NUMERICAL SIMULATION OF UNDER WATER EXPLOSION BY SPH METHOD

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ABSTRACT: The paper presents theoretical and practical fundamentals regarding numerical analysis of under water explosion and its effects upon submerged structures. Numerical analysis is based on free particles method with its version Smoothed Particles Hydrodynamics (SPH). The fundamentals of explosion theory and the SPH method are supposed to be known, so they give the possibility for an easy understanding of such complex phenomenon like explosion and how SPH method works. The example finishing the paper represents an available numerical model for such problems which become more important nowadays in continuum preoccupation of specialists for improving anti-terrorist capabilities or for military aims.

Keywords: explosion, detonation, blast wave, bubble, free particles, SPH, fluid-structure interaction, underwater shock

SIMULAREA NUMERICĂ A UNEI EXPLOZII SUBACVATICE PRIN METODA SPH – REZUMAT: Lucrarea prezintă fundamentele teoretice şi practice privind analiza numerică a unei explozii subacvatice şi a efectelor sale asupra structurilor imerse. Analiza numerică se bazează pe metoda particulelor libere în versiunea SPH. Fundamentele teoriei exploziei şi ale metodei SPH se presupun a fi cunoscute, astfel ele dau posibilitatea înţelegerii uşoare a unui fenomen complex cum este explozia şi cum lucrează metoda SPH. Exemplul care încheie lucrarea reprezintă un model numeric valabil pentru astfel de probleme care devin tot mai importante în zilele noastre, în preocuparea continuă a specialiştilor pentru îmbunătăţirea capabilităţilor anti-teroriste sau pentru scopuri militare.

Cuvinte cheie: explozie, detonaţie, unda exploziei, sferă de aer, particule libere, SPH, interacţiune fluid-structură, şoc subacvatic

1. INTRODUCTION

All the aspects regarding explosives, explosions and the effects of these upon structures present a high complexity and many difficulties for any approaching ways (analytical, numerical and experimental). Among all explosion types, those under water have some particularities which make them a special issue. The scientific literature show us that the studies of explosives, explosions and their effects have been increased after Second World War and under water explosions are very closed by the progress made in investigated possibilities (specially numerical and experimental ways). In this context, the present paper comes to us with a new numerical method, very fitted and efficient one in fluid mechanics. It is about the free particles method with its version Smoothed Particle Hydrodynamics (SPH) method.

1.1 Particularities of Under Water Explosions

Chemical transformation of the explosive, from solid state in gas state, in a underwater detonation, makes a gas bubble which remains confined by water on all sides. The high pressure inside the bubble, together the water with its hydrostatic pressure and moving mass make an oscillating system, having the pressure peaks in water and in bubble too. Each of bubble oscillations transmit a secondary pressure pulse in the surrounding water, but the bubble pulsation generates considerably lower pressure than the first shock.

The pressure and the positive impulse, generated by bubble oscillations vary in time and they depend on charge weight, range and depth. Most important aspect which have the most important effect upon a submerged structure is first peak pressure. Also, other conditions like reflection phenomenon generated by the rigid walls (navigation channels), by the free water surface or by the bottom, could significantly influence the peak pressure and finally the explosion effects upon an under water structure. A rigid surface reflections generate compression waves and water free surface reflections generate rarefaction waves, which superimpose on the original shock wave. These rarefaction waves represent physical support of the cavitation phenomenon which occur near the water free surface in some conditions.

1.2 Types of Under Water Explosions

Generally, an under water explosion is an explosion having the detonation point below the surface of the water. By experiment and even by numerical and just analytical studies, explosion developing and specially its effects depend on the water depth at which detonation occurs. Two main under water explosion exist (shallow and deep) and these are so classified by empirical relation (Le Méhauté and Wang, 1995); if relation exist, a shallow explosion occurs and if relation (2) exist, a deep explosion takes place.

$$\frac{\boldsymbol{d}}{\boldsymbol{W}^{1/3}} < 1 \qquad (1)$$

$$\frac{\boldsymbol{d}}{\boldsymbol{W}^{1/3}} > 16 \qquad (2)$$

In the above relations, $\boldsymbol{d}$ is the explosive position to the free surface (expressed in feet) and $\boldsymbol{W}$ is the yield of the explosive (in pounds), for TNT. For other explosives the equivalence relations have to be used. For the international unit system, the left side of relations (1) and (2) has to be multiplied by a factor of 2.523 value.

