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Effect of Fluid Mesh Modeling on Surface Ship Shock Response under Underwater Explosion

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ABSTRACT

In this study, for the investigation of effects of several parameters, such as fluid mesh boundary size, cylinder or block shape, dimensions of depth, breadth and length at free surface, and fluid mesh element size to the depth direction on a reliable shock response of finite element model under underwater explosion with consideration of the bulk cavitation, analysis of a simplified surface ship was carried out using the LS-DYNA3D/USA code. The shock responses were not much affected by the fluid mesh parameters. The computational time was greatly dependent on the number of DAA boundary segments. It is desirable to reduce the DAA boundary segments in the fluid mesh model, and it is not necessary to cover the fluid mesh boundary to or beyond the bulk cavitation zone just for the concerns about an initial shock wave response. It is also the better way to prefer cylinder type of the fluid mesh model to the block one.

1. INTRODUCTION

Surface ship structure and shipboard equipments must be designed to withstand severe shock excitations induced by underwater explosion. The ship shock test/trials identify the design and construction deficiencies giving a serious negative effect on the survivability of ship, equipment and crew, and also validate shock hardening criteria and performance. Unfortunately, the ship shock trials are very time consuming and expensive. With the advent and ongoing advances in simulation capabilities and sophisticated simulation tools, numerical modeling and simulation has become a viable, less costly alternative as well as more reliable aids to live fire testing(1).

Surface ship shock simulation under underwater explosion is generally complicated by free surface effects, such as bulk cavitation resulting from surface reflection wave, in addition to local cavitation, gas bubble oscillation and migration toward free surface, and cavitation closure pulses(2). Furthermore, complex fluid-structure interaction phenomena occur, as well as the complicated dynamic behavior of the ship and shipboard equipments. For a reliable and accurate shock response of surface ship, therefore, the surrounding fluid mesh model must be constructed to mate exactly with the finite element mesh of ship structure, and must be of sufficient size to capture a bulk cavitation zone. Since the bulk cavitation zone can become quite large, greater computational memory and time are required, depending on the size and depth of the charge.

Three-dimensional surface ship shock analyses were performed using a large scale finite element model of a coupled ship and surrounding fluid using LS-DYNA code(3) coupled with USA code(4), and the predicted results were compared with ship shock test results(5). The effects of reducing the box type fluid mesh size were investigated on the accuracy of the structural response of Navy's Floating Shock Platform (FSP) under underwater explosion, also using the LS-DYNA3D/USA coupled code(6). LS-DYNA is a nonlinear

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dynamic analysis of structure in three dimensions based on the explicit integration, whereas the USA code, a boundary element code for the underwater shock fluid-structure interaction problem based on doubly asymptotic approximation (DAA) consisting of three main modules: FLUMAS, AUGMAT and TIMINT.

In this study, for the investigation of effects of several parameters, such as fluid mesh boundary size, cylinder or block shape, dimensions of depth, breadth and length at free surface, and fluid mesh element size to the depth direction on a reliable shock response of finite element model under underwater explosion, analysis of a simplified surface ship was carried out using the LS-DYNA3D/USA code.

2. FLUID MESH MODELING AND SIMULATION SCENARIOS

Two different charge location geometries were used in the shock simulation runs for this study, as shown in Fig. 1, where both geometries consisted of the same TNT 100 lb charge and of the same Keel Shock Factor. One attack geometry placed the charge directly under ship model in midsection plane at depth of 30.0 ft with standoff distance of 29.0 ft, whereas the second one, from longitudinal center plane by 18.1 ft and at depth of 19.1 ft with standoff distance 25.6 ft. Figure 2 shows the dimensions of ship model, and Table 1, a list of material properties of mild steel shell plate and sea water. UNDEX parameters of the explosion are summarized in Table 2.

