BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXVIII No. 1/2016	13 – 22	Seria Tehnică

Numerical Modeling of an Underwater Explosion Near a Pipe

Vasile Năstăsescu

Military Technical Academy, Bd. George Coşbuc 81-83, Sector 5, Bucharest
e-mail: nastasescuv@gmail.com

Abstract

In this paper, the effects of an underwater explosion upon a pipe are presented. The numerical model is a one based on Finite Element Method (FEM) and on the Smoothed Particle Hydrodynamics (SPH) method. The last method was used for modeling of the water and the explosive. FEM was used only for pipe modeling. The explosion occurs somewhere in the water, being not a shallow underwater explosion no a deep one. At the same depth, the center of a pipe having the diameter of 1 m is placed. The numerical model used dedicated material models for each its component. Using of the SPH method for modeling of the water allowed the analysis together the pipe and the water, in other words, a solving in one-step of the fluid-structure interaction (FSI). In addition, the appearing and developing of the bubble gas was describing by using of SPH method. The obtained quantity and quality results substantiates findings, but in the same time they represent useful information for some practice measures in special circumstances.

Key words: *explosion, SPH, FEM, FSI, underwater, effect, parameter*

Introduction

Nowadays, numerous threats exist and these have different targets. Industrial installations and any other installations that can damage people and civil constructions, or which ensure supplying with energy or others utilities represent targets for terrorist actions.

Knowing the effects of the explosives upon different constructions, in different circumstances, allow to the authorities to take the best measures for prevention and thwarting of terrorist activities. When the effects of different explosives upon characteristic elements of civil or military installations are known, the intervention of the emergency forces can be very efficient.

In this context, this paper comes with a numerical modeling of an underwater explosion upon a pipe. In this paper, the pipe is empty, but the numerical model can take into account the case of a pipe with gas under pressure or with a fluid moving under pressure.

The detonation point is below the surface of the water at 2 m and near the pipe at 0.5 m distance. Because of calculator time, the water space was limited and the analysis of the explosion effect was made only by direct action of the blast wave, so the effect of reflected waves was neglected. For such a very short time, the effect of the atmosphere was also neglected and the hydrostatic pressure could be neglected for its small value, comparatively with the pressure values produced by explosion.

The sketch of the problem is presented in the Figure 1. Therefore, water space has dimensions of 4x6x3 m, but having a symmetry plane (xOy), only one part of 4x6x1.5 m was considered.

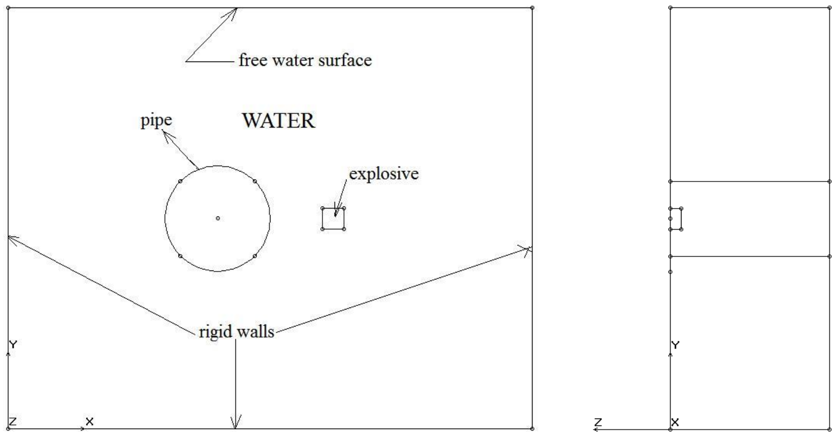


Fig. 1. The problem sketch

The explosive (TNT) quantity, having a cubic shape (0.2x0.2x0.2 m), was 13.04 kg for entire model, but only 6.52 kg for calculus model. The level of pipe center and detonation point is 2 m towards bottom and free water surface. The pipe walls are made of 1018 steel with a thickness of 10 mm. The pipe center there is at 2m from bottom and proxy rigid wall.

An underwater explosion has some characteristics which makes it to be very different of an explosion in air, at the land surface or even in soil. These characteristics are taken into account in numerical modeling and in result analysis.

