CHAPTER 181

Shingle Beach Profiles and Wave Kinematics

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Abstract

An extensive experimental project has been undertaken, in two parts, to measure both the formation of shingle beach profiles due to wave attack and the wave velocity fields using the technique of Particle Image Velocimetry (PIV). The former was achieved with moveable beach experiments carried out in the wave basin at HR Wallingford, and the latter on models in the 9.75m wave flume in The University of Edinburgh. Waves of several JONSWAP spectra, reflecting storm conditions, were allowed to impinge normally on an initial slope of 1:7, the resulting profiles were found to reach dynamic equilibrium after about 3000 wave periods. These profiles were modelled at The University of Edinburgh for the wave velocity measurements using the relatively new technique of PIV. This technique has the benefit of providing very accurate, full-field, instantaneous velocity data. In these experiments monochromatic waves were measured on smooth, impermeable beaches although the extension to multi-frequency waves on rough, permeable beaches is planned for the near future. The effect of the increased backwash component typical of these steeper beaches is dealt with in some detail.

Introduction

The stability of beach profiles, especially under storm conditions, is an important factor in coastal defence and environmental issues. One of the fundamental requirements for a better insight into such coastal processes, is the accurate measurement of the velocity fields of waves breaking on such beaches. In this study the relatively new technique of Particle Image Velocimetry (PIV) has been used to realise the latter. The project has been carried out in two parts. Firstly at HR Wallingford moveable beach experiments were carried out to measure the profile

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change in the beach from an initial 1:7 plane slope, which is typical of the shingle beaches being modelled. The second part of the experiments, to measure the velocity fields of the breaking waves, was carried out in the 9.75m wave flume at Edinburgh University which has been custom built for PIV measurements. Shingle, or gravel, beaches are common around the U.K. coastline and as the material has a much larger diameter than sand (typically 10-50mm D_{50}), it can tolerate steeper beach slopes and provides a good defence material (Powell, 1988).

In general, under storm conditions, the beach profile adopts a formation with a bar at the breaking point, a relatively flat breaking zone and a steep scarp formed by the run-up, just above the Still Water Line (SWL). The length of the relatively flat breaking zone is related to the energy of the incoming wavefield. A typical beach profile is shown in Figure 1.

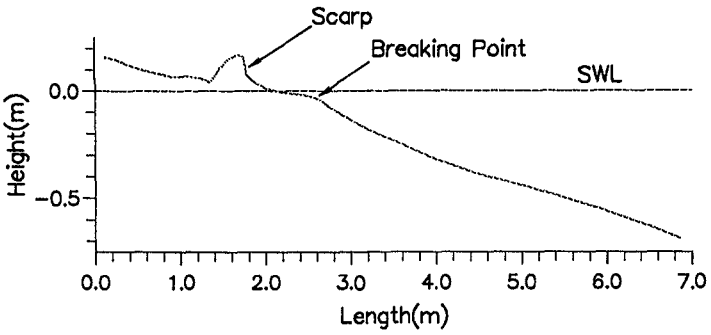

Figure 1: General shingle beach profile formed in a storm

Beach Profile Experiments

Experiments were carried out in the wave basin at HR Wallingford to measure the beach profile change in response to many wave conditions. The beach consisted of coal particles approximately 3.2mm D_{50}, chosen to ensure the correct sediment response at the model scale of 1:17. The beach was initially inclined at 1:7 for each experiment, and waves of various JONSWAP spectra were incident normal to the beach. Waves were created by three 5m absorbing wave boards. The beach profile was measured every 500 waves to establish beach stability and evolution. It was found that after 3000 wave periods the beach had reached dynamic equilibrium, and was therefore effectively stable.

The beach profile was measured automatically by a computer driven tactile probe which was mounted on a rig positioned above the wave basin. The rig was stepped in an offshore direction and at each step the probe was lowered until it touched the beach when the height was recorded. It was then retracted and

stepped onto the next position.

Four profiles were selected for the PIV experiments to be carried out in Edinburgh. These correspond to the profiles obtained from the wave spectra shown in Table 1.