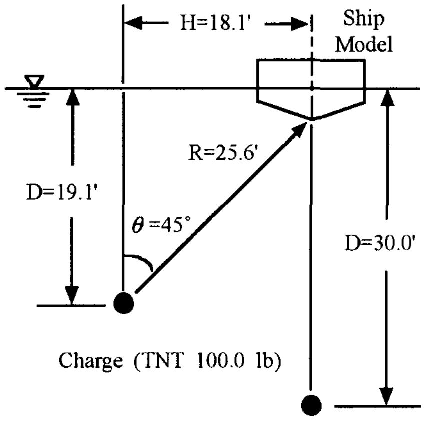


Fig. 1 Geometry of surface ship model

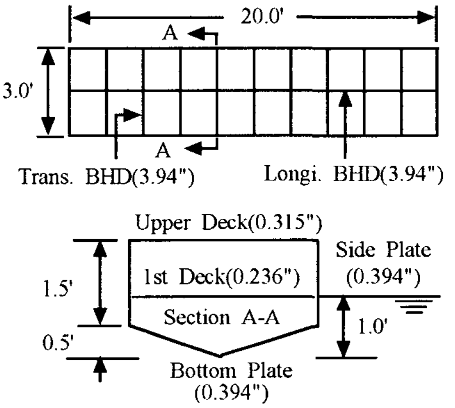


Fig. 2 Dimensions of surface ship model

Table 1 Material properties

Shell Plate	Density	7.350E-04 lbs-sec^2/in^4
	Modulus of Elasticity	3.00E+07 psi
	Poisson's Ratio	0.3
	Yield & Ultimate Stress	34.545 & 65.415 ksi
Sea Water	Density	9.345E-05 lbs-sec^2/in^4
	Sound Speed	5.916E+04 in/sec

Table 2 UNDEX parameters for charge

Parameters	Charge Undership Model	Offset Charge
Standoff Distance (in)	348.0000	294.4800
P_{max} (psi)	2,589.6300	3,153.6600
Θ (msec)	0.3778	0.3663
T (sec)	0.6270	0.7470
A_{max} (in)	177.3600	190.2000

The computed bulk cavitation zones for both geometries are shown in Fig. 3 in their entirety, and five fluid mesh boundary sizes of cylinder type with respect to ship model, also in Figs. 4(a) and 4(b) on a large scale. Their radii in midsection plane were set to 5.0, 7.5, 10.0, 12.5, and 15.0 ft for charge under ship model and offset charge, respectively. Figure 5 shows the configuration of finite element meshes of ship and fluid mesh models typically with radius 7.5 and 15.0 ft, respectively. The fluid mesh element size to the radial direction increases proportionally for both attack geometries. The following fluid mesh parameters were also examined: fluid mesh shape such as cylinder type (Case 1_2) in Fig 4(a) and block one (Case 2_1) in Fig. 6(b), and fluid mesh dimensions at free surface such as depth (Case 2_2), breadth (Case 2_3), and length (Case 2_4) compared with standard one (Case 2_1), respectively.