Underwater Explosion Characteristics

By an underwater detonation, an explosive, pass from the solid state in the gas state, resulting a gas bubble that remains confined by water on all sides. The high pressure inside the bubble, together the water with its hydrostatic pressure and moving mass are elements of 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 has the most important effect upon a submerged structure is first peak pressure.

In addition, other conditions like reflection phenomenon generated by a wall, by the free water surface or by the bottom, could significantly influence the peak pressure and finally the explosion effects upon an underwater structure. A rigid surface reflection generates compression waves, while water free surface reflection generates rarefaction waves, which superimpose on the original shock wave. These rarefaction waves represent physical support of the cavitations phenomenon, which occur near the water free surface in some conditions.

An underwater explosion is an explosion having the detonation point below the surface of the water. Two main types of underwater explosion exist: shallow and deep. These two underwater explosion types are different by effects upon structures and upon behavior of the free water surface. There are two empirical relation (Le Méhauté and Wang, 1995) which defines those two underwater explosion types, where $\boldsymbol{d}$ is the explosive distance 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.

$$\frac{\boldsymbol{d}}{\boldsymbol{W}^{1/3}} < 1 \tag{1}$$

$$\frac{\boldsymbol{d}}{\boldsymbol{W}^{1/3}} > 16 \tag{2}$$

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 below 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 (especially 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.

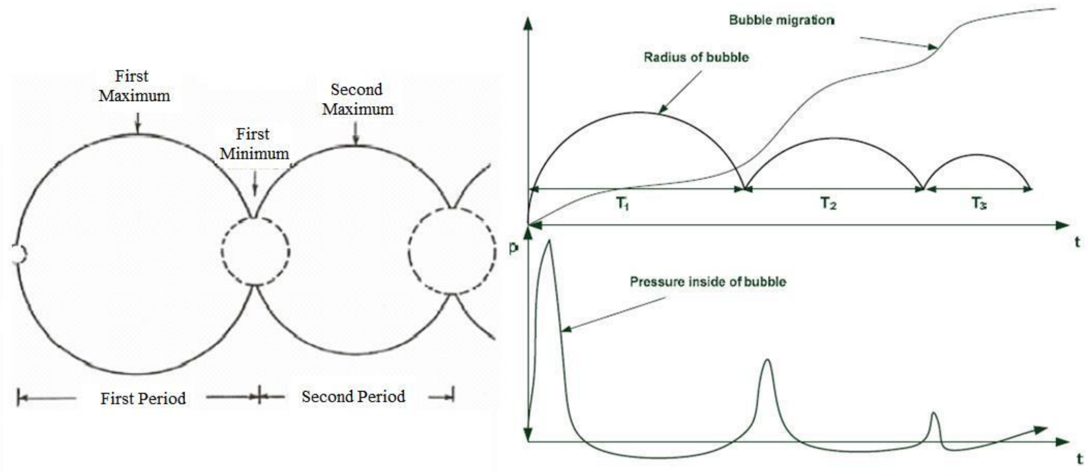


Fig. 2. Gas bubble oscillations

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. Therefore, 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.

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.

Numerical Model

Numerical model consist in modeling with finite elements (SHELL) for the pipe and with free particles, for the water and explosive. Rigid walls were used for water space delimitation. For all nodes of symmetry plane, the properly restrictions were formulated (UZ=0).