Profile	$H_{sig}(m)$	$T_{mean}(s)$	$T_{peak}(s)$	*Steepness*
1	0.106	1.17	1.35	0.05
2	0.085	1.16	1.33	0.04
3	0.068	1.20	1.38	0.03
4	0.105	1.57	1.81	0.02

Table 1: Wave Parameters for Profiles to be used in PIV tests.

Figure 2 shows three of the four profiles to highlight the effect of the different wave conditions. In particular one should note that the size of the scarp increases with wave energy and tends to move quite significantly in an offshore direction, making the relatively flat breaker zone shorter with increasing wave energy.

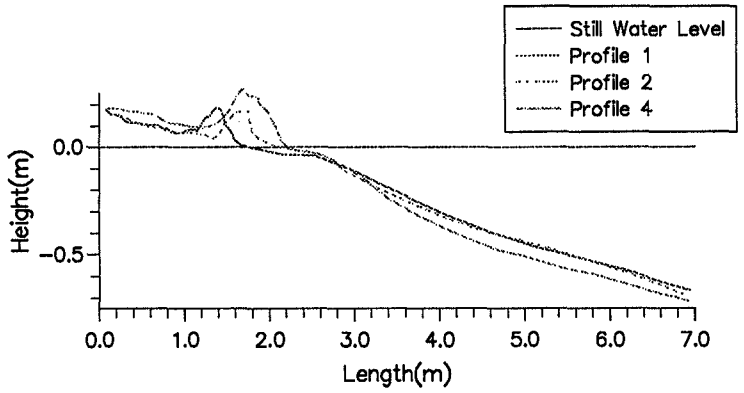

Figure 2: Different profiles formed from the various wave conditions.

Wave Velocity Measurements

The wave velocity fields were to be measured using the technique of Particle Image Velocimetry (PIV). This method obtains very accurate, instantaneous, full-field velocity data of the flow to be measured. It is an optical method and therefore non-intrusive. It is beyond the scope of this paper to discuss this technique in detail, however Adrian (1988) gives a good introduction and the following papers deal more specifically with hydrodynamic applications, in particular Greated et al (ICCE '92), (Gray & Greated, 1988; Quinn et al, 1991). As this is

a relatively new technique a brief outline of PIV is included.

PIV is a two stage process involving initially photographing the seeded flow which is illuminated stroboscopically. The shutter of the camera is held open for several light pulses so that multiple images of the seeding particles appear on the film. The developed negative is then analysed point-by-point on an automated system to measure the average displacement of the particles at each point. This, coupled with the knowledge of the light pulse period, yields the velocity at each point in the field. The pulsed illumination is provided by a scanning beam system. The beam of a 15W Argon ion laser is scanned by a rotating octagonal mirror along a parabolic mirror which reflects the light in a vertical "*sheet*" up into the tank. This method of illumination has proved to be the best for hydrodynamic flows (Gray et al, 1991).

The analysis method used is the so-called "Young's Fringe" method. The developed negative is probed systematically by a low power He-Ne laser with a beam diameter of about 1mm. The multiple images of the seeding particles cause interference of the laser beam and the light field transmitted by the negative is focussed by a lens forming Young's fringes on the array of a ccd camera. This is transferred to a microcomputer via a frame-grabber and a second mathematical Fourier transform is performed to obtain the autocorrelation plane, the first Fourier transform having been performed optically by the lens in front of the ccd camera. Peaks formed by the autocorrelation of a particle with its nearest image are located using a peak detection program, yielding the average displacement in that small interrogation region. As the illumination scan time is known the velocity at this point is obtained. The computer then steps the translation stage holding the negative onto the next position and the process is repeated.

The inherent accuracy of this technique is one of its main advantages, typical errors range from 1.2% for velocities with small velocity gradients across the interrogation region in the centre of the imaged flow field, to 5.9% for high velocity gradients at the edge of the imaged flow field. It is the velocity gradient across the interrogation region which causes the greatest loss of accuracy, and in extreme cases can cause signal drop-out (Quinn et al, 1991).