For a surface explosion, the gas bubble vents to the atmosphere, so no subsequent bubble oscillations exist. By the first gas bubble, the explosion energy is transmitted to the water and the reflection of the shock wave from the free surface is not a very important one by effects. On the other hand, a substantial attenuation of the pressure and positive impulse occurs.

The most important blast wave front is developed above the free surface, and the effects appear both above and bellow the free surface. A characteristic phenomenon is the crater formed at the water surface, which is large one, comparatively with the depth of the explosion, and a hollow water column.

In the case of a deep underwater explosion, much more explosion energy is delivered to the water, so the heights of the water free surface waves can be significantly by height and volume, being able to damage coastal areas, next to the damages of an underwater structure.

In underwater explosion (specially deep explosion) the gas bubble (sphere of gas with high temperature and pressure) interacts with the surrounding water (fluid) in two different phases.

The first phase is characterized by a transient shock wave, which causes a rapid change of the fluid velocity and a large inertial loading. Also, the peak pressure is very high, but its duration is very short. The second phase is represented by a radial pulsation of the gas bubble. The oscillations of the gas bubble are repeated for a number of cycles (ten or more). The period of the bubble pulsations is very long comparatively with the shock wave and pulsation duration is long enough for the gravity force to become effective. So, such a gas bubble appears to have a great buoyancy and migrates upwards in time. Its buoyancy, its floating up is not compared with a balloon, because the gas bubble goes upward in jumps.

1.3 Effects upon Immersed Structures

An underwater explosion may cause serious damages upon nearby immersed structures. The water, being much less compressible than air, the same amount of explosive can produce greater damages. There are three damage mechanisms of an immersed structure.

The first damaging mechanism is based on high pressure. Just after the detonation, a shock wave appears together with the high pressure gas bubble which is expanding. The shock wave moves at very high speed, generating very high pressure. When this shock wave will hit the structure, the first damaging mechanism begins. This mechanism is the main one.

The second damaging mechanism is known as whipping effect. This is a result of the gas bubble oscillations, when large water accounts are moving, all these meaning pressure variations applied to a structure. If the frequency of the bubble oscillation matches the eigen-frequency of the structure a so-called "whipping" effect occur, which represents the second damaging mechanism.

The third damaging mechanism or "jet impact" occur in the collapse phase of an immersed structure. As the gas bubble goes to a structure and this is touched, a high speed water jet traverses the bubble and impact the structure. Such a phenomenon is known as third damaging mechanism or jet impact mechanism, which can develop or amplify the damages.

2. NUMERICAL MODELS FOR UNDER WATER EXPLOSION PARAMETERS

Regarding numerical analysis of an under water explosion, two main aspects are taken into account: explosion parameters of the under water explosion and the effects of an under water explosion upon an immersed structure (submarine, ship's hull or ship's keel, port structures, immersed parts of an offshore) and living beings (underwater creatures and divers). For numerical studying of the underwater explosion parameters, 1D, 2D and 3D models can be used.

2.1 The 1D SPH numerical model

Detonation parameters can be determined using an 1D SPH model, as is presented in the Figure 1, for a TNT slab of 0.2 m length, surrounding by 10 m of water, the ignition point being just in the center.

