An experimental study of shallow water impact

H.D. Kang[a], S.H. Oh[a], S.H. Kwon[a], J.Y. Chung[a], K.H. Jung[b], H.J. Jo[c]
[a] Department of Naval Architecture & Ocean Engineering, Pusan National University, Busan, Korea
kanghyodong@pusan.ac.kr, carot541@pusan.ac.kr, shkwon@pusan.ac.kr, chungjy@pusan.ac.kr
[b] Dept. of Naval Architecture and Ocean Engineering, Dong-Eui University, Busan, Korea
khjung@deu.ac.kr
[c] Division of naval architecture and ocean systems engineering, Korea Maritime University, Busan, Korea
hjjo@hhu.ac.kr

1. Introduction

Impact of a body with water surface itself is a very complex phenomenon. To make the problem more complex, one can introduce shallow water environment. In other words we are talking about extreme of extremes. When it comes to the shallow water impact, Korobkin (1999) analyzed impact of box-like structure onto shallow water with the help of asymptotic methods. He classified the phenomenon into three stages as follows. The first stage ends just right after the impact. The flow beneath the bottom is not developed yet. The formation of spray jet can be seen. In the second stage the fluid beneath the bottom is under developed. The formation of spray jet and splash jet is visible. In the third stage the jets are inclined towards the body. The flow region in the third stage is divided into 6 parts. He derived equations for the flow patterns and pressure distributions for the third stage based on matched asymptotic methods. An experimental work on gravity wave generation by a body falling onto shallow water was carried out by Bukreev (1996). He obtained wave elevation time histories of soliton for various shape of bodies.
This study presents an experimental examination of the three stages by the analysis of video image captured by high speed camera, flow field measurement by PIV, and pressure measurement in the divided region. The video images showed quite good agreement with the description given by Korobkin (1999). The PIV measurement of velocity field gave clear view of the flow pattern of all the three stages. The pressure was measured at the bottom of the tank with strain gauge type pressure gauges. The measurement of the pressure showed the characteristics of divided regions.

2. Experimental setup

When it comes to the impact of a body onto free surface free fall is usual practice. However, the air pressure cylinder was used at the present study to force the specimen to penetrate the free surface with excellent repeatability. The test facility and experimental set up is shown in Fig. 1. The box-type model with size of 306x306x70mm was tested as shown in Fig. 2. The high speed camera was used to capture flow pattern of the impact. The maximum speed of the camera reaches up to 64,000 frames per second. The camera speed adopted in this research was 1000 frames per second. The specification of the camera is presented in Table 1. The impact speed of the specimen with water surface was 1.05m/s.

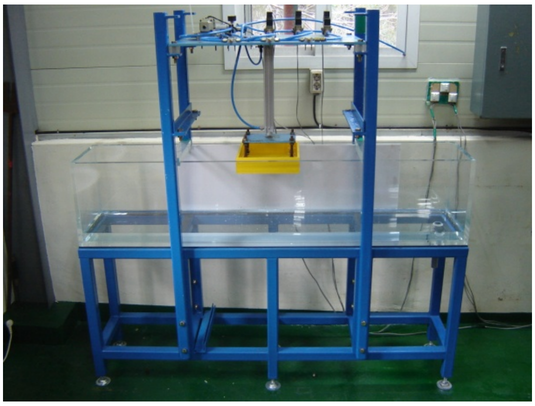

Fig.1. Experimental set up

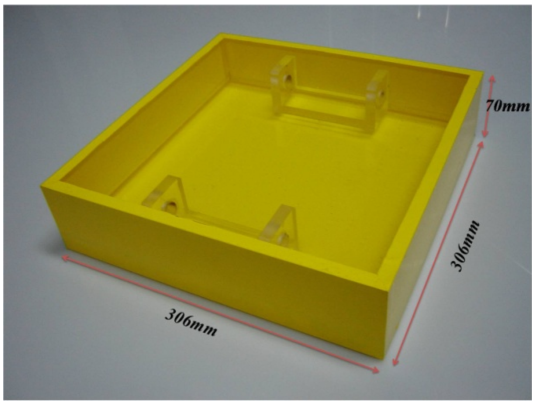

Fig. 2. Specimen shape & dimension

Table 1 High speed of camera specification

Image resolution	1280 x 1024 at 1000 fps
Internal memory	4 GB
Recording rates	Selectable, up to 64,000 fps
Control software	MotionPro X
Camera to PC interface	USB 2.0