One practical requirement for PIV experiments is the large degree of optical access. The wave flume at Edinburgh University was designed specifically for PIV experiments and has glass walls and bottom. It is 9.75m long, 0.4m wide and 1.0m deep with a SWL of 0.75m. The waves are created by a computer driven hinged, absorbing wave maker (Salter, 1982). The laser beam illumination enters through the bottom of the tank and can illuminate a region up to 1m in length. A consequence of this is that the laser beam has to pass through the beach in order to illuminate the wave field. This is achieved by building the beach in two halves, with a 10mm gap running longitudinally down the middle. This gap is

covered by thin transparent plastic to maintain the shape of the beach and the optical access required. A section of the tank with the scanning beam system and measurement zone is shown in Figure 3.

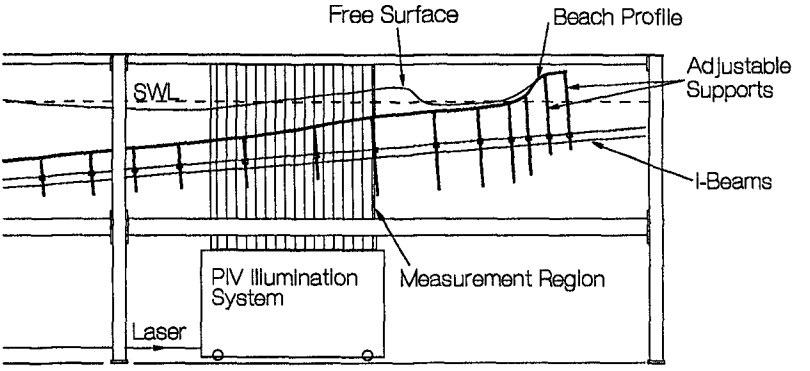

Figure 3: The wave tank, beach and illumination system

As several beach profiles had to be made an elaborate supporting system was designed enabling all the profiles to be made with the same apparatus. Two pairs of fibre-glass "I"-beams provide the main support for the beach, individually adjustable supports are attached to this to hold the beach surface in the correct position. These supports can be located discretely along the length of the "I"-beams and continuously adjusted vertically. The beach surface is made from 10mm thick "Coplast" plastic sheet, except for the breaker region where 3mm thick perspex sheet is required to adopt the more complicated profile. A photograph of the structure of the beach is shown in Figure 4.

PIV Experiments

As the area of interest of the beach was seaward of the scarp, it was possible to work at a larger scale of 1:10 than the experiments at HR Wallingford. The waves chosen for the present study were monochromatic waves whose frequency matched the mean frequency of the appropriate spectrum and whose height was derived from the significant wave height according to the relations given by:

$$H = \sqrt{2} H_{rms} \qquad H_{rms} = \frac{H_{sig}}{4}$$

The use of monochromatic waves may seem unjustifiable at first, however, this choice was made mainly due to the fact that PIV produces a spatial distribution of the velocity field at an instant, and so measuring a constantly varying wave field as in a JONSWAP spectrum, would provide results of dubious value. One

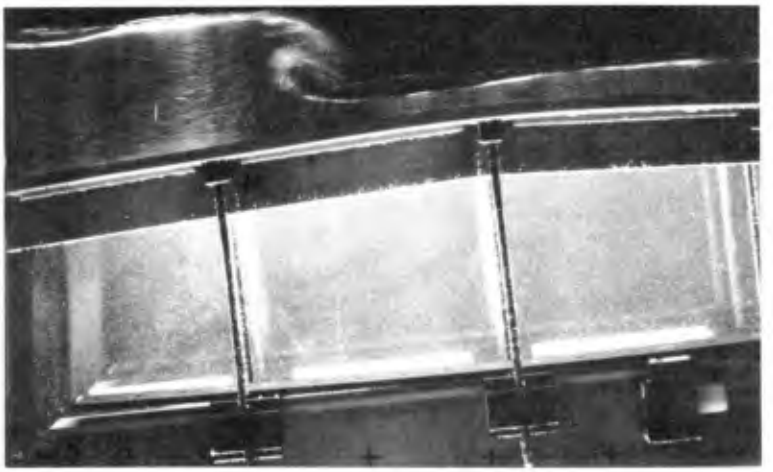

Figure 4: The beach structure

further consideration is that although the beach still reacts to individual waves, the average effect of the spectrum has resulted in a stable profile, hence our use of the mean wave frequency. It is intended, however, to measure bi-chromatic and possibly tri-chromatic waves in the future to represent the original spectra more accurately. This is important as the use of monochromatic waves excludes the significant effects of wave grouping and surf beat.