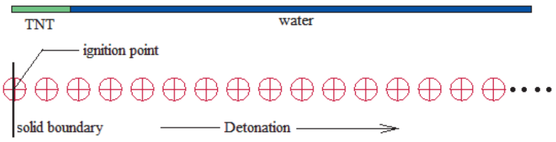


Fig. 1. The 1D SPH numerical model

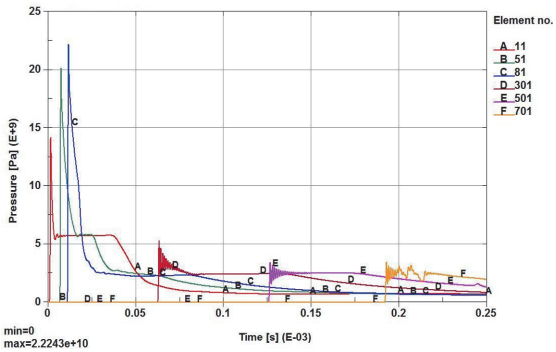


Fig. 2. Time variation of the pressure in different points (TNT and water) of the model

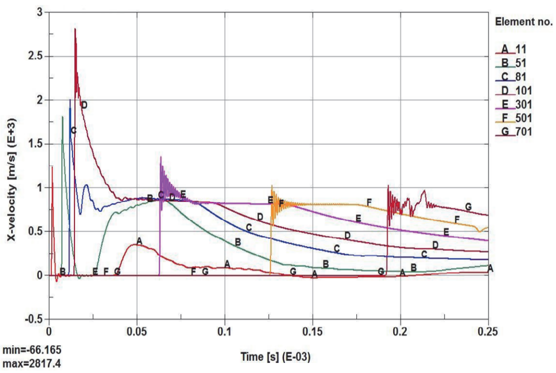


Fig. 3. Time variation of the velocity in different points (TNT and water) of the model

The adopted numerical model is 1/2 of the real model because such a slab has a symmetry plan. In this model, along x axis, for a 0.10 m TNT length and 9.9 m water, 1001 particles were used, the left side head being the ignition point. The numerical models presented above were used by Ls-Dyna program. The used material models were "MAT_HIGH_EXPLOSIVE_BURN" and the equation of state (EOS) Jones-Wilkins-Lee (JWL) for TNT and "MAT_ELASTIC_PLASTIC_HYDRO" and the EOS GRUNEISEN for water. Figures 2 and 3 present variation in time of two main parameters in some points (from TNT and water): the pressure and the velocity. We can notice that these parameters have greater values in detonation process (points belonging to TNT) than the values of the water particles. Next to it, in the case of water particles, those parameters present some oscillations - characteristic phenomenon of the underwater explosions, because gas bubble.

2.2 The 2D SPH numerical model

Such a numerical model is fitted for studying of explosion parameters and explosion effects too. In many cases the 2D model for explosion modeling is a 2D plain strain or 2D ax symmetric state. This model can be a realistic approaching in some conditions, but often can be an acceptable approaching, specially for analysis of explosion parameters and not only. In the Figure 4, a 2D SPH model, in plane strain state, is presented for studying of the detonation parameters in the case of a perfect rigid confining of the charge. Also, the Figure 4 presents the pressure field time evolution - detonation pressure. The TNT charge fills all the space (1m x 1m) and the ignition occurs just in the middle of the space. We can notice those two zones: burned and unburned explosive.

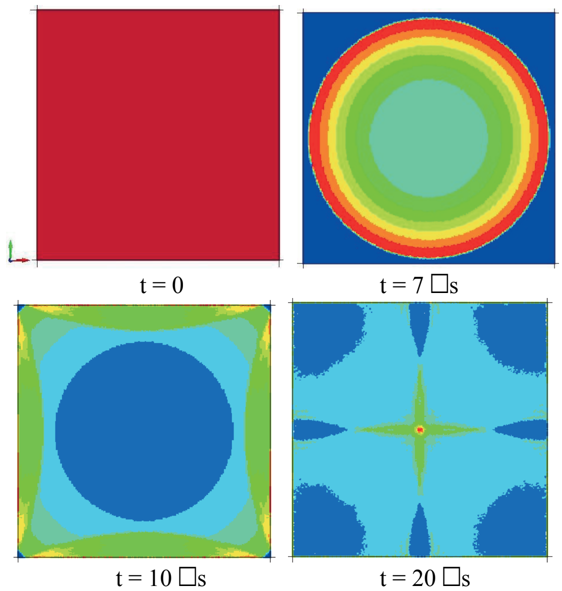


Fig. 4. Time evolution of the detonation pressure in a confined space

The central part, developed like a circle represents burned explosive (gas part); the maximum pressure occurs at the border between burned and unburned explosive.

