Modeling of the Shock Wave Impact on the Flexible Shell

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Introduction

The underwater explosion and its effects on the floating structure represent a matter of considerable interest for researchers. The sequence of events associated to an underwater explosion of a typical military explosive in their order of occurrence can be summarized as [1]:

- detonation,
- shock wave propagation,
- motion of the gas bubble.

Chemical reaction of the mass occurring during the explosion results in a perturbation of the surrounding water (shock wave) and the creation of a gas bubble. Designers should realistically estimate the possible damage condition to effectively design a floating structure resistant to any various underwater weapons.

The main aim of the performed work was to simulate the behavior of flexible shell under wave impact. The non-linear simulation was also performed for the example structure affected by the underwater explosion. The results were compared with behavior of floating shell in ordinary exploitation.

The numerical part of current work was based on non-linear, explicit, dynamic, finite element analysis (FEA) using the LS-DYNA computer code. This so-called hydrocode is used for the purpose of a wide variety of analyses, including airbag and water dynamics or to estimate exploitation loading.

The preliminary analysis of a new ballistic protection system is demonstrated in the paper,.

Problem statement

A new structure of a floating bridge was developed. The floating bridges consist of a continuous metal roadway leaned on the floats or pontoons. Pneumatic floats are airtight compartments made of a rubberized fabric inflated with the air.

The FE model of the floating bridge (see Figure 1) used for the preliminary analysis included a frame/cassette in which the folded, empty flexible composite shell was mounted. Pair of doors was attached to the frame with revolute joints. These elements reflected hinges placed in the actual object. The shell included three different components – upper and lower envelopes as well as additional webs located inside the shell. They reinforced the structure of the fully opened shell and made its shape more compact. The selected configurations during filling the floating bridge are presented in Figure 2.

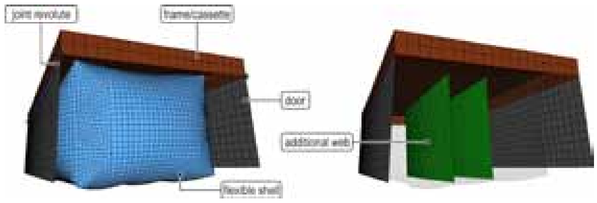

Figure 1. The single segment of the floating bridge – the flexible shell filled with air

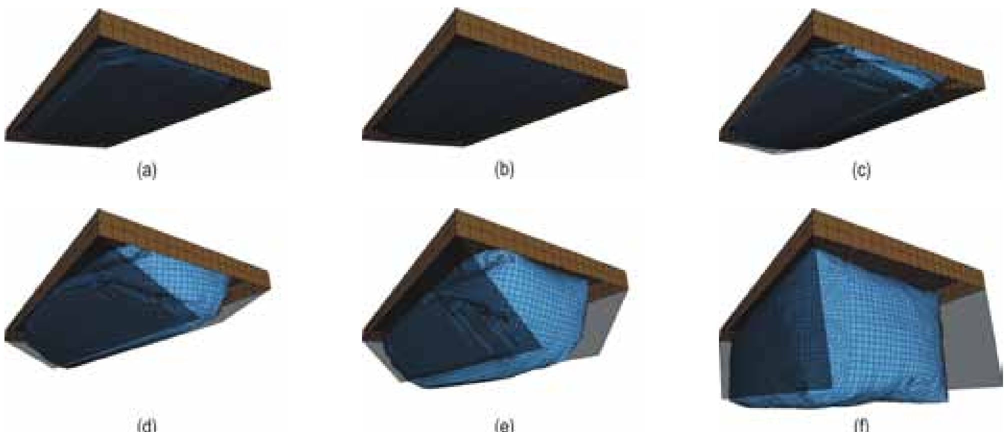

Figure 2. Successive stages of filling the pontoon of the floating bridge

FE modeling and analysis

The FE models of the float bridge were developed base on Altair HyperMesh software, whereas the LS -Prepost program was a preprocessor for defining all necessary parameters such as boundary conditions, element properties, material properties, solution type, and many others. Complete FE models were exported as a key files with the LS-DYNA preferences. In order to prescribe behavior of the selected materials (e.g. water, HE charge) as well as the complete structures (e.g. airbags) equations of state were used. Each equation defines the state by different variables. The coefficient for each equation come from data-fitting, phenomenological descriptions, or derivations based on classical thermodynamics [3, 4].