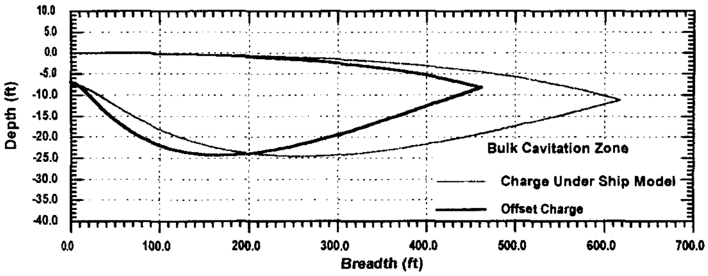
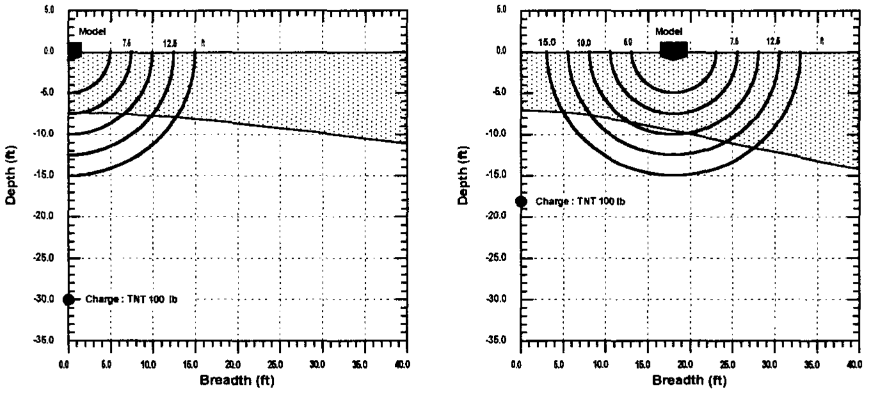
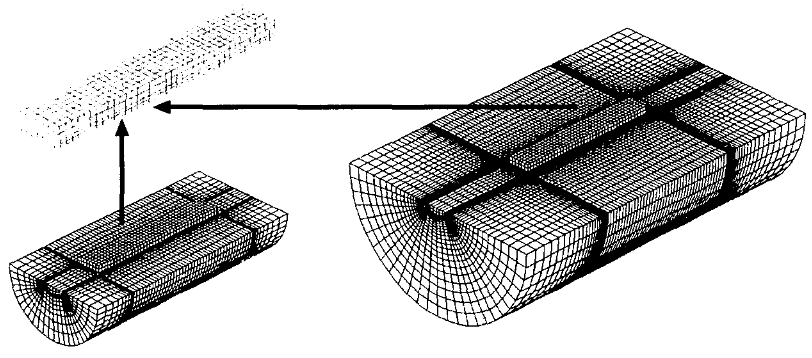


Fig. 3 Entire bulk cavitation zones



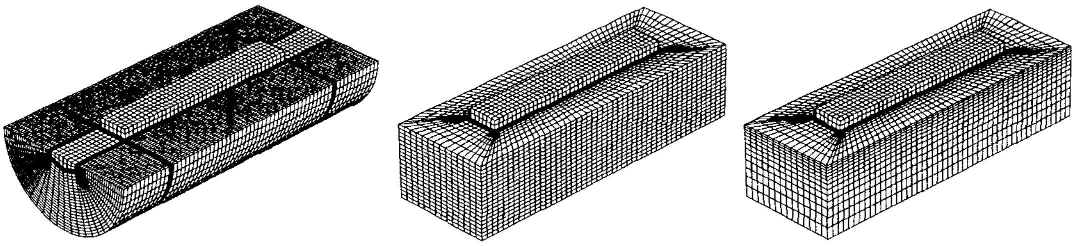
(a) Charge under ship model (b) Offset charge

Fig. 4 Ship models and fluid mesh boundary locations in bulk cavitation zones



(a) Case 1_2 (radius 7.5 ft) (b) Case 1_5 (radius 15.0 ft)

Fig. 5 Configuration of finite element meshes with radius 7.5 and 1.0 ft



(a) Case 1_6 (b) Case 2_1 (c) Case 3_1

Fig. 6 Configuration of finite element meshes with radius 7.5 ft

In addition, the effect of fluid mesh element size to the radial direction in midsection plane on the shock response was considered comparing equal ratio fluid element (Case 1_2) with equal size fluid element (Case 1_6) for cylinder shape, as shown in Figs. 5(a) and 6(a), and (Case 2_1)~(Case 2_4) with (Case 3_1)~(Case 3_4) for block shape, as shown in Figs. 6(b) and 6(c). The ship model contains 1,464 4-noded shell elements, and the wetted surface, 464 ones. Table 3 shows a list of fluid mesh model, such as total number of nodes, acoustic elements, and ADD boundary segments, where L is referred to fluid mesh length fore or aft ship at free surface, B, its breadth to port or starboard, and D, its depth.