The wave conditions now Froude scaled in the ratio 1:10 are shown in table 2.

Profile	*Frequency*(Hz)	*Wave Height*(mm)
1	0.655	63.72
2	0.660	50.10
3	0.640	40.80
4	0.490	63.10

Table 2: Wave Parameters used in PIV tests.

Measurements were made all along each beach for all of the above wave conditions. At each measurement position four phases of each wave were recorded. In this way a complete flow field all along the beach could be obtained for four phases of all of the waves.

Results

Some examples of vector plots and PIV photographs of waves measured on the first two profiled beaches are shown. The main points to note are the detail of the PIV measurements and the shape of the breaking waves.

Figures 5, 6 and 7 show vector plots of the three positions near the breaking point on beach profile 2. Figure 7 shows a surging breaker is formed on this beach. Figure 8 shows the same position with the phase changed by π radians. The maximum velocity in Figure 7 is $0.35 ms^{-1}$ which is considerably less than the maximum velocity in the backwash, shown in Figure 8, which is $0.74\ ms^{-1}$.

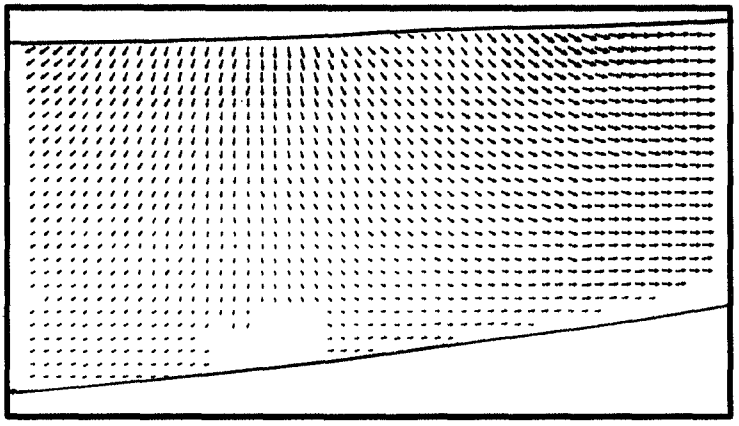

Figure 5: Profiled Beach 2, f=0.66Hz, H=50.1mm, Posn.: 3

The photographs in Figures 9 and 11 and the vector plot in Figure 10 show three different frequency waves breaking on beach profile 1. This has a longer breaking zone than profile 2 and a less steep scarp. In all cases plunging breakers are observed.

Discussion

One of the most significant properties of steep beaches is the increased backwash component, which is further emphasized by the length of the relatively flat breaking zone and the formation of a steep scarp just above the SWL. The effect of this scarp is to rapidly halt the run-up. This, coupled with the fact that for the higher energy waves the length of the breaking zone is shorter (Figure 2), results in the backwash being formed very quickly after the wave has broken. The returning flow can suppress the degree to which a plunging breaker is formed

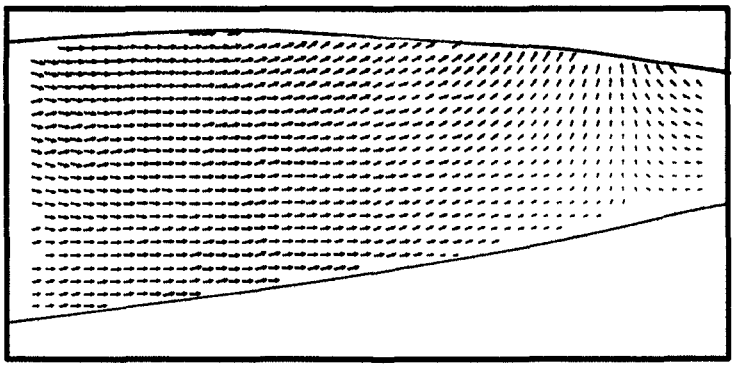

Figure 6: Profiled Beach 2, f=0.66Hz, H=50.1mm, Posn.: 2

to the extent that for the case of the second beach profile surging breakers are evident (Figure 7). In the case of a relatively long breaking zone or a plane beach, the increased length of run-up gives time for the incoming wave to break before the backwash is completely formed. This is evident from Figures 9, 10 and 11 on profile 1 where plunging breakers are still formed.