Presented FE model consist of about 12,000 shell elements used for the frame/cassette, door and the float modeling. About 180,000 solid elements were applied for the water FE model. The float shell was modeled with use of the Belytschko-Tsay membrane element with 2 integration points through the element thickness. These elements are based on a combined co-rotational and velocity-strain formulation. The fabric elastic - perfectly plastic material model was applied for the purpose of shell modeling. Properties of the fiber are presented in Table 1. Since, the reference configuration of the flexible shell is taken as the folded configuration the geometrical accuracy of the deployed shell will be affected by both the stretching and the compression of elements during the folding process. The elastic float was attached to the rigid frame with an extra nodes set. Nodes for the surface type of contact was applied to describe an interaction between the flexible shell and other components of the floating bridge and the water as well.

Two different types of airbag model were selected depending on the considered case. The airbag models allow to describe the behavior of the gas flow into the volume as well as the closed volume already inflated with gas [3, 4].

Simple airbag model was used in analysis of the inflating shell. In this case a curve describing the input mass flow rate had to be determined and declared in the model. Proposed curve is depicted in Figure 3.

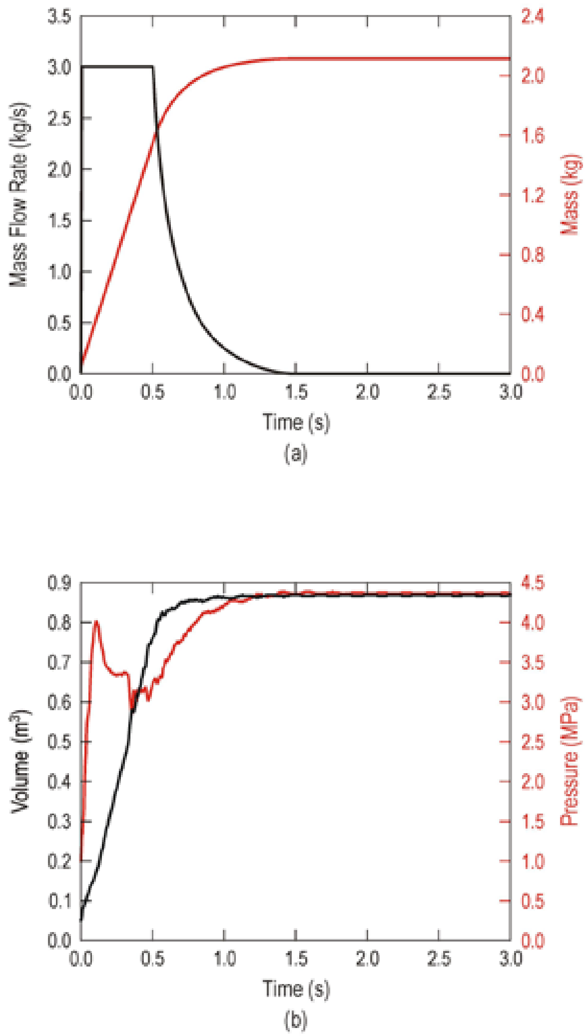

Figure 3. The input mass flow rate curve for the simple airbag model (a) and selected results (b)

Table 1. Properties of the fiber applied in the LS-Dyna fabric material model [5]

Young's moduluses (GPa)			Poisson's ratios			Shear moduluses (GPa)		
E_1 (GPa)	E_2 (GPa)	E_3 (GPa)	ν_{12} (–)	ν_{23} (–)	ν_{13} (–)	G_{12} (GPa)	G_{23} (GPa)	G_{31} (GPa)
24.1	24.1	10.4	0.12	0.12	0.12	5.9	5.9	5.9

For the second case—a fully inflated float—simple pressure volume airbag model was applied. A constant value of the pressure inside the float was declared on the basis of the final results taken from the first case.