Particle image velocimetry (PIV) system was employed to measure the two-dimensional velocity fields in the vicinity of the structure. The x-y Cartesian coordinate system will be used. The x-axis directs the propagation direction of the generated waves. Positive y-axis measures vertically upwards from the free surface as shown in Fig. 3. Field of view (FOV) was chosen to obtain velocity fields near the specimen which is depicted in Fig. 3. The size of FOV was fixed as 220×130 mm^2. FOV was intended to cover the region in which the detail flow pattern was induced due to structure impinging into the shallow water. The illumination source of the PIV system is a dual-head frequency-doubled Nd:YAG laser, which has a maximum energy output of 120 mJ per pulse at a wavelength of 532 nm, a pulse duration of 10 ns, and a repetition rate of 10 Hz for each head. The laser light sheet was positioned vertically upward from lens system below the shallow water tank and aligned with the tank centerline. The water was seeded with particles that have a mean diameter of 57 μm and a specific gravity of 1.02. A digital CCD camera was used to capture the PIV images.

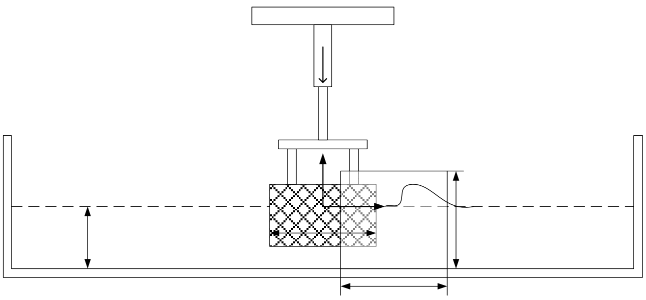

Fig.3. Coordinate system & field of view

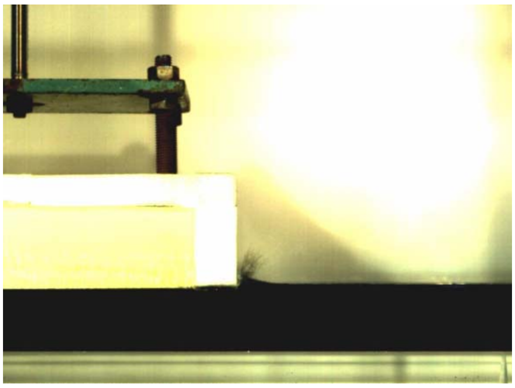

Fig.4. The flow pattern at stage 1

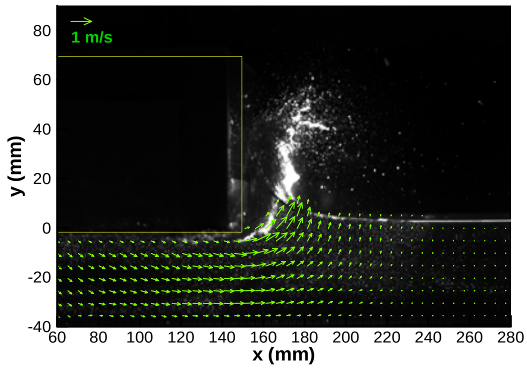

Fig.5. PIV measurement at stage 1

The camera has a resolution of 1600×1200 pixels and a maximum framing rate of 30 frames per second (fps). A 60 mm focal lens was mounted on the camera with the aperture set at f/2.8. The double-frame/single-pulse method was used in the analysis. The particle displacement within an interrogation window was calculated using a cross-correlation algorithm based on the two-dimensional fast Fourier transform. The size of the interrogation area is 32×32 pixels and the number of velocity vectors are 50×38 velocity vectors. The spatial resolution of 32 pixels is equivalent to 5.0 mm in physical dimension for FOV. A median filter using eight neighboring vectors surrounding the vector of interest was applied to identify and remove the spurious vectors. The empty "holes" due to stray vectors or low correlations in the PIV velocity map were then filled by interpolation. A 3×3 filter was later applied to remove the sudden change in the velocity field. The time separation between two laser pulses in an image pair was 1 ms. The uncertainties in PIV measurements can be expressed as the sum of the bias error and the random error. These errors are a function of dτ/dpix with dτ being the particle image diameter and dpix the pixel size (Prasad et al., 1992). In this study, the measurement error is estimated to be about 0.15 pixel for dτ/dpix being equal to 0.59. This corresponds to an uncertainty of about 0.024 m/s in the velocity measurements, and an error less than 2.0% of the local maximum velocity.