With a wall-like scarp just above the SWL a "standing-wave" is formed in the breaker zone with the almost total reflection being driven by the incoming waves. Obviously this effect is emphasized in these experiments as only monochromatic waves are being measured on an impermeable slope, however, this is perhaps the effect the beach is "trying" to achieve in order to absorb the most energy.

The formation of a "standing wave" in the breaker zone will be affected greatly by multi-frequency waves, not only because they all by definition have different periods, but also because they will break at different positions. In addition to this the permeability of shingle beaches is particularly important due to the large material size. There is significant flow into the beach above the MSL and also within the beach itself. This "draining" of water from the run-up will affect the amount of water returning in backwash.

Conclusion

Experiments to measure the profiles of shingle beaches formed in simulated storm conditions by waves of various JONSWAP spectra have been carried out. The modelling of these beaches for wave velocity measurements using PIV has also been successful. The detail of the results obtainable from this measurement technique has been shown for the case of monochromatic waves on impermeable beaches. Whilst it is hoped that these results can be used for comparison with numerical models, the extension to measuring multi-frequency waves on imper-

meable slopes would seem the obvious next step.

Acknowledgement

This collaborative project between HR Wallingford and The University of Edinburgh is funded jointly by the Science and Engineering Research Council (SERC) and by the commission of the European Communities Directorate General for Science, Research and Development under contract N°. MAST 0035C .

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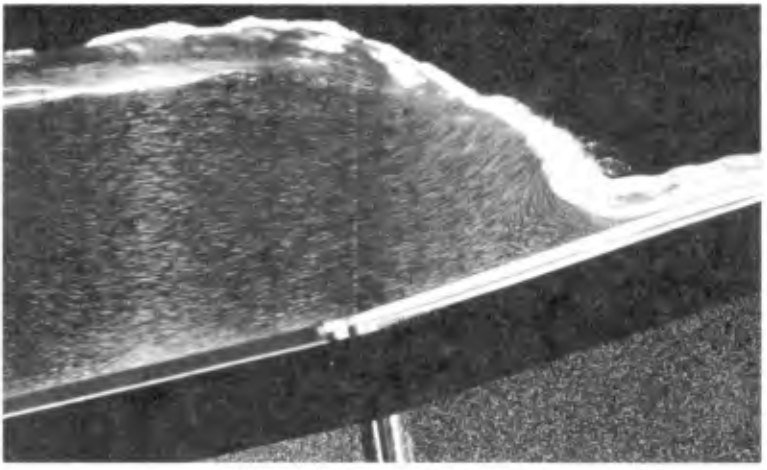

