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WAVE OVERTOPPING DISCHARGE CALCULATION FROM VELOCITY MEASUREMENTS

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Abstract: Wave overtopping discharge is one of the most important parameter for the design of seawalls. During past 50 years methods for predicting wave overtopping of coastal structures have continuously been developed. A seawall is a protection wall, which is built for protecting coastal environment against large waves. Analytical work consists of repeated programme runs where two consecutive Overtopping Images were input every time. For obtaining velocity vector field, MPIV algorithms and for determining layer thickness on the crest of the seawall AUTOCAD software was used. In this project total of 1377 wave overtopping images were analysed for three different seawalls configurations (freeboard elevations of 15 cm, 20 cm, 25 cm and the wall slope of 27 degree angle with vertical axis) under flip-through wave. The programme was run 118 times by utilizing '*mpiv*' algorithm. Using simple analytical equations overtopping volumes were calculated. In this study, a new technique was developed to compute overtopping discharge on the top of the seawalls, based on the Bubble Image Velocimetry (BIV). Analytical discharges were compared with laboratory measured data. Results presented in this project, covered only sloped seawalls subjected to flip-through type waves. A satisfactory agreement was found from the analytical and measured overtopping discharges.

Keywords: *Overtopping discharges, Sloped sewalls, Bubble image velocimetry, Laboratory measurements, Analytical discharge, Flip-through wave.*

Introduction

For developing and increasing the recreational activities, people of the world are interested for living in coastal zones. The main hazard associate for

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people, property and infrastructures, when wave overtopping on coastal structures. Different types of coastal defence structures like breakwaters, seawalls etc. are commonly construct for protecting these coastal zones against large waves. Seawalls are very familiar structure for protecting coastal area from wave attack. When waves are running through the crest of the coastal structure like seawall then overtopping discharge occurs. The aims of this project are to calculate the overtopping discharge on the slope seawalls from velocity measurements. MPIV (Matlab Particle Image Velocimetry) algorithms and AUTOCAD (Version-2006) software will be used for carried out this project analysis. For calculating average and maximum single overtopping volume, Empirical formula will be used. At last the analytical value will be compared with the existing laboratory measured data by Jayaratne et al. (2008). The analytical work consists of repeated programme runs where two consecutive Overtopping Images were input every time.

Background

In the recent years, Researchers of coastal engineering, trying to develop a model of wave-transformations on sea defence structures accurately both physically and numerically in shallow water conditions. Different types of experimental investigations have been done on wave overtopping for various types of waves. Every single event has expressive effect on coastal structures like wave impact and overtopping volume. From the physical model examination in the UKCRF wave basin Hunt (2003) showed a comprehensive analysis of focused wave groups. At the end of the experiment a set of conclusions were found which were related to the effect of wave groups on run-up and overtopping of coastal structures. Researchers tried to find out some significant parameters for designing of coastal structures, for this reason some important projects like Violent Overtopping of Wave at Seawalls (VOWS) have already been reviewed and analysed overtopping of vertical and composite seawalls by Bruce et al. (2001) and Pearson et al. (2001). In the laboratory experiment, Goda and Kishira (1976) predicted wave run-up rate on inclined seawall and provide a chart. Shankar and Jayaratne (2003), viewed their project '*Wave run-up and overtopping on smooth and rough slopes coastal structure*', wave steepness is an important parameter for expressing overtopping rate. Under the PROVERBS project, Oumeraci et al. (2001) tried to describe the comprehensive study on vertical breakwaters. In this study they classified waves into four categories which are as follows; (a) Quasi-standing wave, (b) Impact loads, (c) slightly breaking wave and (d) broken waves. Particle Image Velocimetry (PIV) is a whole-flow field, non-intrusive technique which is often used to investigate time dependent flows. By using this technique it is possible to calculate momentary velocity vector maps in a cross-section of a flow. The efforts of Govender et al. (2002) were succeeded to obtain more comprehensive quantities, for this experiment they used a method which is similar to PIV based on the digital image acquisition and cross-correlation algorithms and for removing the aerated region they used a laser light sheet