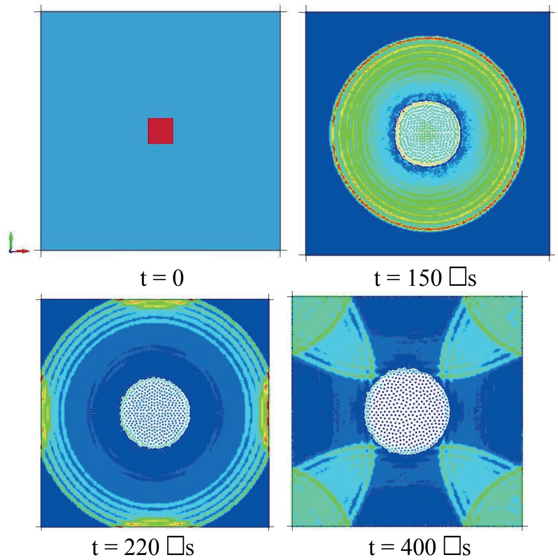


Fig. 5. Pressure field time evolution for an under water explosion in a confined space

In the Figure 5, a 2D SPH model, in plane strain state is presented for studying of the underwater explosion parameters. This explosion occurs in a confined space of 1m x 1m of water, having just in the middle a TNT charge with 0.1m x 0.1m . The thickness of such models is considered to be the unit measure. The distance between nodes is 0.005 m and entire model has 40401 particles.

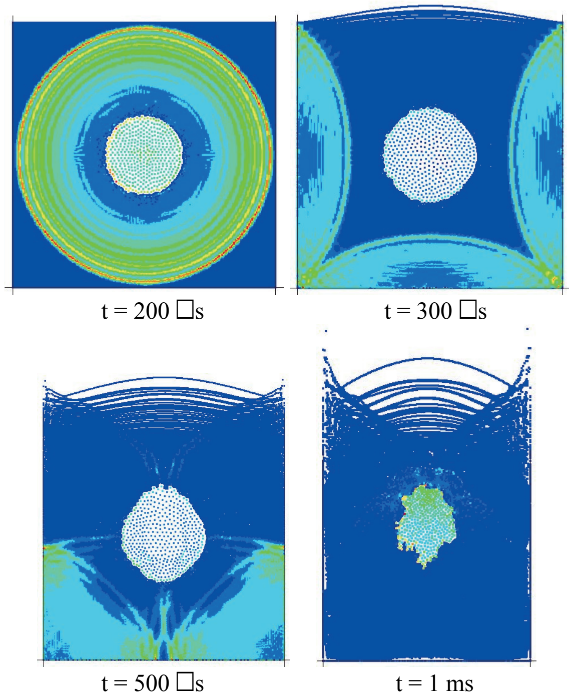


Fig. 6. Pressure field time evolution for an under water explosion in a space partially opened (upper part)

In the Figure 6, some results are presented, using the same SPH model but having opened upper part. A part of the phenomenon described in this paper (Introduction) can be noticed in the Figures 5 and 6.

So, the gas bubble appearing, its developing, the waves reflection and the place of maximum pressure can be noticed too. Depending on the explosive type and quantity, on the water characteristics, on the ignition point etc. all the parameters can be quantitatively evaluated.