Table 3 List of fluid mesh model, total CPU, kick off velocity and peak pressure

Type of Fluid Model	Case	Description		No. of nodes	No. of elements	No. of DAA Segment	Charge Location	CPU Time (h. m. s)	Kick off velocity (in/sec)	Peak pressure (psi)
		dimension (ft)	mesh size depth direction							
Cylinder	1_1	radius 5.0	equal ratio	16,621	13,920	2,040	under	1. 16. 04	514.14	2,558.8
							offset	1. 18. 06	528.48	2,798.1
	1_2	radius 7.5	equal ratio	18,856	16,012	2,144	under	1. 23. 05	515.06	2,596.8
							offset	1. 22. 45	515.06	2,855.6
	1_3	radius 10.0	equal ratio	31,651	28,032	2,664	under	2. 07. 08	596.57	2,665.9
							offset	2. 06. 48	540.38	3,121.3
	1_4	radius 12.5	equal ratio	34,534	30,748	2,768	under	2. 17. 26	539.21	2,715.6
							offset	2. 17. 30	549.31	3,092.2
	1_5	radius 15.0	equal ratio	50,569	45,888	3,288	under	3. 18. 21	552.18	2,791.6
							offset	3. 15. 55	561.93	3,259.4
	1_6	radius 7.5	equal size	48,046	43,620	3,080	under	1. 48. 20	519.17	2,610.0
Block (L×B×D)	2_1	5.0× 5.0× 7.5	equal size	29,914	26,424	3,772	under	3. 54. 27	533.24	2,572.6
	2_2	5.0× 5.0×12.5	equal size	40,267	36,336	4,640	under	6. 33. 55	572.01	2,668.0
	2_3	5.0×10.0× 7.5	equal size	44,794	40,560	4,516	under	6. 16. 56	495.38	2,571.8
	2_4	10.0× 5.0× 7.5	equal size	51,034	46,336	5,124	under	10. 38. 15	541.90	2,574.6
	3_1	5.0× 5.0× 7.5	equal ratio	21,040	17,928	3,028	under	2. 28. 52	492.48	2,537.1
	3_2	5.0× 5.0×12.5	equal ratio	29,914	26,424	3,772	under	3. 48. 48	493.23	2,630.6
	3_3	5.0×10.0× 7.5	equal ratio	31,456	27,600	3,772	under	3. 55. 54	476.22	2,520.9
	3_4	10.0× 5.0× 7.5	equal ratio	29,914	27,600	3,772	under	5. 55. 21	495.69	2,543.3

LS-DYNA's Material Type 90 (acoustic pressure 8-noded solid element) was used to model the pressure wave translation properties of water. The length of each fluid mesh model fore and aft ship is the same as its breadth at free surface. An important aspect of fluid mesh model is a finite element size next to the structural mesh. For cavitation analysis using the USA code, critical element size is determined by $2T\rho/\rho_s t_s \le 5$, where ρ= density of water, T = thickness of the fluid element in the direction normal to the wetted surface of the structure, ρ_s = density of the submerged structure, and t_s = thickness of the submerged structure. The elements adjacent to the structural model were set a value less than this value of thickness.

3. SHOCK SIMULATION RESULTS

The shock simulation results for the scenarios in the previously mentioned chapter were compared to the average kick off velocity of ship under free surface and the peak pressure under the keel for both attack geometries from the empirical formulation, as shown in Table 4. Table 3 also shows a list of total CPU time, and the kick off velocity of ship under free surface and the peak pressure under the keel for each case. The vertical velocity responses and fluid mesh pressure profile were almost the same as the empirical calculations, and the results of five fluid mesh boundary models for each attack geometry, as shown in Table 3 and Figs. 7~10, except that cavitation closure pulses occurred a little bit late according to an increase of fluid mesh boundary, and some fluctuation phenomena on the response were found in Case1_1 of small fluid mesh boundary, 5.0 ft. There was also not much difference in the effects of several fluid mesh parameters on the shock response, as shown in Figs. 11~13, such as fluid mesh element size to the depth direction of each shape, fluid mesh model shape, dimensions of fluid mesh boundary at free surface.

Total CPU computational time was affected greatly by the number of DAA boundary segments, as shown in Table 3. In addition to the restriction of number of DAA boundary segments of the USA code, it could be found again to reduce its segment number as small as possible. It might be desirable to model the fluid mesh boundary in a way to increase element size proportionally to the radial direction. The lower cavitation boundary must not be included to the fluid mesh boundary for the consideration of the bulk cavitation effects and the initial shock wave response. However, too small fluid mesh boundary is not desirable through this study. It is also the better way to prefer cylinder type of the fluid mesh model to the block one.