All water was simulated by the solid element with one point integration. The Gruneisen equation of state with cubic shock velocity vs. particle velocity relation was used to describe the internal characteristic of water. This below equation defines pressure for compressed materials [3]

$$p = \frac{\rho_0 C^2 \mu \left[1 + \left(1 - \frac{\gamma_0}{2}\right)\mu - \frac{a}{2}\mu^2\right]}{\left[1 - (S_1 - 1)\mu - S_2 \frac{\mu^2}{\mu+1} - S_3 \frac{\mu^3}{(\mu+1)^2}\right]^2} + (\gamma_0 + a\mu)E \qquad (1)$$

and for expanded materials

$$p = \rho_0 C^2 \mu + (\gamma_0 + a\mu)E \qquad (2)$$

where C is the intercept of the u_s–u_p curve; S_1, S_2, S_3 are the coefficients of the slope of the u_s–u_p curve; γ_0 is the Gruneisen gamma; α in the first order volume correction to γ_0; and $\mu = (\rho / \rho_0) - 1$.

Necessary parameters declared in the Gruneisen equation of state are provided in Table 2.

$$p = A\left(1 - \frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E}{V} \qquad (3)$$

The detonation of the high explosive under water was modeled. The Jones Wilkins Lee equation of state is defined as an exponential function form given by:

where *V* is the initial relative volume; *E* is the internal energy per unit volume; *A, B, R1, R2,* and ω are material constants obtained from the experiments.

Material constants in the JWL equation for the TNT (Trinitrotoluene) applied in current model are provided in Table 3.

The variation of pressure for the blast wave propagating in the water FE model are presented in Figure 4. The graphs based on values of the pressure in selected elements along the vertical line initiated in the center of the HE charge, are depicted in Figure 5. The outline of the contours presented in the figure is not exactly circular due to FE water model mesh shape. However, obtained results are thoroughly satisfying.

Table 2. Parameters applied in the Gruneisen equation of state for the water FE model [2]

Mass density	Intercept of the u_s–u_p curve	Gruneisen coefficients			Gruneisen gamma
ρ (kg/mm³)	C (mm/ms)	S_1 (–)	S_2 (–)	S_3 (–)	γ_0 (–)
	2417	1.41	—	—	1

Table 3. Material properties of the TNT used for the HE material model [2]

Mass density	Detonation velocity	Chapman-Jouget pressure	Internal energy per unit volume	Initial relative volume
ρ (kg/mm³)	*D* (mm/ms)	p_{CJ} (GPa)	*E* (J/mm³)	*V*
$1.63 \cdot 10^{-6}$	7840	26	4.3	1
		Constants		
A (GPa)	*B* (GPa)	R_1 (–)	R_2 (–)	ω (–)
371	3.73	4.15	0.95	0.3