Methodology

This paper is totally software base and the goal of this thesis is that, analyse the existing overtopping images and calculate the individual overtopping volume on seawall. The working procedures are as follows:

a) Two overtopping images were taken every time for running the *mpiv* algorithm.
b) When two consecutive Bitmap images were inserted into the mpiv algorithm a new image with velocity vectors were obtained as output.
c) By using data cursor velocity vectors (U and V) were measured on the crest of the seawall at three different points on the same line.
d) From the measured velocity vectors U and V, resultant velocity was calculated by using excel spread sheet in three different locations.
e) From three resultant velocities, an average resultant velocity was calculated by using excel spread sheet.
f) The angle (α) between velocity vector and the cross-sectional area of water jet was calculated for three different points and average angle was calculated.
g) Obtaining all *mpiv* images was converted into JPEG format.
h) The JPEG figures were imported one by one in AUTOCAD (Version-2006) software for calculating overtopping water layer thickness on the crest of the seawall.
i) From the AUTOCAD data overtopping layer thickness was calculated.
j) Cross-sectional area of the water jet on the crest of the seawall was calculated by multiplying the layer thickness and width of the channel.
k) The overtopping flow rate, Q (m^3/s) was calculated by utilizing a numerical equation.
l) Overtopping flow rate (Q) was multiplied by time interval (dt) and divided by the width of the wave flume for calculating overtopping volume per unit width (m^3/m).
m) Steps a – l were repeated for the next two images analysis.
n) At the end of image analysis, overtopping volumes (m^3/m) were integrated to determine the overtopping volume at the end of the single overtopping event.

Data Analysis

Overtopping volumes were calculated by analyzing still images. By using MPIV, velocity calculation from two consecutive images is straight forward. *mpiv* developed by Mori & Change (2003). AUTOCAD (Version-2006) software was used for measuring water layer thickness on the crest of the seawall. By utilizing some numerical equations and the obtained value from software, analysis was carried out.

Three different resultant velocity (R) was calculated from mpiv figure and average velocity (V) was taken for overtopping volume calculation.

$$R = \sqrt{u^2 + v^2} \qquad (1)$$

$$V = \frac{R_1 + R_2 + R_3}{3} \qquad (2)$$

The input augments of *mpiv*.m are as follows:

Input Argument	Input Value	Description
Im1 and Im2	---	Two consecutive gray scale bitmap images
nx_windo, ny_window	32 × 32	Processing window size in x and y
Overlop [x, y]	0.5 × 0.5 (50% overlap)	Fraction of overlapping windows in x and y
{iu,iv}_max	10 × 10	Maximum allowed velocity in x and y (in pixels)
dt	0.002 seconds	Time separation between Im1 and Im2
Piv_type	Mqd	MQD Algorithm
i_recur	1	One recurrence with the same window size
i_plot	1	Plot the calculated results

Some numerical equations were used for calculating layer thickness (Y), water jet area (A) and angle (α) between velocity vector and cross-sectional area, which are given below one by one:

$$Y = \frac{0.54}{P} \times Q \qquad (3)$$

Where,

P = Length of the figure (m) in y direction (calculated from AUTOCAD).

Q = Layer thickness (m) at the top of the seawall (calculated from AUTOCAD).

$$A = t \times d \quad (4)$$

$$\alpha = tan^{-1}\left(\frac{v}{u}\right) \quad (5)$$

$$\alpha = \frac{\alpha_1 + \alpha_2 + \alpha_3}{3} \quad (6)$$

Having the area and the velocity vectors, the discharge rate (m3/s) can be estimated using the following formula

$$Q = V \times A \times Cos(\alpha) \quad (7)$$

In this project the analysis was carried every 10 frames for two consecutive images and the results were integrated over time to get the overtopping volumes per unit width. The equation which was used for integration is as follows

$$V = \int Q.dt \quad (8)$$

Three different configurations of seawall were used for determining overtopping volumes. For checking the obtained results another set of data was analyzed and satisfactory result was found.