Table 4 Kick off velocity and pressure from empirical formulation

Items	Charge under ship model	Offset charge
Kick off velocity (in/sec)	523.40	512.64
Peak pressure under the keel (psi)	2,488.08	3,000.16

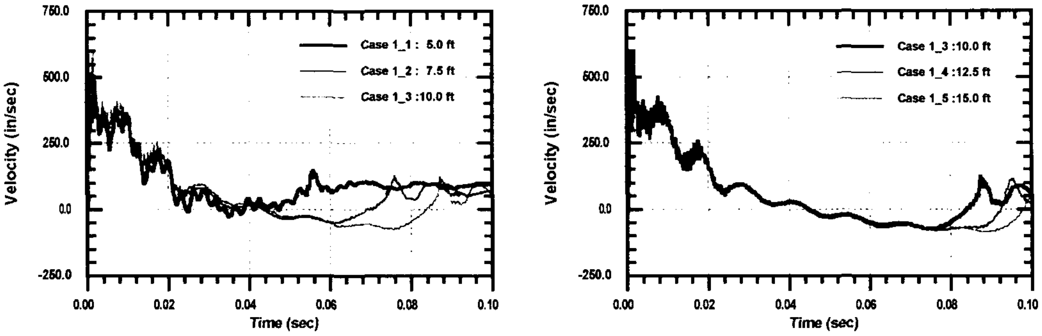


Fig. 7 Vertical velocity response w/ charge under ship model

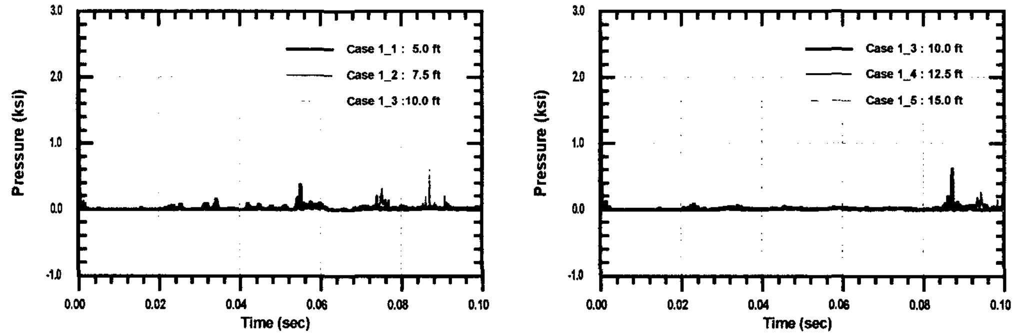


Fig. 8 Fluid mesh pressure profile w/ charge under ship model

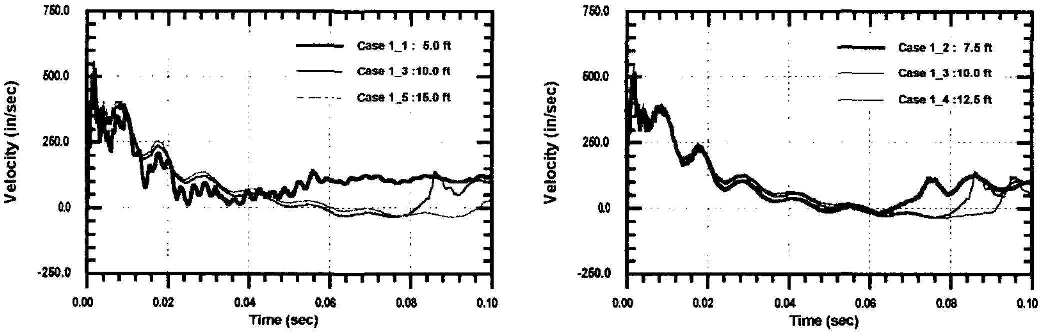