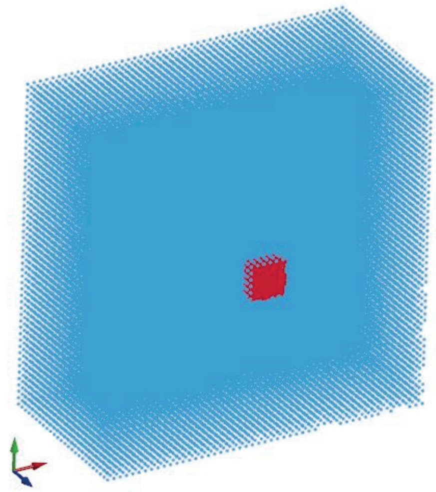


Fig. 7. A half of a 3D SPH model

A 3D SPH model can be used both for explosion parameters analysis and for explosion effects analysis or simulation. Of course, such model is the best, is most closed by reality, but sometimes could require too much computer time, so some difficulties in problem solving can appear. Boundary conditions are the most important for a right solution.

3. UNDER WATER EXPLOSION EFFECTS UPON IMMERSED STRUCTURE

Numerical simulation of an under water explosion by SPH method is illustrated by an example consisting in a channel with water, an immersed body and an explosive placed near the body. The channel has rigid walls with 6 m length, 4 m deep and 3 m width.

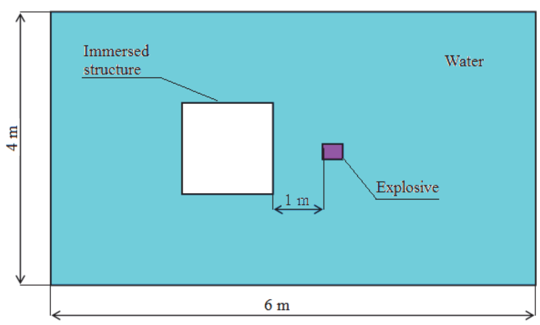


Fig. 8. Schedule of the problem

The immersed body is represented by a cubic structure modeled by shell finite elements. The water and the explosive are modeled by free particles.

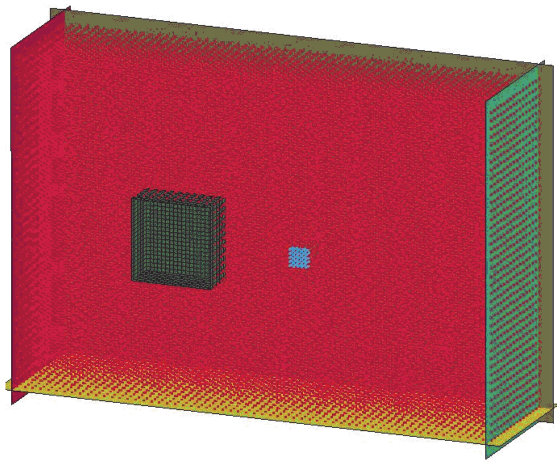


Fig. 9. The 3D numerical model of the problem

Because of symmetry, the numerical model consist only in half of the problem modeling. The immersed structure is represented by a box of 1m x 1m x 1m dimensions, having the wall thickness of 0.010 m. The symmetry plane is XY plane and the proper restrictions (UZ=0) were imposed to all nodes of this.The explosive has a volume of 0.008 m^3 (13 kg of TNT). Finally, the used model has 39567 free particles of water, 1081 free particles of explosive and 1040 shell elements. The water was modeled by MAT_NULL with LINEAR_POLYNOMIAL EOS, the explosive was modeled by MAT_HIGH_EXPLOSIVE_BURN with JWL EOS and the immersed body was modeled by MAT_PLASTIC_KINEMATIC with fracture mechanism and taking into account of the strain rate.