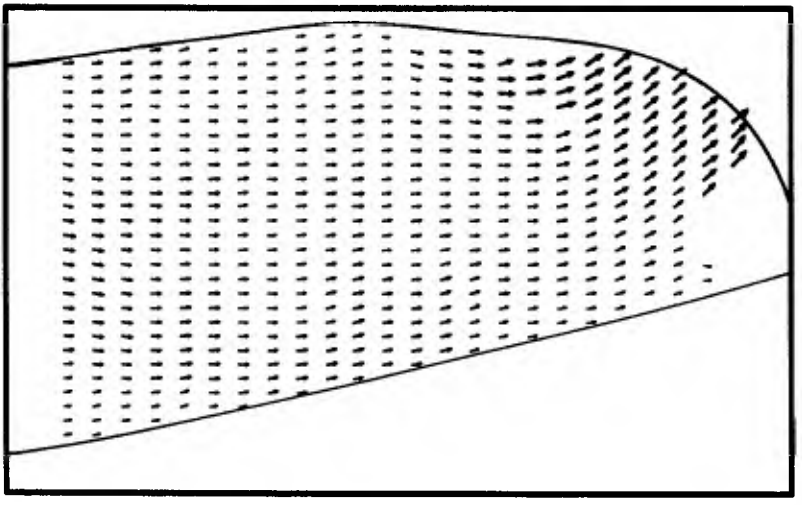

Figure 7: Profiled Beach 2, f=0.66Hz, H=50.1mm, Posn.: 1

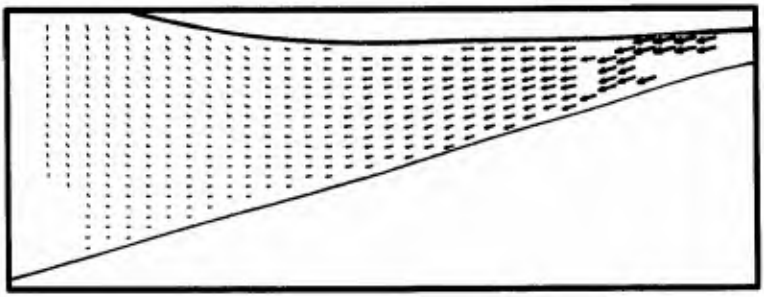

Figure 8: Profiled Beach 2, f=0.66Hz, H=50.1mm, Posn.: 1

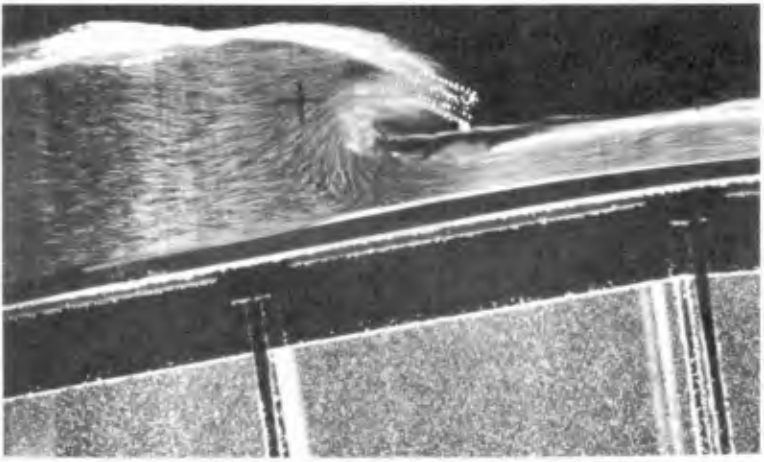

Figure 9: Profiled Beach 1, f=0.655Hz, H=63.1mm, Posn.: 1

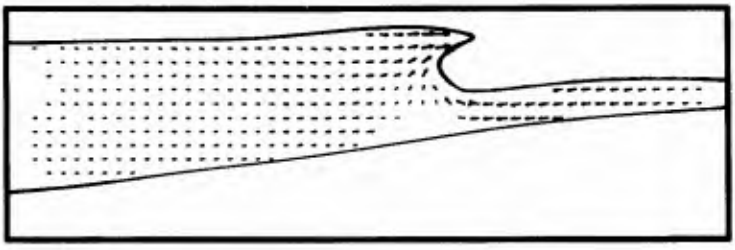

Figure 10: Profiled Beach 1, f=0.66Hz, H=50.1mm, Posn.: 1

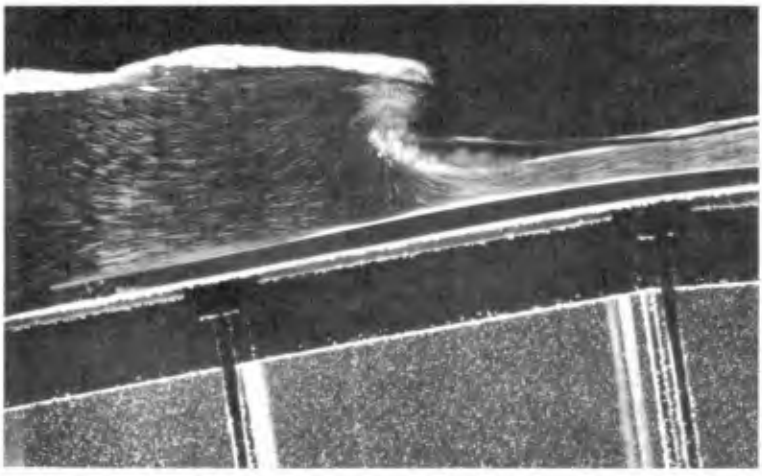

Figure 11: Profiled Beach 1, f=0.64Hz, H=40.8mm, Posn.: 1