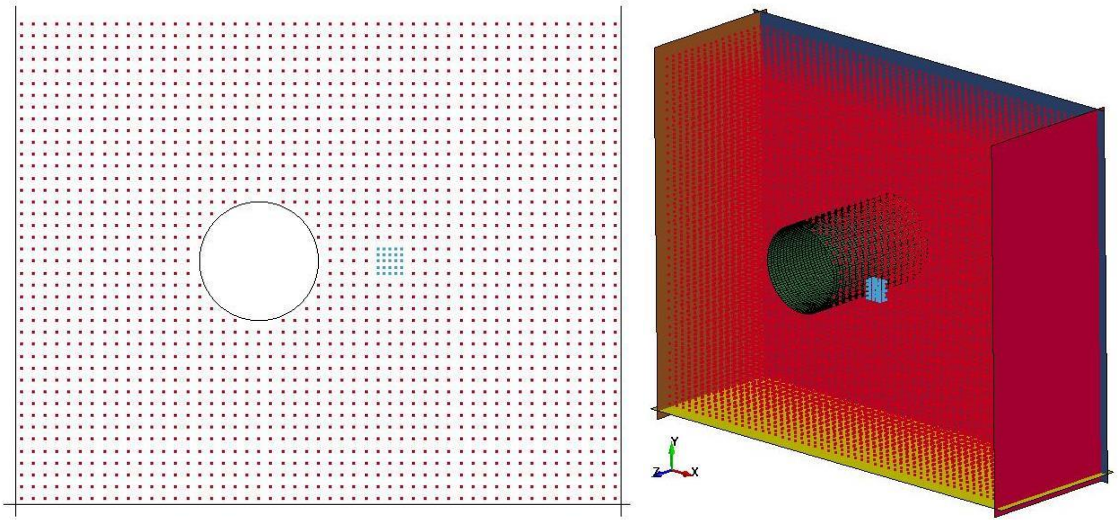


Fig. 3. Numerical analysis model

The model version presented above consist in 32014 particles of water, 75 particles of explosive and 3600 shell elements having 3720 nodes for pipe. In this version of discretization, the distance between nodes was 10 cm and the shell side length was 5 cm.

Because I was interested in the explosion effect upon pipe and NOT in the water state, the analysis time was reduced until the time value, in which the blast wave in water not to reach the wall. So, the effect of reflected waves was avoided, it being not interesting in this study.

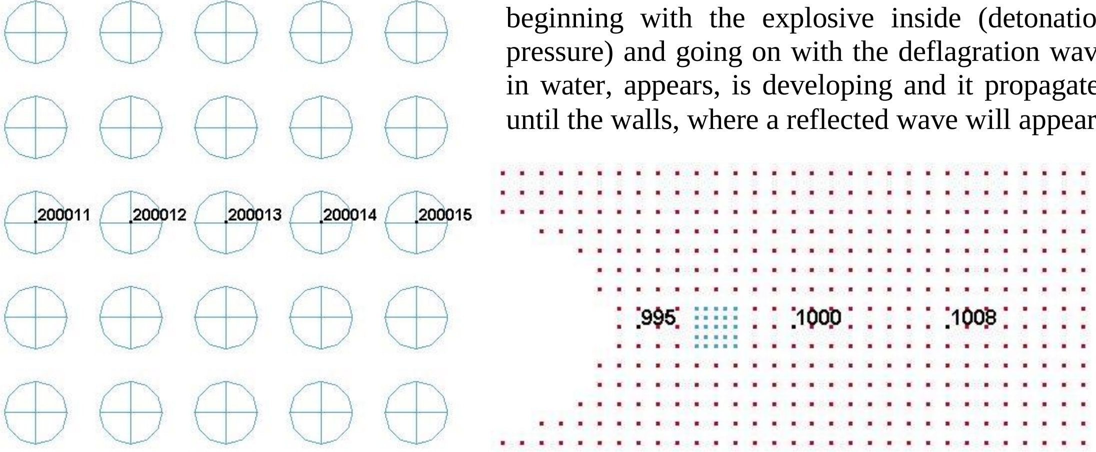
For water, MAT_NULL material model was used and LINEAR_POLYNOMIAL equation of state (EOS); for explosive, HIGH_EXPLOSIVE_BURN material model was used and Jones-Wilkens-Lee-Baker (JWLB) equation of state; for pipe, PLASTIC_KINEMATIC material model was used.

All these material models are those implemented in Ls-Dyna material library. The ignition point was the middle of the explosive.

Results

The aim of this study was about pipe: which will be the pipe state in conditions of an underwater explosion; which will be damages of pipe; which are the explosion parameters in water around the pipe and others. By graphical post processing the results, the answers to the above formulated aims are presented below.

As a result of the explosion, the pressure, beginning with the explosive inside (detonation pressure) and going on with the deflagration wave in water, appears, is developing and it propagates until the walls, where a reflected wave will appear.



a) Explosive particles

b) Some water particles

Fig. 4. Selected particles for graphical representation of the pressure

In the Figures 5 and 6, the time evolution of the pressure, in the selected particles, is presented. So, in the Figure 5 detonation pressure is presented. We can see very high pressure picks, which appear at the explosion beginning, some oscillations of the pressure values, then a pressure inside the explosive (gas bubble) at about 6000...8000 MPa.

