**The Journal of Undergraduate Research**

Volume 6 *Journal of Undergraduate Research, Volume 6: 2008*

Article 10

2008

# Particle Motion On A Plane Slope Under Spilling Breaking Waves

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# Particle Motion On A Plane Slope Under Spilling Breaking Waves

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## ABSTRACT

The experiments discussed in this paper involve the motion of discrete solid particles on a plane slope under spilling breaking wave conditions. Particle Image Velocimetry was used to capture images of seeder particles in water so the motion of the fluid particles and solid particles could be traced. The images produced from the experiments have two phases. Since the behavior of the water and the sediment particles must be studied individually, the two phases of the image must be separated. A series of functions in MATLAB allows the two-phase image to be separated into two images—one containing only the sediment particles and one with the background seeder particles which represent the fluid phase. The ultimate goal of this study was to determine how the sediment particles behave under spilling breaker wave conditions. MATLAB was used to fit a fourth order polynomial to seven data points from which the sediment particle velocities and accelerations could be found. Three situations of interest were investigated: (1) no large-scale turbulence in the field of view, (2) a turbulence burst landing shoreward of a sediment particle, and (3) a turbulence burst occurring seaward of a sediment particle. It was found that regardless of which of the above three situations occurred, the net transport of the sediment particles over one wave cycle was offshore for the spilling breaker case. The intensity and location of the downbursts determined only the magnitude of the net offshore transport.

## INTRODUCTION

Organized flow structures occurring intermittently in space and time characterize the turbulent flow field under breaking waves. These structures are imperative to sediment suspension in the surf zone (Ting, 2006). The behavior of sediment particle motion in fluid under various breaking wave conditions is a complex problem. In order to study a complex problem, it is essential to start with a simple situation before looking at all of the variables together. The experiments discussed in this paper involve the study of discrete particle motion on a plane slope under spilling breaking wave conditions. Preliminary conclusions have been drawn as a result of these experiments.

Particle Image Velocimetry, or PIV, is a technique used to study fluid motion by capturing images of seeder particles in fluid. In such studies, seeders are stirred into the water to allow the fluid motion to be traced, and glass spheres are placed to represent sediment particles. Because of this, the images that are produced have two phases. The motion of the water and of the sediment particles must be studied individually so the two phase images must be separated. MATLAB software was used to accomplish this.

## *Methods*

The experiments were conducted in a wave flume tilted to a slope of three percent. The two-phase PIV measurements were taken in a plane parallel to the bottom of the flume at a height of approximately one millimeter above the bottom. The measurements captured the fluid and particle motion just shoreward of the wave breaking point. The field of view of the measurements was approximately 400 millimeters in the longitudinal direction and 200 millimeters in the transverse direction. Figure 1 illustrates the experimental setup.

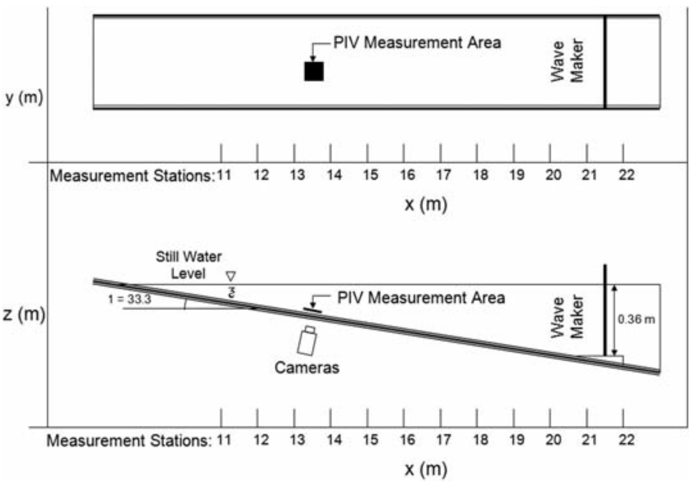


**Figure 1.** Experimental Setup

The spilling breaker has a wave period of two seconds in the experiments. The measured wave height and still water depth at the center of the measurement area were 0.08 and 0.146 meters, respectively. A total of 30 test runs were completed in which 200 straddled frames were captured with a sampling rate of 15 frames per second. Precision glass spheres with a specific gravity of 2.5 and diameters of 1.0 and 1.58 millimeters were used to represent sediment particles.

