, $T=8.46s$ and $\omega t=30^\circ$.

Results and Discussion

The sequences of pictures were obtained for each of the three amplitudes and show the evolution of the flow over half-cycles, where one half-cycle runs from 0° when the bed is stationary through 90° at maximum velocity to 180° when the

bed is momentarily stationary again. Detailed information about the generation of vortices, their trajectories and their decay can be obtained from the data.

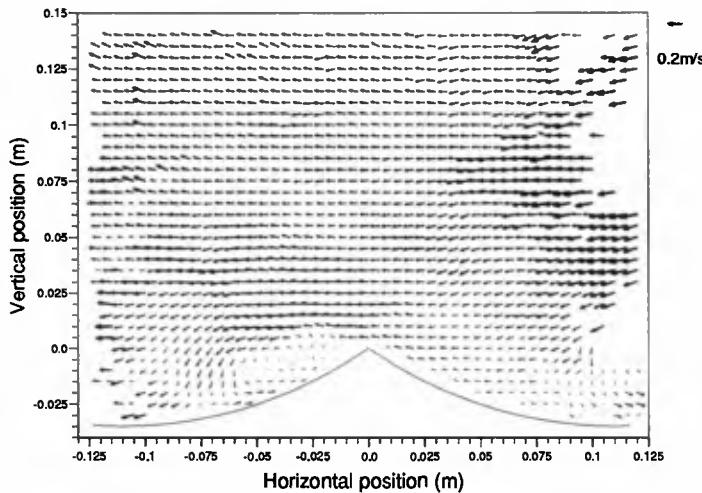


Figure 5: Velocity map for $a/L=0.8$, $T=8.46s$ and $\omega t=120^\circ$.

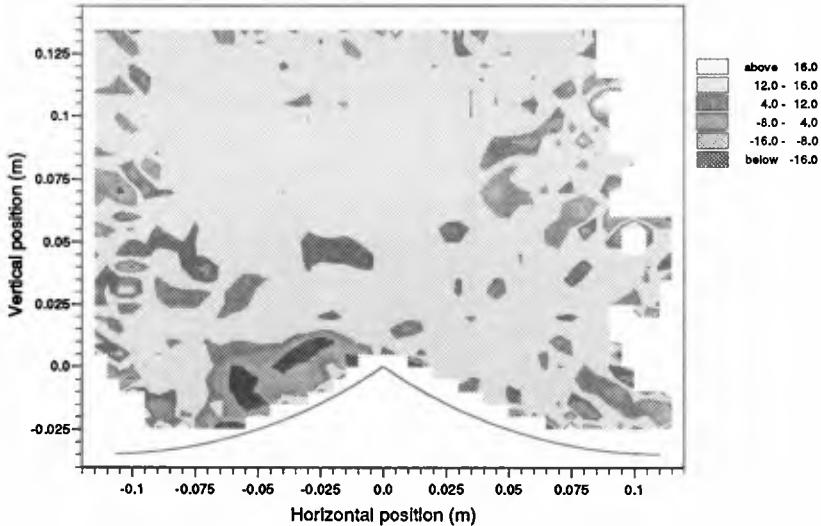


Figure 6: Vorticity plot for $a/L=0.8$, $T=8.46s$ and $\omega t=120^\circ$.

Figure 3 shows a typical measured velocity field and figure 4 its derived vorticity contour plot. These are for the slowest oscillation, $a/L=0.8$, at phase 30°

that is, just after the bed begins to move. The bed is accelerating from left to right, so the flow appears as right to left. The black areas on the vorticity plot correspond to areas of high negative vorticity, the colour lightens to a neutral grey background and then to areas of increasingly positive vorticity. A vortex, ejected from the crest of this ripple in the previous half-cycle, is now travelling up and away from the bed, above and to the right of the crest, whilst a new vortex is just being formed immediately to the left of the crest.

Later in the half-cycle (figure 5 and figure 6) the lee vortex has grown considerably whilst the positive vortex has dissipated a lot of its energy and has been swept across by the main flow.

These flow fields have been compared (Perrier, 1993) with the results of numerical models, in particular the Discrete Vortex Model developed by Danish Hydraulic Institute (DHI), Technical University of Denmark (ISVA) and Laboratoire National d'Hydraulique, France (LNH). Qualitative agreement was noted in the formation, shedding and trajectories of the vortices. Quantitative comparisons of the spatial flow fields are now possible for the first time. One way of approaching this would be to look more closely at the vortices and try to measure their positions and strengths as functions of time.

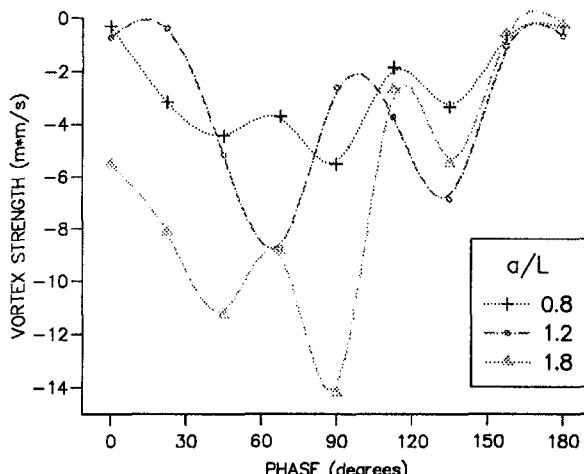


Figure 7: Plot showing vortex strength varying with phase for each of the three amplitudes of oscillation.

As a preliminary study the developing lee vortex has been looked at more closely. Calculations of vortex strength were made by imposing a boundary, defined by a lower vorticity level, on the vortex and summing the vorticity over all

the discrete points within the boundary. Figure 7 shows the variation of vortex strength through the half-cycles for each of the three amplitudes of oscillation. The data is rather scattered and the method needs a lot more thought but as a first calculation it does show roughly the trends expected. The negative vorticity increases towards 90°, corresponding to the flow's maximum velocity, and decreases again as the flow slows down at the end of the half-cycle. The faster, stronger flows generate more vorticity.

Concluding Remarks and Future Work

These new measurements give a lot more detail than previous point measurements and have shown the expected vortices in the right places. Qualitatively they agree with previous experiments and with numerical models.

One of the main problems with these experiments is the question of the repeatability of the flow from one period to the next. Successive pictures are not taken in the same oscillation due to the camera's finite wind-on time. One sequence of pictures is taken over several oscillations. One of the next things to be done is to check how repeatable the flow is from cycle to cycle. It has been suggested that the spikes in the vortex strength curves may be due to the effect of the positive vortices moving across the field and therefore affecting the calculations of negative vortex strength. Again this possibility needs to be tested. The next step is to develop a method of quantifying the information in the pictures so the results will be of help in predicting the sediment transport over ripples.

Acknowledgement

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