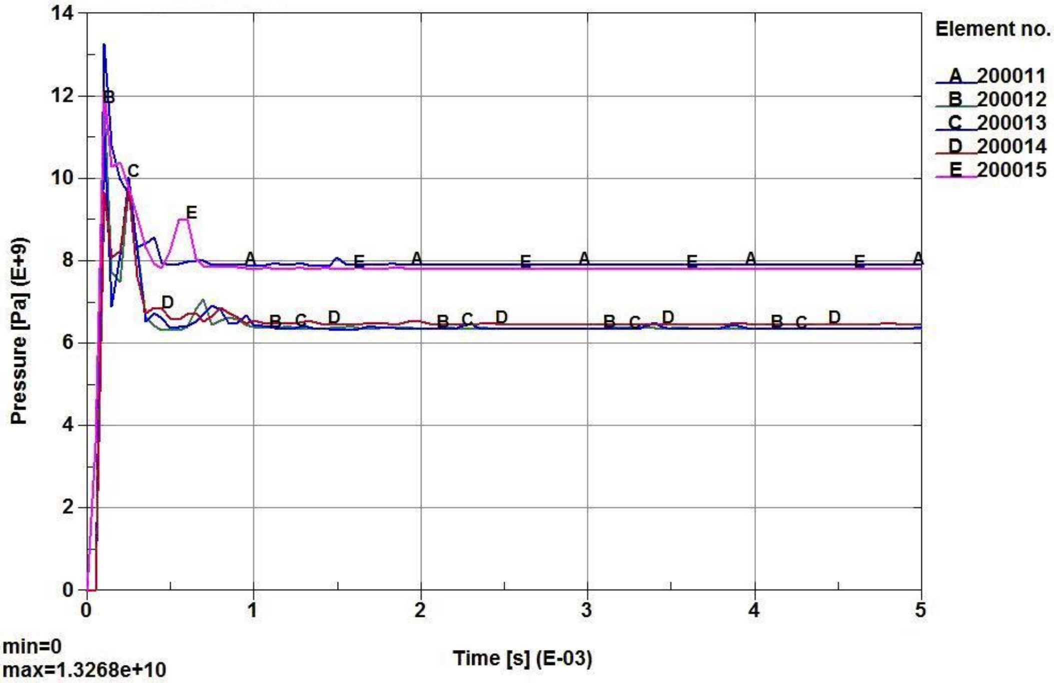


Fig. 5. Detonation pressures and its evolution in time

In Figure 6, the time evolution of the pressure in the water can be watched (in selected particles, Fig. 4-b). The deflagration pressure (over 15 MPa) is significantly less then detonation pressure, variation allure is that known from literature and in analysis time the deflagration wave did not arrive at particle 1008 (over 1m towards explosive).

