Response of model structure to the proximity of an underwater explosion

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Abstract

The importance of underwater explosion tests is increasing to assess the vulnerability of ships and underwater structures against underwater explosion phenomena. The near-field underwater explosion causes severe fluid-structure interaction on a target; shock wave contact, resulting fluid cavitation formation and closure, and finally bubble expansion and collapse leading possibly to water jet impact. A series of near-field underwater explosion tests were performed to investigate the response of a model target during underwater shock and bubble pulse loading. The relation between deformation of a model target and the effect of explosive composition was obtained.

1 Introduction

During the last decades, the underwater explosion tests have contributed extensively to understand the detonation effects of explosives in terms of their measured underwater shock wave and bubble effects. The underwater shock wave and bubble period have been widely measured to determine the underwater explosion performance of various explosives [1, 2]. Much attention has been paid to the underwater shock wave, and only limited data exists for bubble pulse. In our recent works, we measured precisely bubble pulse profile by pressure gauge using fluoropolymer as sensing element [3, 4]. The experimental results showed that the impulse of bubble pulse is about 1.5-2.5 greater than that of the underwater shock wave, although peak bubble pulse pressure is only 15-30% of peak shock wave pressure. Consequently, bubble pulse was shown to present important dynamic loading against the underwater targets.

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underwater explosion phenomena. The near-field underwater explosion causes severe complex fluid-structure interaction on a target; shock wave contact, resulting fluid cavitation formation and closure, and finally bubble expansion and collapse leading possibly to water jet impact.

Investigations of near-field underwater explosion and resulting fluid-structure interaction with targets are very important, but very scare at present time [5].

In this study, a series of near-field underwater explosion tests were performed using aluminized and non-aluminized explosives to investigate quantitatively the effects of underwater shock and bubble pulse loading on the deformation of model target and the effect of explosive composition. Profiles of the underwater shock and bubble pulse were measured by pressure gauge using fluoropolymer as sensing element, and deformation of model target was measured by strain gauge. The relation between the deformation of model target and the underwater shock and bubble pulse loading, and the effect of explosive composition were obtained. The experimental results present the importance of bubble pulse loading against model target.

2 Experimental

A series of near-field underwater explosion tests were conducted in testing pond of 36m diameter by 8m deep at NOF Taketoyo Plant Testing Site. Fig. 1 shows the experimental set-up. A rigid test fixture was constructed for mounting model target and pressure gauge. Fig. 2 presents the structure of model target. A circular steel plate (SS400) of 1.2 or 2.4mm thick and 300mm in effective diameter was clamped to rigid steel cylindrical body.

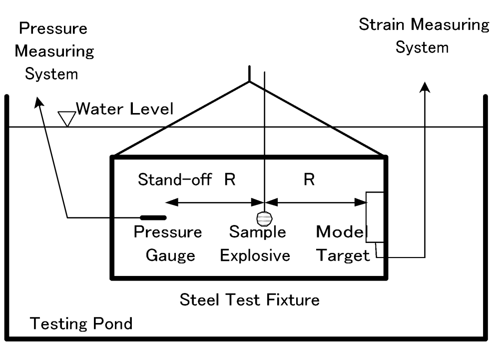

Figure 1: Experimental set-up.

Inside of model target was filled with air, and strain gauge was attached on the inner face of the circular steel plate to measure deformation against the underwater shock and bubble pulse loading. A rigid test fixture was placed in the center of testing pond to set model target, pressure gauge and sample explosive at the depth of 4m. Stand-off distance R between circular steel plate and sample explosive and that between pressure gauge and sample explosive were fixed to be 0.9m.

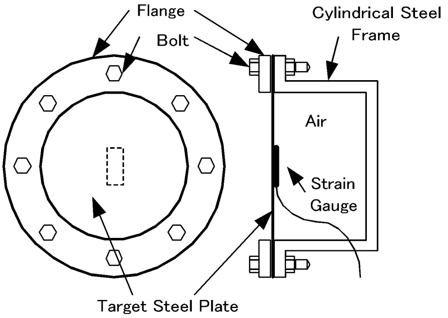

Figure 2: Structure of model target.

Table 1: Properties of sample explosive.

Sample explosive	Density (g/cm^3)	Detonation velocity (m/s)	Composition		
			Base emulsion (wt.%)	MB (wt.%)	Al powder (wt.%)
EMX	1.15	3390	98.9	1.1	0
Al-EMX	1.22	3360	82.4	0.92	16.7

Table 2: Similitude equations of sample explosives.

Sample Explosive		EMX		AL-EMX	
Y	**$Y=K(R/W^{1/3})^{\alpha}$**	K	α	K	α
Pmax	MPa	39.0	-1.10	37.5	-1.00
Is/W$^{1/3}$	Pa· s/kg$^{1/3}$	5760	-0.96	7290	-0.93
Pmaxb	MPa	4.57	-1.02	5.68	-1.02
Ib/W$^{1/3}$	Pa· s/kg$^{1/3}$	15100	-1.10	18210	-1.07

R(m), W(kg)

The emulsion explosive (EMX) and aluminized emulsion explosive (Al-EMX) containing 16.7wt.% of aluminum powder were used as sample explosive. Composition of base emulsion matrix was consisted of 74.6 wt.% of ammonium nitrate, 10.6 wt.% of water, 4.2 wt.% of wax and emulsifier. Formed polystyrene sphere was used as micro-balloon (MB). Aluminum powder was atomized type whose mean diameter was about 30 micron. Properties of sample explosives are shown in Table 1.