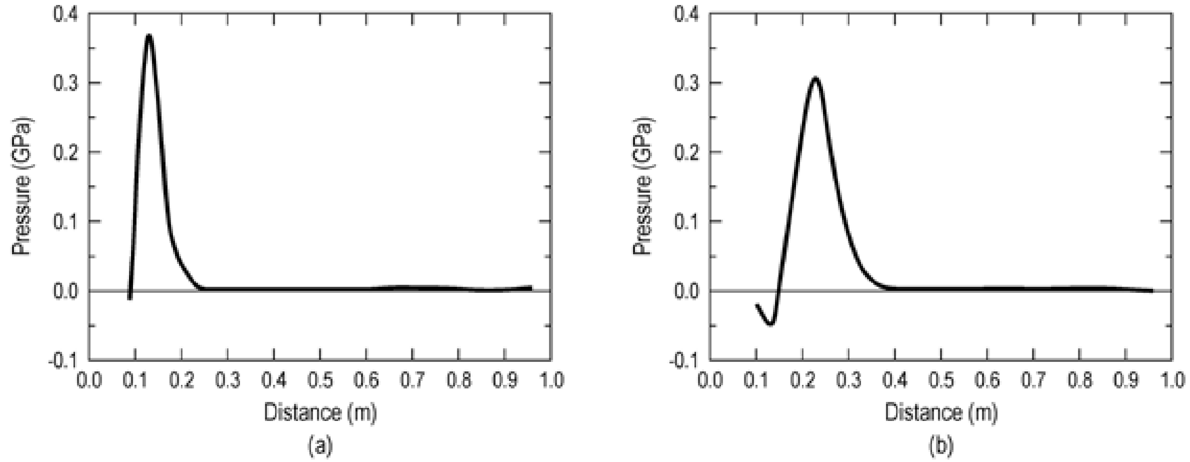

Figure 4. Variation of the pressure of the blast wave front in the water FE model: time = 0.05 ms (a), and time = 0.10 ms

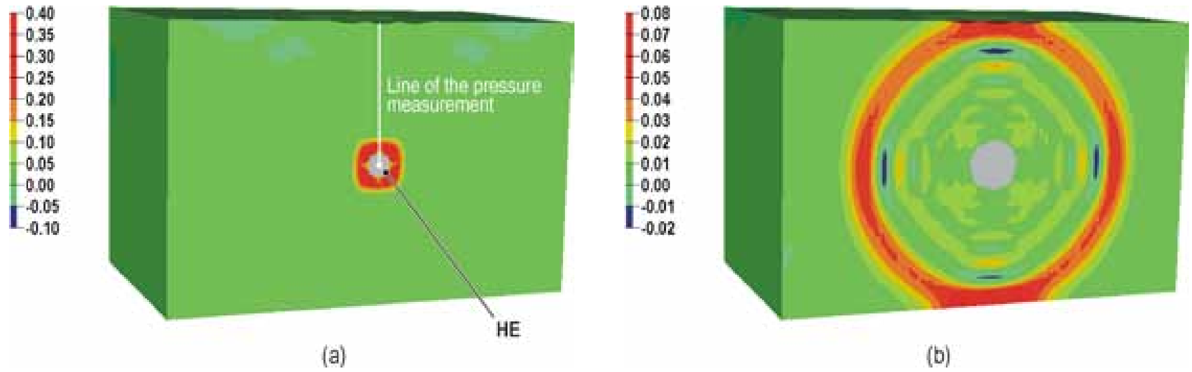

Figure 5. Contours of the pressure (GPa) for the cross-section of the water FE model: time = 0.05 ms (a), time = 0.40 ms (b)

Results and Conclusions

The purpose of this paper was to present the single segment of the floating bridge supported on the flexible shell preliminary analysis. Description of interacting flexible shell, rigid bodies and water is a complex problem which also desires the consideration of the contact problem.

During the explosion a blast wave influenced on the flexible shell. Values of the strains for selected elements of the flexible shell FE model (Figure 6) located above the HE charge were registered and compared with values obtained for the model without explosion. Four elements were selected as representatives for the analysis, and the average value of strains were taken into consideration. The HE charge was located in a different distance from the flexible shell - between 0.1 m through 1.0 m. Changes in values of the strains for selected distances are depicted in Figure 7a. About 40% increase was observed for the HE charge located in distance of 0.1 meter from the float surface. Explosion does not affect the pressure inside the float to a high degree (Figure 7b). The changes do not exceed 0.5%.