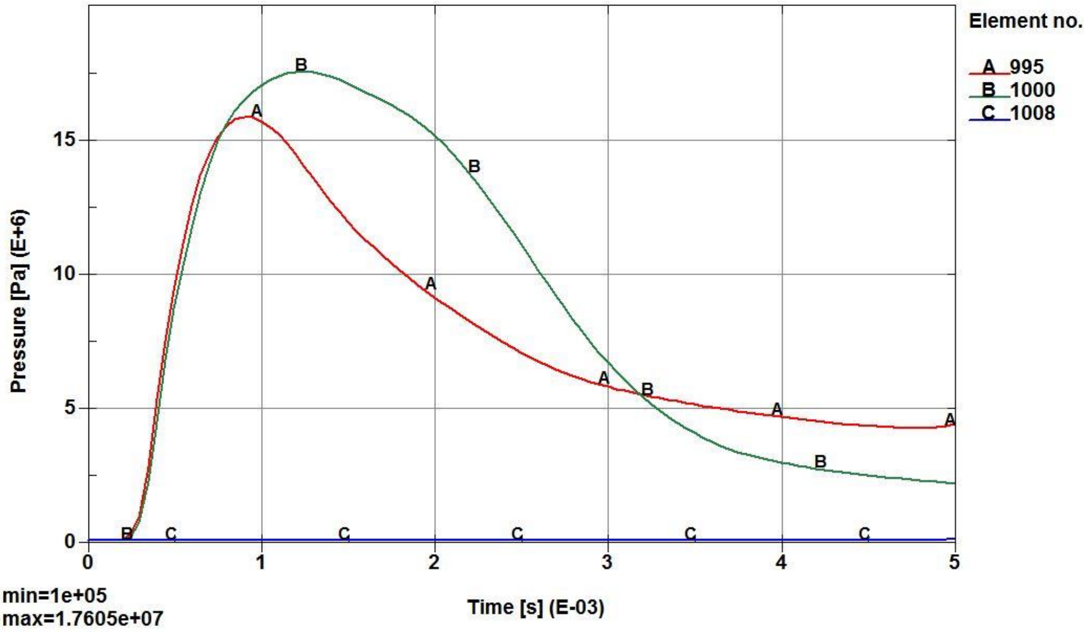
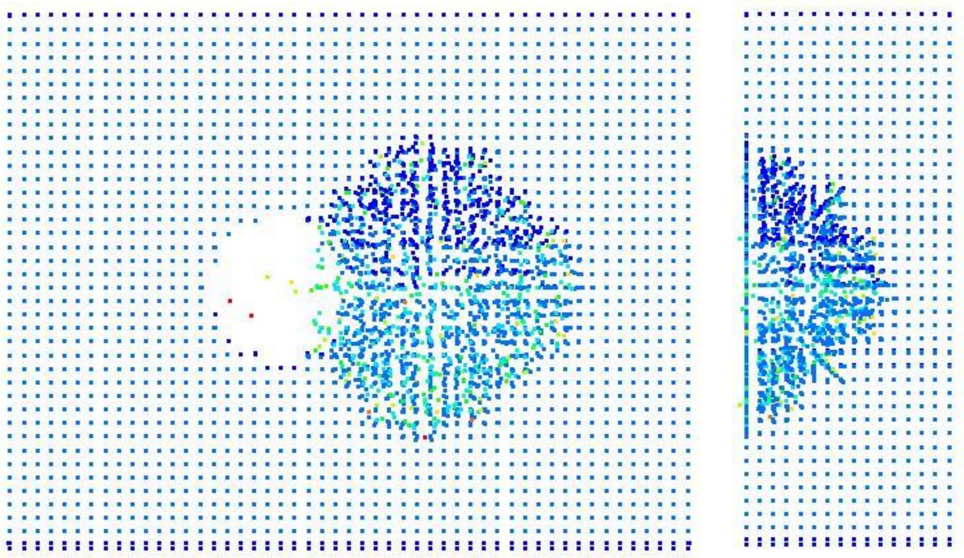


Fig. 6. The evolution of the deflagration pressure



a) Frontal view b) Side view

Fig. 7. Gas bubble development in analysis time

In Figures 7...9 the developing of the gas bubble is presented. As we can see, choosing of the water domain and analysis time, we managed to study the effect of an under water explosion upon a pipe, without the influence of the reflected waves. This influence is an other issue, which can be studied, but it is not a aim of this paper.

By explosion process, the explosive of 0.20 m side dimension is transformed in gas, the bubble, having at the considered time, the dimension (over 1 m) presented in Figure 8.