Charge weight of sample explosive (W) was varied to 1, 5, 10 and 100g. Sample explosive was initiated by No.6 electric detonator. The relations between peak shock wave pressure (Pmax), reduced shock wave impulse ($Is/W^{1/3}$), peak bubble pulse pressure (Pmaxb), reduced bubble pulse impulse ($Ib/W^{1/3}$) and reduced distance ($R/W^{1/3}$) are expressed by similitude equations. Table 2 summarized the similitude equations of sample explosives.

3 Results and discussion

Fig. 3 shows the example of time-base plots of measured shock wave, first bubble pulse and strain of circular steel plate. When shock wave contacted circular steel plate, circular steel plate started to deform immediately and its strain attained the level of 130$\mu\varepsilon$ after oscillation during first 30ms due to shock wave reflection. Then circular steel plate started to deform by the effects of first bubble pulse and its total strain attained the level of 330$\mu\varepsilon$. The experimental results showed that strain of circular steel plate caused by first bubble pulse was much greater than that caused by shock wave, although peak shock wave pressure was much greater than that of first bubble pulse. In this experiment, first bubble period was 120ms, and direction of water flow due to bubble expansion and collapse was reversed at about 60ms. Deformation of circular steel plate caused by water flow was not observed in this experiment. When circular steel plate was detached from rigid cylindrical body, it was deformed in concave shape, and its total deformation agreed with that calculated from measured total strain.

Table 3 summarizes measured shock wave and first bubble pulse properties of sample explosives. Peak shock wave pressure is 4.7-7.0 times greater than peak first bubble pulse pressure, but first bubble pulse impulse is 1.8-2.5 times greater than shock wave impulse. Shock wave impulse of Al-EMX is 35-40% greater than that of EMX, and first bubble pulse impulse of Al-EMX is about 25% greater than of EMX.

Fig. 4 presents the relation between deformation of 1.2 and 2.4mm thick circular steel plate due to shock wave loading and peak shock wave pressure. It is observed that deformation of circular steel plate increases with the increase of peak shock wave pressure. Fig. 5 shows the relation between deformation of 1.2 and 2.4mm thick circular steel plate due to first bubble pulse loading and peak first bubble pulse pressure. It is shown that deformation of circular steel plate increases with the increase of peak first bubble pulse pressure. From Fig. 4 and 5, it is recognized that deformation effects of first bubble pulse is much greater than that of shock wave, although peak shock wave pressure is 4.7-7.0 times greater than peak first bubble pulse pressure.

Fig. 6 presents the relation between deformation of 1.2 and 2.4mm thick circular steel plate due to shock wave loading and shock wave impulse. Fig. 7 presents the relation between deformation of 1.2 and 2.4mm thick circular steel plate due to first bubble pulse loading and first bubble pulse impulse. From Fig.

6 and 7, it is recognized that deformation of circular steel plate is lineally increases with the increase of shock wave impulse and first bubble pulse impulse, and that Al-EMX has higher deformation effect than EMX because of its higher shock wave impulse and first bubble pulse impulse. It is shown quantitatively that deformation effects of first bubble pulse are much more important than that of shock wave in near-field underwater explosion.

Table 3: Summary of measured shock wave and first bubble pulse properties.

Explosive	Explosive weight (g)	Shock wave		First bubble pulse	
		Pmax (MPa)	Is (Pa・s)	Pmaxb (MPa)	Ib (Pa・s)
EMX	1.0	3.67	67	0.79	135
	5.0	6.62	192	1.28	417
	10.0	8.52	301	1.58	677
	100.0	19.80	1351	3.17	3383
Al-EMX	1.0	4.15	94	0.62	170
	5.0	7.11	266	1.02	520
	10.0	8.99	417	1.32	853
	100.0	19.30	1828	2.89	4162

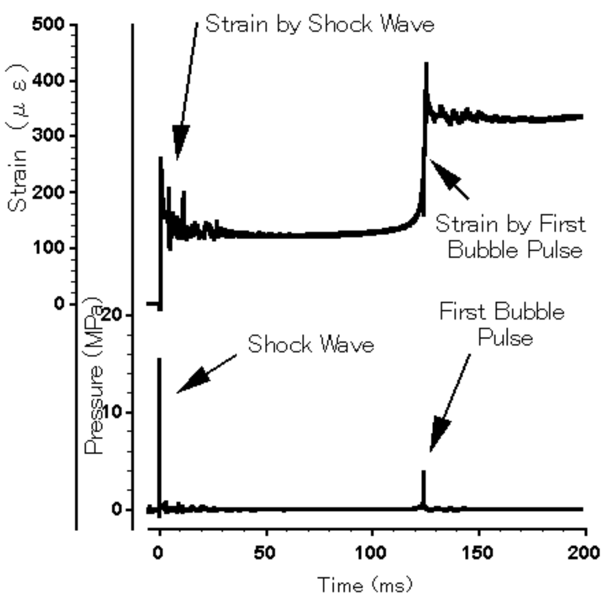

Figure 3: Example of time-base plot of measured shock wave, first bubble pulse and strain.