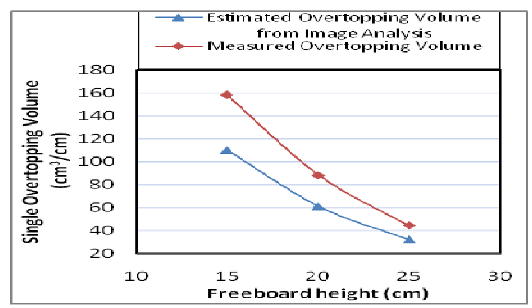
Table 1 difference between Analytical and Measured overtopping volumes.

Seawall type	Case No.	Analytical volume (cm^3/cm)	Measured volume (cm^3/cm)
15cm freeboard 27 degree	1504f1	**104.42**	**158.20**
15cm freeboard 27 degree	1504f2	115.91	158.20
20cm freeboard 27 degree	2804f1	61.07	88.44
25cm freeboard 27 degree	3103f3	32.35	44.30

Discussion

It is evident that the methodology of estimating overtopping volumes from still image analysis is useful and most promising. The results which were

computed from image analysis were more accurate with measured volumes by Jayaratne et al. (2008). The observed trend in the plots shows that the analytical volumes are little bit less from measured volumes with a certain constant. It is expected some difference, when any one compute overtopping volumes with different ways. For this analysis, the range of difference was calculated 26% to 34% of the measured overtopping volumes. The two curve lines were drowned and it depicts a steady difference between the analytical and measured overtopping volumes. Some reasons are described below which are the main fact for the difference of overtopping volume in this analysis. (a) The MPIV (Matlab Partical Image Velocimetry) performed analysis on the whole image but, it was not able to calculate velocity vector at every point in the image. (b)Water layer thickness was calculated by using AUTOCAD (Version-2006) software, however it was very difficult to determine the layer thickness at the end of wave period, because that time layer thickness was very thin but water moving over the crest of the seawall. Another important point is that, at the initial moment some water fly over the crest of the seawall that water was not considered for overtopping volume calculation. This may be the reason for difference between analytical overtopping volumes and measured volumes by Jayaratne et al.(2008). (c)Time period is one of the important parameter for analyzing overtopping volume from images. The time period for calculating overtopping volumes from images and the overtopping volumes from laboratory experiment was little bit different, because in the laboratory, time counting started from the start of the water jet at the crest of the wall until the water stops moving upwards and changes its direction and move downwards. But for image analysis, times for initial and last moment of wave overtopping were neglected, because that time, layer thickness was very thin. This might have also an effect on the outcome of the overtopping volumes estimation.



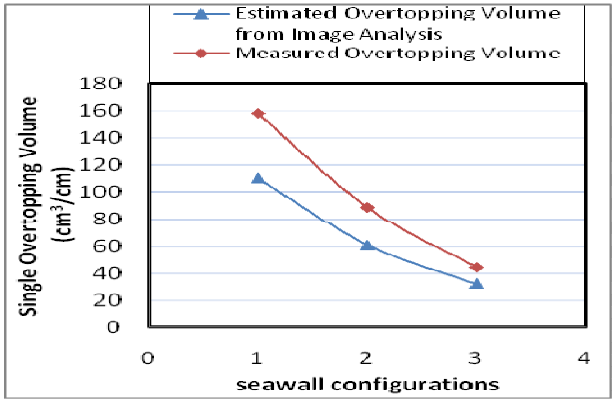


Figure 1 Estimated vs. Measured Overtopping Figure 2 Estimated vs. Measured Overtopping Volumes plotted against freeboard height. Volumes for three different seawall configurations.

(In the above Figure 2, seawall configuration 1 represents data set no. 1504f1, seawall configuration 2 represents data set no. 2804f1 and seawall configuration 3 represents data set no. 3103f3)

Conclusion

In this dissertation mainly discussed about the methods for capturing overtopping discharges and recording the individual wave volume by using software. A methodology is proposed for estimating overtopping volumes from the pairs of still images by using mpiv algorithm and AUTOCAD (Version-2006) software. Overtopping volume which is one of the main reasons for damages coastal structure like seawall. The design of an efficient seawall should be such that overtopping is minimized. As a coastal engineer, it is very important to understand about the amount of overtopping volume when he will go to design any coastal protection structure. For the majority of coastal structures, quantification of overtopping, dictates the crest elevation required. In this sense it is one of the parameters that have the greatest potential to have an impact on the cost of a structure.

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