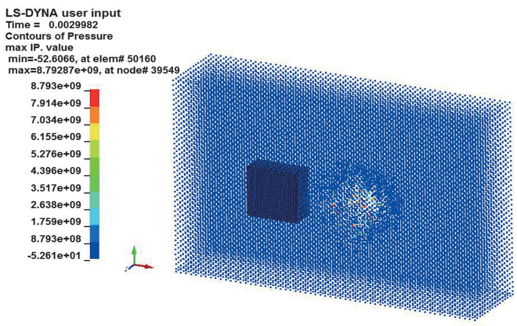


Fig. 10. Pressure field and gas bubble appearing at 3 ms

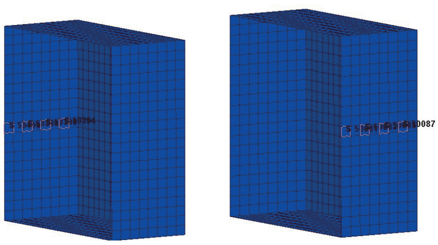


Fig. 11. Selected FE for pressure analysis

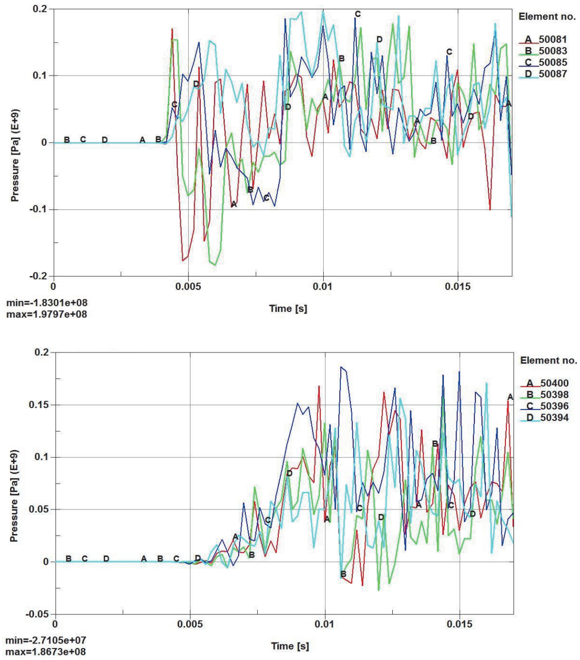
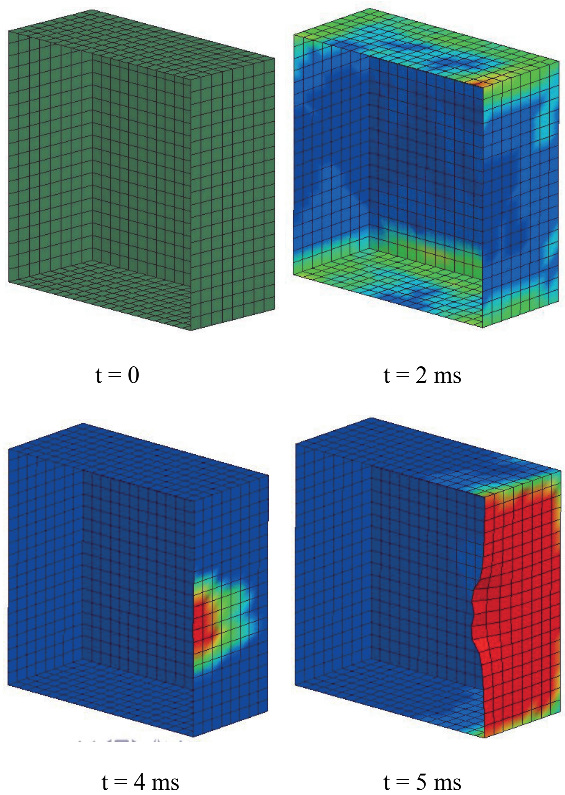


Fig. 12. Time variation of pressure on the selected shell elements

The analysis of the curves presented in the Figure 12, representing the variation in time of the pressure applied on the selected FE (Figure 11), shows the maximum values (197 MPa), oscillator process caused by the gas bubble and different way of pressure applying: on the part towards explosion, the pressure comes in a shorter time, having greatest pressure picks, but on the opposite part, the pressure comes in a longer time.