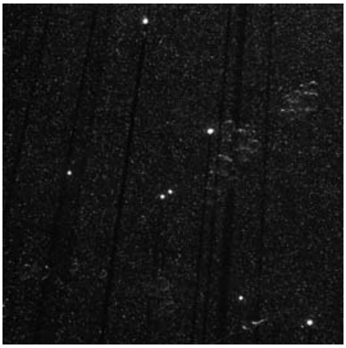

**Figure 2.** Original image

Figure 2 shows an original image captured by the cameras in the PIV measurements. The image shows the 1.58 and 1.0 millimeter particles, the seeder particles, and entrained air bubbles. A series of functions in MATLAB allows the two-phase image to be separated into two images—one containing only the sediment particles and one with the background seeder particles. The images are made up of pixels with gray levels ranging from 0 to 255 in MATLAB. Pixels values of 0 are shown as black and values of 255 are shown as white.

The first step in this process is to morphologically open the image with a disk structuring element of radius three pixels. Morphological opening of an image by a structuring element is erosion of the image by the structuring element followed by dilation of the result by the structuring element (Gonzalez et al., 2004). Dilation adds pixels to the boundaries of objects in an image and erosion deletes pixels on the boundaries of objects. The result of this operation blends the seeder particles into the background allowing the sediment particles to stand out.

The next step was to separate the sediment particles from the background. The goal in this process was to keep the shape of the particles as round as possible while retaining their sizes. All pixels that had gray levels less than 80 were set to 0 and all others were set to 255. Next the particles edges were smoothed with a filtering function to make the particles nearly round. The particles were then eroded back to their original sizes. The background image without the sediment particles is shown in Figure 3. The image with only the sediment particles is shown in Figure 4.

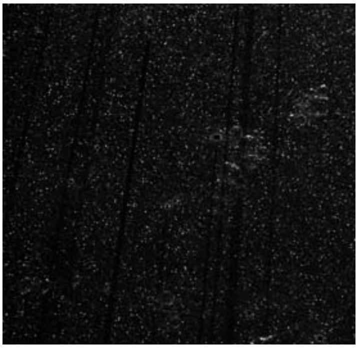

**Figure 3.** Background

**Figure 4.** Sediment Particles

After separating the sediment particles, the coordinates of the centroid of each particle were exported into Excel. The coordinates were then converted from pixels to millimeters. The particles' information from each frame was then manually copied into a separate table for further analysis.

The ultimate goal of this study was to determine how the sediment particles move under breaking wave conditions. The particles' velocities and accelerations are two important parameters in studying their behaviors. The velocities and accelerations were found through basic calculus of taking the derivatives and second derivatives of the positions with respect to time. Because the plots of the particles' positions versus times were so irregular, only seven positions were analyzed at one time.

An algorithm in MATLAB was developed to fit a fourth order polynomial to seven adjacent data points. The center data point was the position of interest, and a for loop was used to advance to subsequent points. The polynomial, its derivative, and its second derivative were evaluated at the position of interest to give the instantaneous velocity and acceleration at that point.

## RESULTS

The effect of different turbulence conditions on the motion of sediment particles have been observed in this experiment. The offshore, onshore, and net movement of the sediment particle changes with respect to the location of turbulence bursts. Three situations of interest were investigated: (1) no large-scale turbulence in the field of view, (2) a turbulence burst landing shoreward of a sediment particle, and (3) a turbulence burst occurring seaward of a sediment particle.

The position with respect to time of a 1.0 millimeter particle when there is no large-scale turbulence in the field of view is shown in Figure 5. The graph shows that the sediment particle moves about 120 millimeters offshore and 80 millimeters onshore. This creates a net offshore transport of about 40 millimeters over one wave cycle.