Fig. 9 Vertical velocity response w/ offset charge

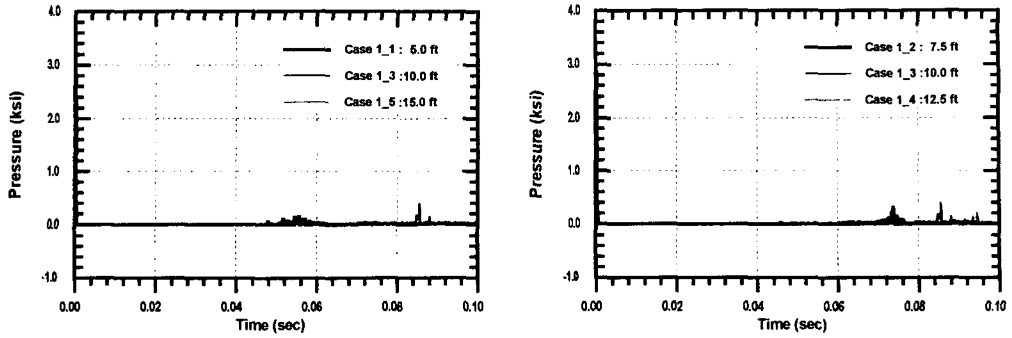
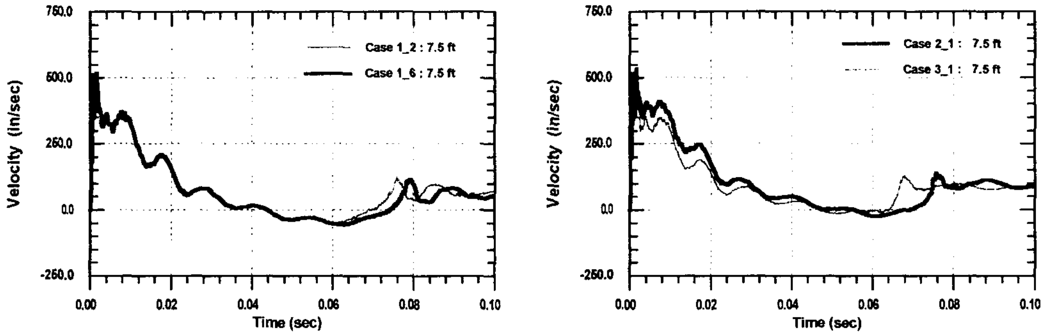
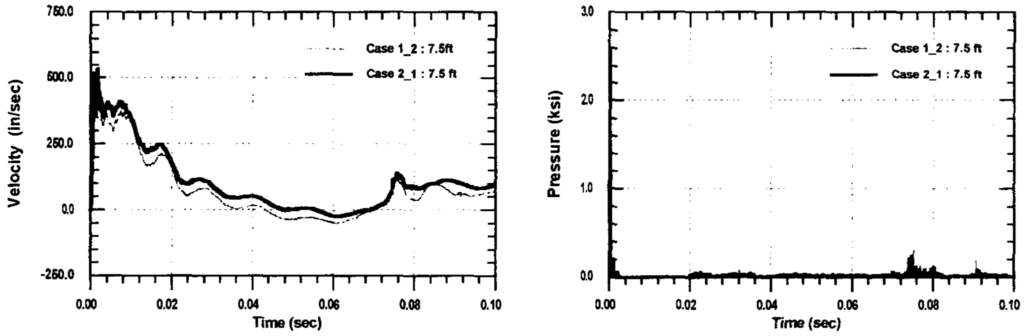


Fig. 10 Fluid mesh pressure profile w/ offset charge



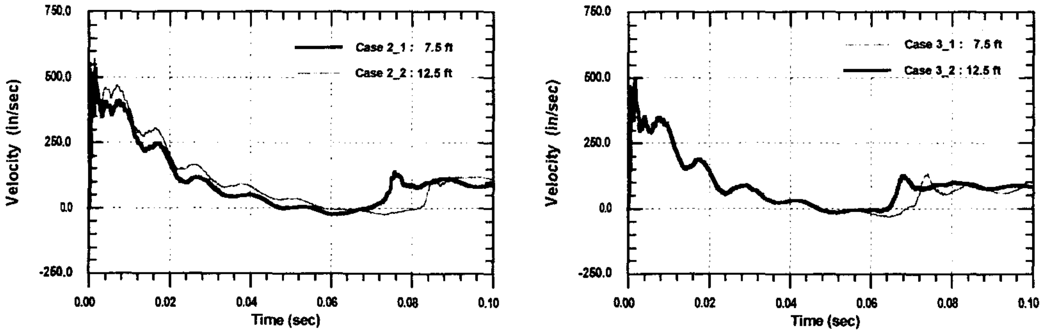
(a) Cylinder type (b) Block type

Fig. 11 Effect of fluid mesh element size to depth direction of each shape on shock response (vertical velocity response) w/ charge under ship