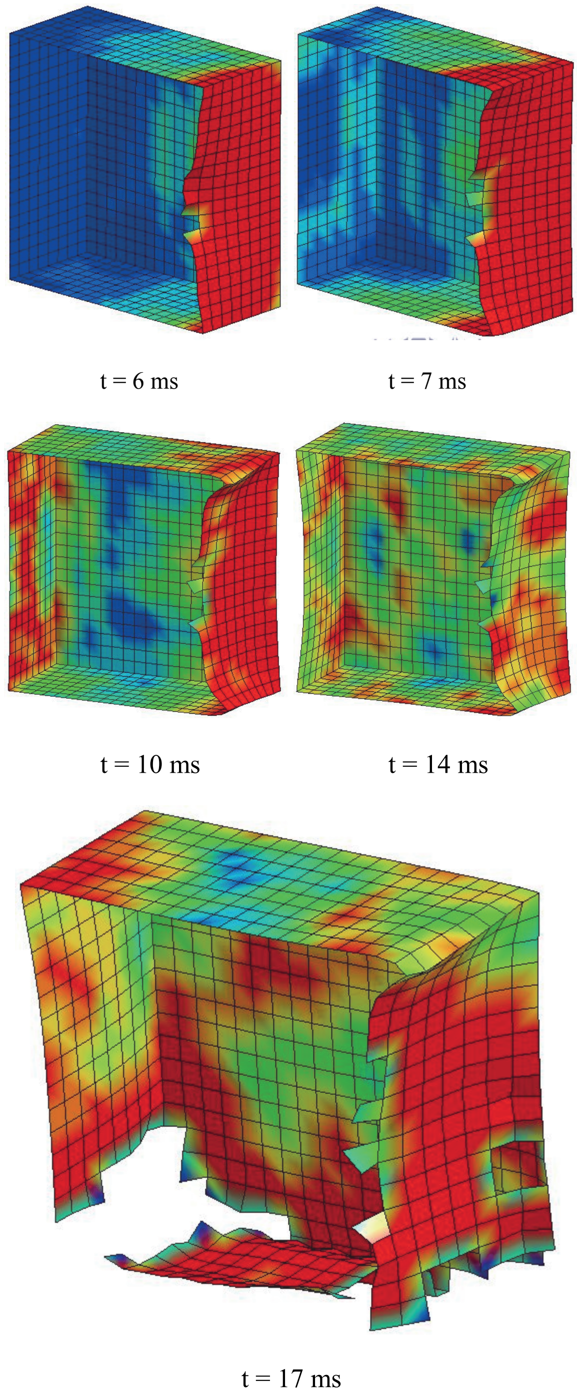


Fig. 13. Time evolution of structure damages

The effects of the under water explosion upon the structure can be watched in the Figure 13, in their time developing. The analysis of the images of the structure damages shows the evolution in time of these, as a result of time propagation of the pressure waves and as a result of time propagation of the elastic waves in the structure, on the other hand.

The most important and large damages occurred at the bottom of the structure owing to the reflected pressure waves by the channel bottom and the left side wall. Other distances from structure to rigid walls or even free surface are longer.

When the wave reflection has to be avoided - by the real conditions of explosion occurring - the SPH modeling must be made for larger dimensions. When the walls exist but they are not perfectly rigid, the walls could be modeled by FE or by free particles.

3. CONCLUSIONS

The present paper is not only a signal regarding applying SPH method for under water explosion parameters and effects calculus; this paper presents some numerical available models which can be used in problem solving of such type.

Almost all physical aspects described in Introduction are reflected in the presented examples. All damaging mechanism are illustrated. That whipping effect can be watched by the time variation of the pressure (Figure 12).

Numerical simulation of the submerged structures and equipment behavior in underwater explosion conditions is a very important problem for peace and war conditions and against terrorist actions.

Not all aspects appearing in an underwater explosion were presented or simulated, like cavitation and the free surface state, but these aspects can be also studied by SPH method.

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