3. Results and analysis

The three stages of the impact process are analyzed. Fig. 4 shows the flow pattern at stage 1. The submergence of the specimen is very small. The formation of spray jet can be seen. The PIV measurement of the velocity field of the stage 1 is shown in Fig. 5. The velocity component of the flow beneath the specimen is almost horizontal. The large magnitudes of the velocity vectors are distributed around the curved area of the jets. The elevation of the free surface due to the impact is small in this stage. The time taken to reach this stage is 4ms. The formation of the jets is clearly seen in this figure. The flow pattern of the stage 2 is depicted in Fig. 6. The strong spray jet and splash jet appears. The flow field measurement by PIV is presented in Fig. 7. The velocity vectors of the flow beneath the specimen get large when they are compared to those of the stage 1. The velocity vectors leaving the specimen become almost horizontal and large when compared to those left behind.

Fig.8 shows the flow pattern occurred in stage 3. The jets are inclined towards the specimen. The elevation of the wave gets largest in this stage. The PIV measurement of flow field in this stage is shown in Fig. 9. The magnitudes of the velocity vectors

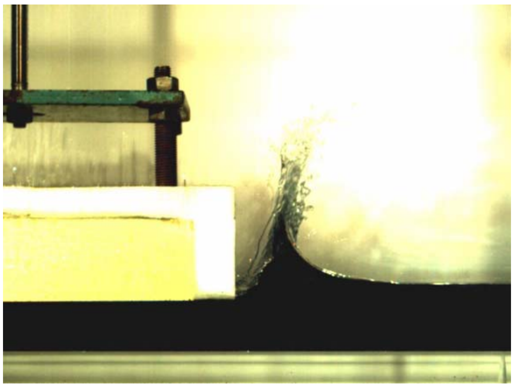

Fig.6. The flow pattern of stage 2

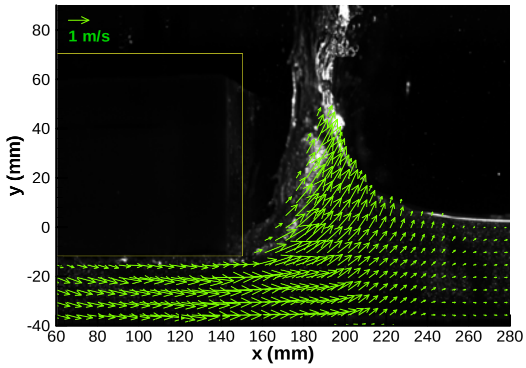

Fig.7. PIV measurement at stage 2

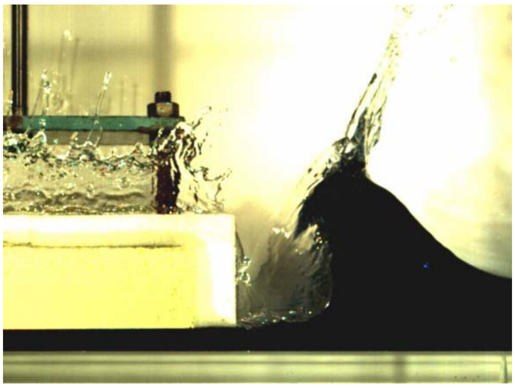

Fig.8. The flow pattern of stage 3

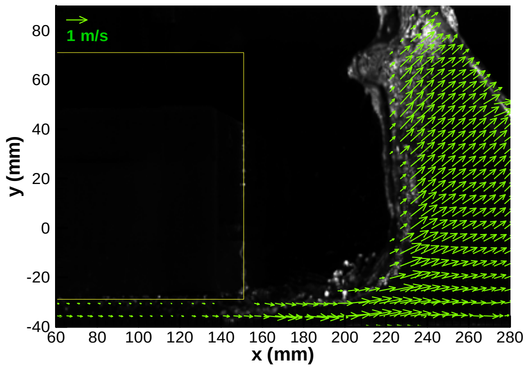

Fig.9. PIV measurement at stage 3

beneath the specimen get small when it is compared to those of other regions.
All the velocity vectors in the jet area still direct positive angles with respect to x axis.

4. Concluding remarks

The shallow water impact problem with box-like structure was investigated by experiment. The three stages of the impact process were analyzed by video images, PIV measurement of flow field. The free surface elevations at three stages of the impact process described by Korobkin were in quite good agreement with the video observations. The PIV measurement of the flow clearly showed all the kinematics of the impact process.

5. References

V.I. Burkreev and A.V. Gusev (1996), Gravity waves generated by a body falling onto shallow water, Zh. Prikl. Mech. Tekh, Fiz. Vol.37(2), pp90-98.

A.A. Korobkin (1999), Shallow water impact problems, Journal of Engineering Mathematics, vol.35, pp.233-250.

Prasad, A.K., Adrian, R.J., Landreth, C.C., and Offutt, P.W., 1992. Effect of Resolution on the Speed and Accuracy of Particle Image Velocimetry Interrogations, Experiments in Fluids 13, 105-116.