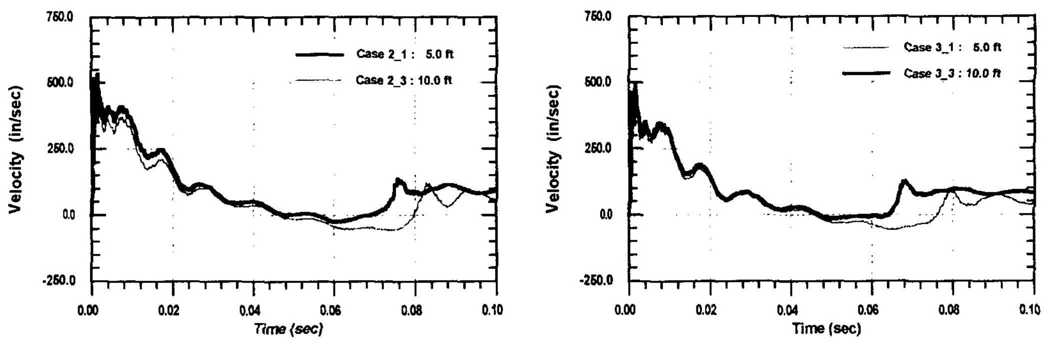


(a) Vertical velocity responses (b) Fluid mesh pressure profiles

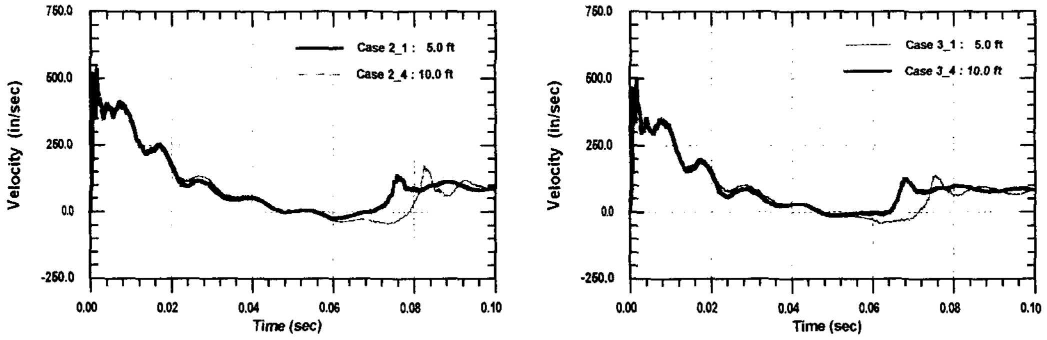
Fig. 12 Effect of fluid mesh model shape type on shock response w/ charge under ship



(a) Fluid mesh depth



(b) Fluid mesh breadth at free surface



(c) Fluid mesh length at free surface

Fig. 13 Effect of fluid mesh dimensions at free surface on vertical velocity response w/ charge under ship model

4. CONCLUSIONS

In this study, the shock simulations have been carried out to investigate the effects of the several fluid mesh parameters on the shock response with respective to the simplified surface ship using LS-DYNA/USA code. The shock responses were not much affected by the fluid mesh parameters. The computational time was greatly dependent on the number of DAA boundary segments. It is desirable to reduce the DAA boundary segments in the fluid mesh model, and it is not necessary to cover the fluid mesh boundary to or beyond the bulk cavitation zone just for the concerns about an initial shock wave response. It is also the better way to prefer cylinder type of the fluid mesh model to the block one. As the next study, more reliable response of cavitation closure time and bubble characteristics will be examined using the test results.

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