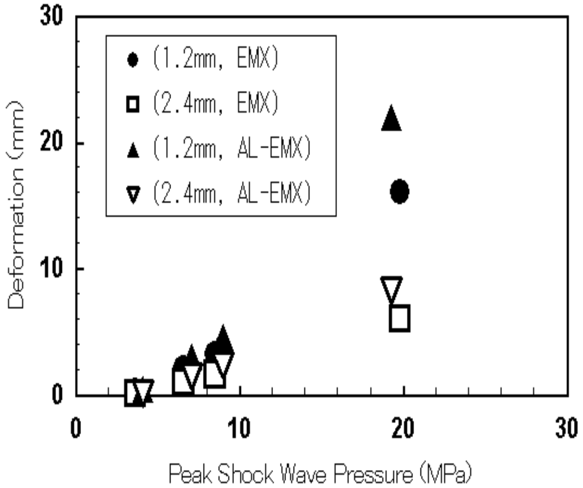

Figure 4: Relation between deformation of target plate and peak shock wave pressure.

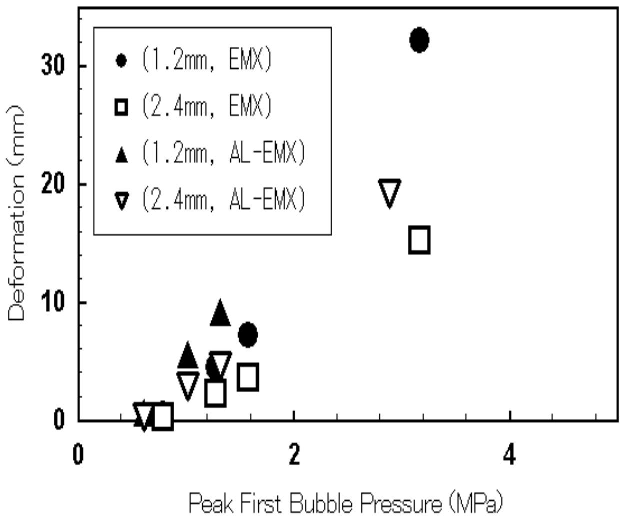

Figure 5: Relation between deformation of target plate and peak first bubble pulse pressure.

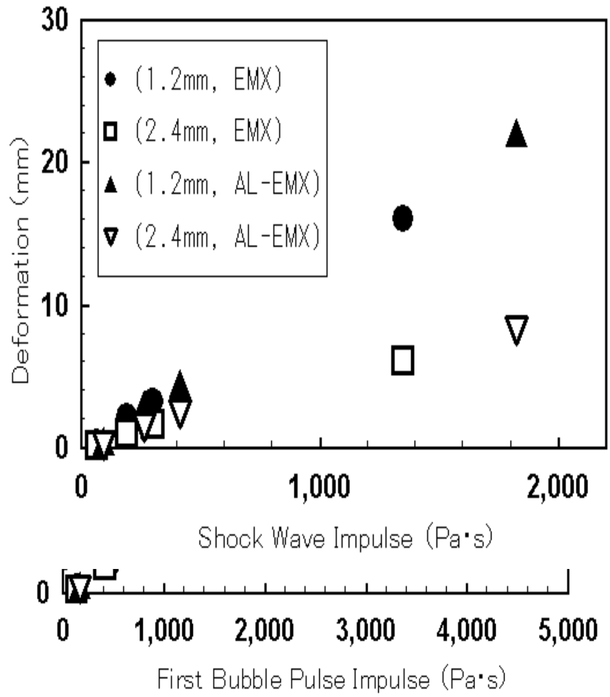

Figure 6: Relation between deformation of target plate and first bubble impulse.

4 Summary

A series of underwater explosion tests were performed using aluminized and non-aluminized explosives to investigate the response of model structure to shock wave and bubble pulse loading and the effect of explosive composition. The experimental results presented quantitatively the relation between deformation of model structure and shock wave and first bubble pulse loading. The experimental results revealed that the effects of first bubble pulse loading is much more important than that of shock wave loading, although peak shock wave pressure is much higher than peak first bubble pulse pressure. It was shown that deformation of model structure increases lineally with the increase of shock wave impulse and first bubble pulse impulse. It was also demonstrated that aluminized explosive has higher deformation effects than non-aluminized explosive because of its higher shock wave impulse and first bubble pulse impulse. The experimental results gained from this investigation are vital in the development and validation of suitable numerical modeling to simulate complex fluid-structure interaction caused in near-field underwater explosion.

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