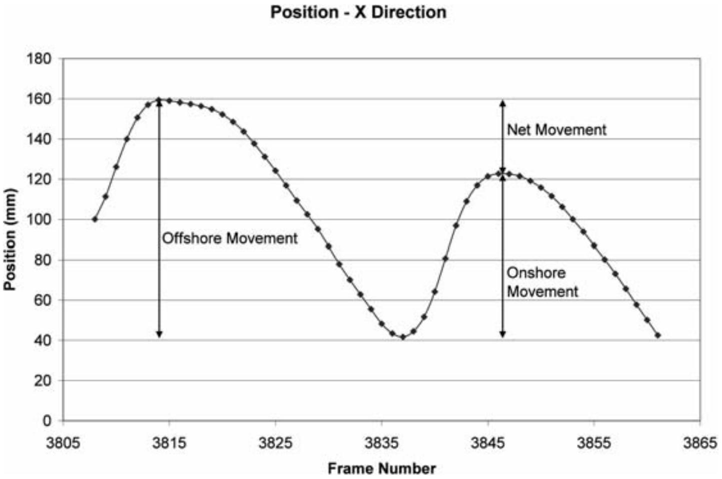


**Figure 5.** Weak Turbulence

A situation where a downburst of turbulence impinges on the bed in front of the 1.0 millimeter sediment particle is shown in Figure 6. In this case, the sediment particle still moves about 120 millimeters offshore but only 32 millimeters onshore. The onshore movement is significantly smaller than the previous case creating a net offshore transport of about 85 millimeters over one wave cycle.

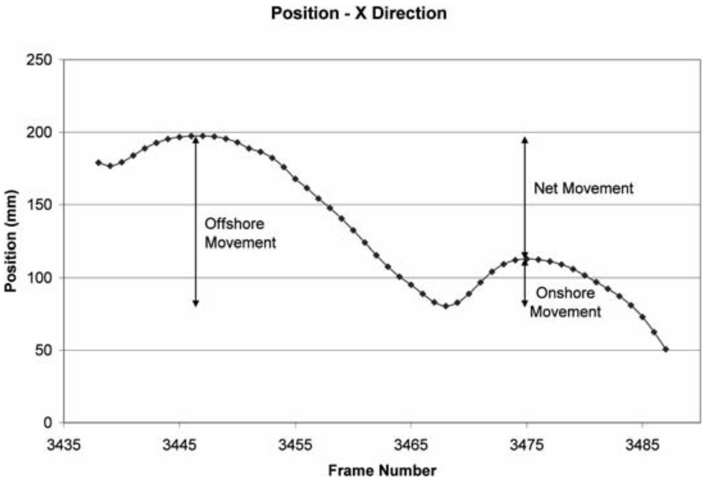


**Figure 6.** Turbulence Burst Onshore

The opposite situation is shown in Figure 7. The graph shows the situation where a downburst of turbulence impinges on the bed behind the 1.0 millimeter sediment particle. In this case, the offshore movement of the sediment is about 90 millimeters which is much less than the previous cases. The onshore movement is about 70 millimeters leading to a reduction in the net offshore transport of only about 20 millimeters.

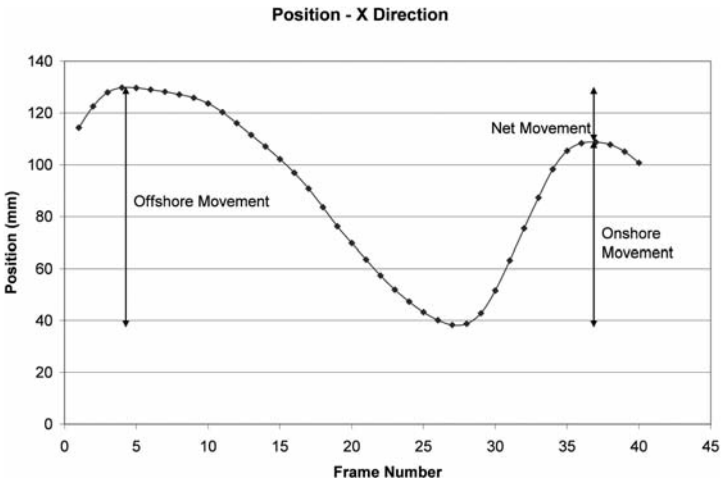


**Figure 7.** Turbulence Burst Offshore

## CONCLUSIONS

The techniques discussed in this report would allow one to analyze the motion of particles under breaking wave conditions. Important parameters to study include the displacement of different sized particles as the wave passes, evidence of particles trapped in a vortex, outward displacement of particles from a center which may indicate a downburst of turbulence, and any indications of particle suspensions.

The three different scenarios described in the results section show how turbulence downbursts in the wave can affect the movement of the sediment particle. However, regardless of which of the three situations occurs, the net transport of the sediment particles over one wave cycle is offshore for the spilling breaker case. The intensity and location of the downbursts affect only the magnitude of the net offshore transport.

## ACKNOWLEDGEMENTS

This study was funded by National Science Foundation (NSF) Grant OCE-0525676 and the Research Experience for Undergraduate (REU) program. I am grateful for the support from NSF. I would also like to acknowledge Dr. Francis Ting for this research opportunity from which I have gained many valuable experiences.

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