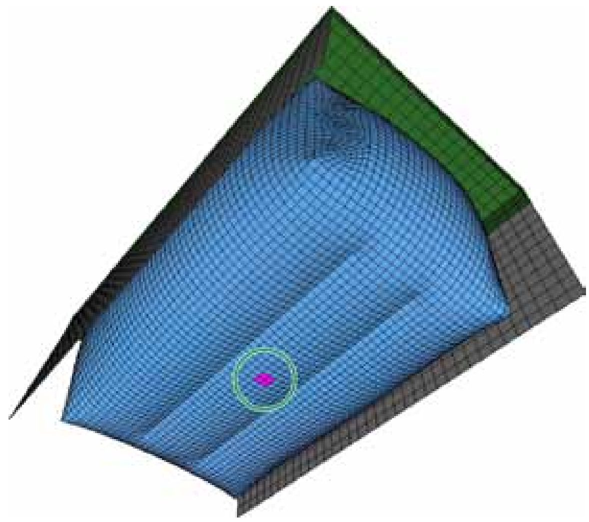

Figure 6. Location of the elements taken into consideration in the strain analysis state for the water FE model [2]

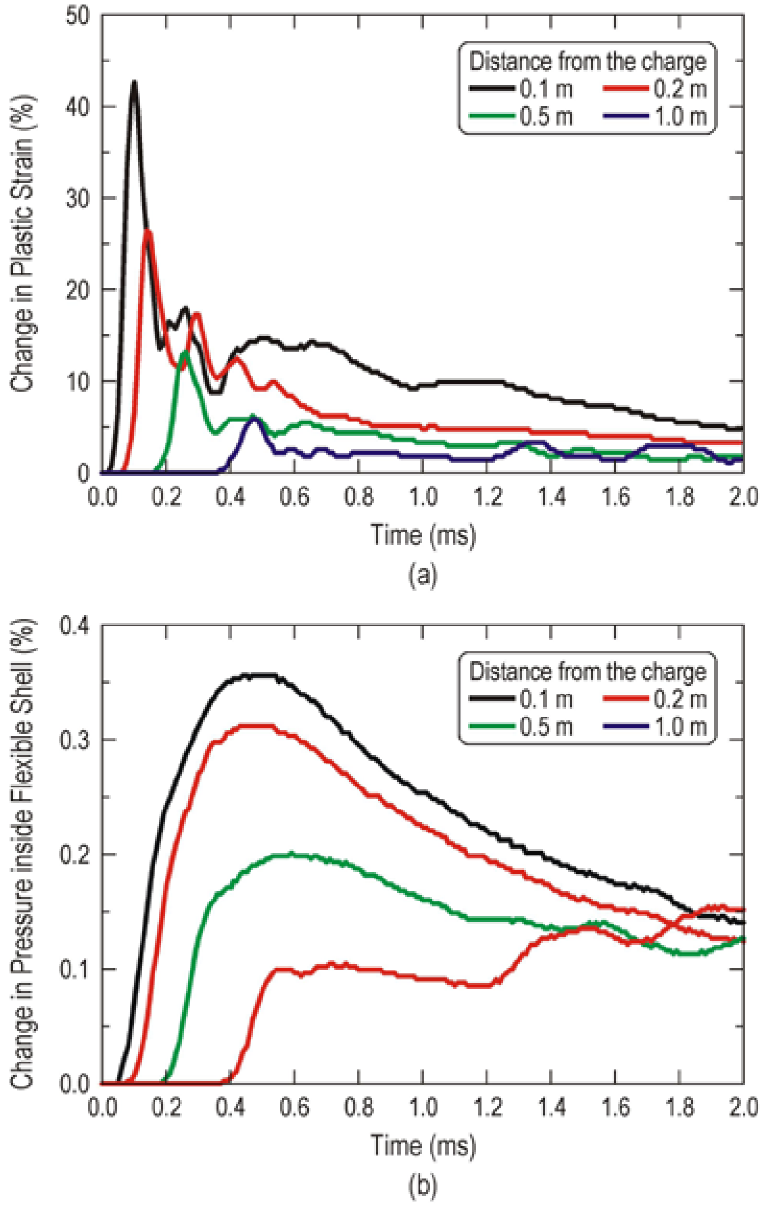

Figure 7. Change in values of the plastic strain (a) and the pressure inside the float (b) subjected to the blast wave

The global model is utilized to obtain displacement/stress/strain to be applied to the local model of flexible structure. Further development of the presented analysis is being carried out to determine the optimal structure.

Literature

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