MCEN 4151: FLOW VISUALIZATION

Wave Breaking in Flume

First Team Image

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March 21, 2012

The third assignment for the Flow Visualization course is the first team image. For this assignment, each student is expected to work in their groups of five to take a photo of a fluids phenomenon that both demonstrates the situation and is artistically sound. This is similar to the first "Get Wet" assignment expect that by working in groups, the students are expected to put their resources and expertise together to create even more brilliant images than were done initially. My group chose to work with a water flume to try to capture the many fluid dynamics which are created when water interacts with objects in its flow. Although we tried many different situations, my final image shows the effects of a wave breaking.

The open channel flume used to create this image has a 2.5m by 76mm by 250mm channel bed. To create this image, two different obstructions were used: the triangular wooden block, which can be seen in the bottom of the image, and a square block, which was used upstream from the triangular block to completely block the flow. This set up can be seen in Figure 1.

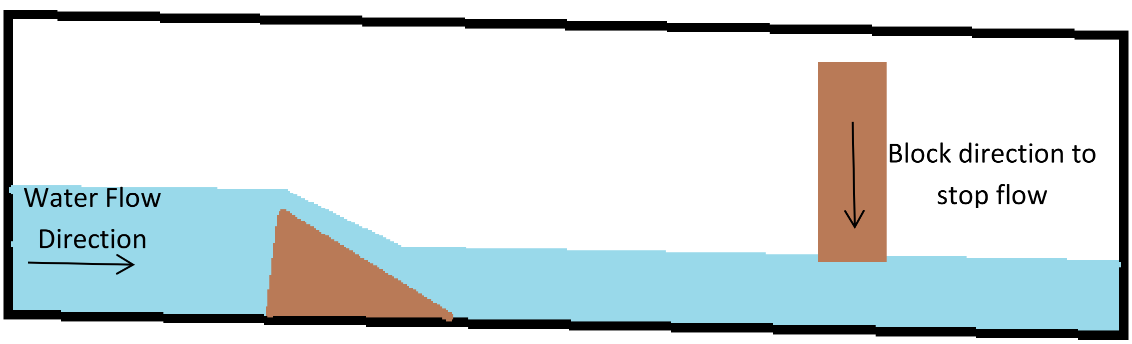

Figure 1: Flume Set-Up

The water was allowed to flow normally until the water was flowing consistently over the triangular block. The square block was then moved down in order to block the flow of water until the water level had risen significantly on the left side. Then the square block was taken out of the water, allowing the water to quickly flow out of the channel, which created a small wave over the triangular block. As this small wave was traveling towards the square block, the block was quickly lowered into the water to stop the flow, and create a larger wave, which was then traveling towards the smaller wave. My image shows the moment at which the two waves collide, and the larger wave on the right breaks over the smaller wave on the left. This creates a large amount of turbulence in the water at the area of the waves, which can be seen by the white bubbles in the image.

The wave breaking which can be seen in this image is similar to a wave breaking on a beach. The wave is traveling up a small incline. Due to the friction between the bottom of the wave and the bottom of the flume, as well as the incline, cause the water at the front of the wave to move slower than the water in the rear of the wave. This change in speed causes the water to bunch and the wave to grow larger. At this point the water depth at the crest is much larger than the water depth around the wave. This makes the top of the wave unstable. Finally, the wave reaches a point at which it can no longer stand and the water at the back of the wave is moving quickly enough compared to the water at the front of the wave that the water from the back of the wave travels over the water at the front, causing the wave to collapse or break.[1] This breaking is also caused by the small wave which is travelling towards the larger wave, which causes it to break more quickly as the wave is slowed down and forced to grow larger and more unstable.

The kinetic energy in the wave as it moves is transferred into the surrounding water after the wave breaks.[2] This transfer of energy can be seen in the turbulence and bubbles in the water. The breaking waves moves in a circular path as the water of the wave and surrounding water mix.

The phenomenon which is shown can also be described as a hydraulic jump. A hydraulic jump is the sudden transition from a high velocity open channel to a lower velocity constricted flow. This transition causes kinetic energy to be changed to potential energy, and the wave grows higher. This eventually becomes unstable and falls, as described above. A hydraulic jump can be described by a Froude number, which is shown in Equation 1.

$$Fr = V/\sqrt{g * d}$$

The Froude number can be calculated for the wave at the point before the wave crashed. The velocity is estimated to be 1 m/s and the wave depth is estimated to be 0.75 m. This gives a Froude number of 0.369. This gives a Froude number close to unity, which says that the hydraulic jump is largely stable.

This picture is spatially resolved, which can be seen by comparing the magnitude of the flow to the magnitude of the photo. The smallest point of interest in the photo is the bubbles, which can be seen around the wave. These are estimated to be around 1/16th in. The largest part of the flow is all that is included in the frame. This is estimated to be approximately 16 inches. Comparing these two figures, there is a separation of 2 to 3 decades. The picture is approximately 4000 pixels in size, which is equivalent to 3 decades. As the flow requires 2 to 3 decades to be spatially resolved, and the picture has 3 decades of information, the photo is spatially resolved. This means that all parts of the photo pertinent to understanding the flow in the picture can be seen.

The visualization technique used here is the water in the flume. The flume was lit in two directions, with florescent lights from above, and work lights below, to try to bring as much light as the area as possible while keeping glare down. A black sheet was placed behind the flume to bring contrast between the white turbulent water and the black background. The photo was taken with the lens perpendicular to the flume to try to further reduce glare.

The camera settings were defined by the shutter speed and ISO, which were set in such a way as to freeze the motion of the water, while keeping the picture bright enough to capture the details. The camera specifications and settings are shown in Table 1.

Table 1: Camera Specs and Settings

Camera Body	Canon Rebel T2i
Camera Lens	50mm
Aperture	1.8
Shutter Speed	1/320
ISO	400

The photo was digitally altered in Photoshop. The brightness and contrast were increased to bring out the details of the photo. Small water droplets which were on the glass but irrelevant to the flow were cloned out, as they were distracting. The photo was cropped to bring focus to the crashing wave. The initial pixel size of the photo was 5184 x 3456, and the final pixel size of the photo after cropping is 4602 x 2268.

I feel that this image captures a unique moment in this fluid flow. I think this image could be enhanced by increasing the lighting, which would allow an increase in the shutter speed and reduce the blur in the photo. I also think adding dye to the image would be interesting. I think taking a video of this image would be very interesting. I realized while trying to analyze the physics of the flow that I could have taken more data during the process, such as the flow rate, and the velocity of the wave. I think these would have been interesting numbers to have.

References

[1]Wilson, Tracy V. "How Surfing Works." *HowStuffWorks.com*. HowSuffWorks, INC. Web. 21 Mar. 2012.
[2] Science Daily. "Breaking Waves." *ScienceDaily*. Web. 22 Mar. 2012.
[2] Chanson, Hubert. "Current Knowledge in Hydraulic Jumps and Related Phenomena. A Survey of Experimental Results." *European Journal of Mechanics - B/Fluids* 28.2 (2009): 191-210. Print.