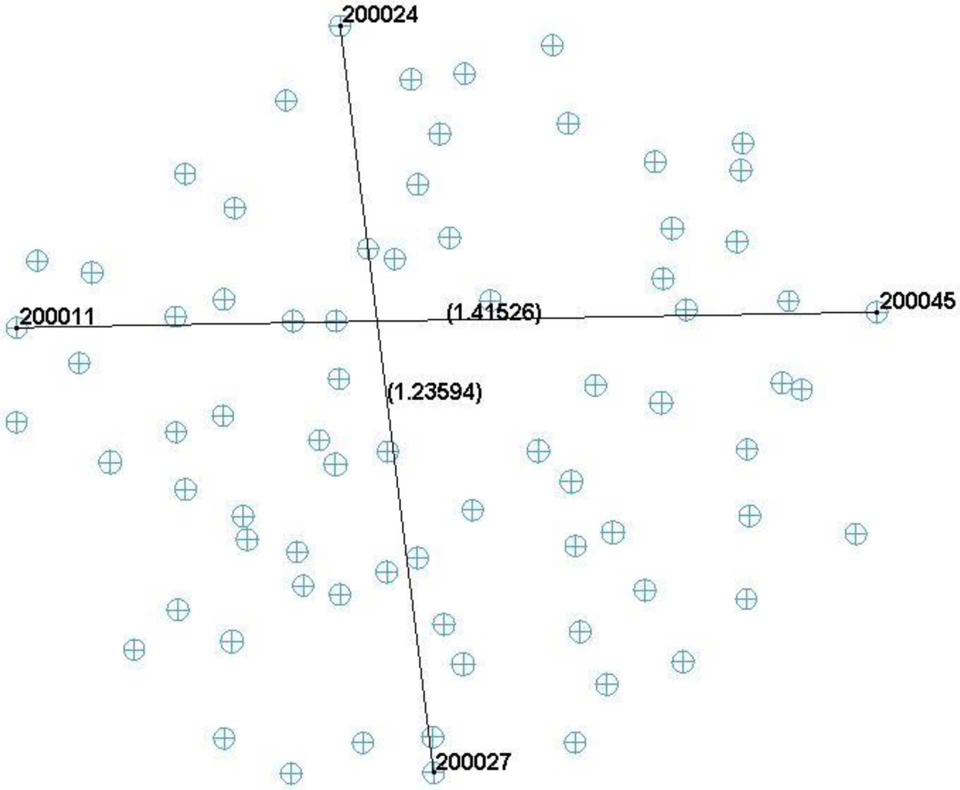


Fig. 8. Gas bubble dimensions

In Figure 9, we can see the variation in time of the horizontal explosive dimension, by explosive transformation from solid state in the gas state. The evolution is not a linear one. Even for this very short time period, the curve from Figure 9 put in evidence the oscillation process.

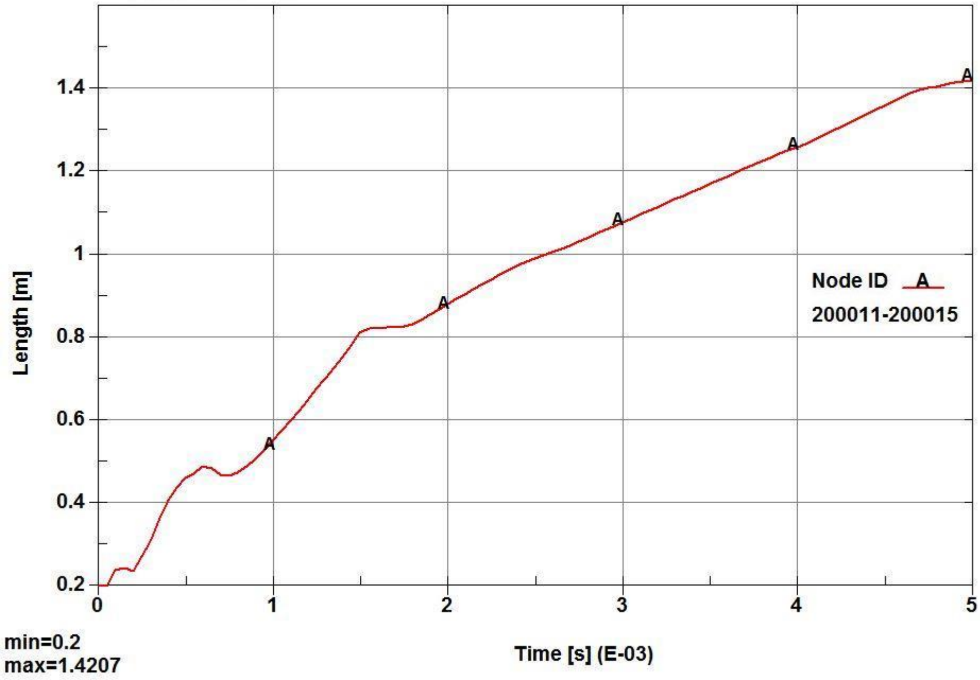


Fig. 9. Evolution in time of the horizontal explosive dimension

The effects of the explosion upon the pipe can be seen in the Figures 10...14. Figure 10 presents the state of the pipe, the water and explosion at 5 ms after explosion initiation. It is very interesting to notice that fluid-structure interaction (FSI) occurs automatically; this aspect is characteristics for using of SPH modeling. We also see in the Figure 10 and 11 that the equivalent von Mises stress values, in the material of the pipe, are much more greater that in explosive or water particles.

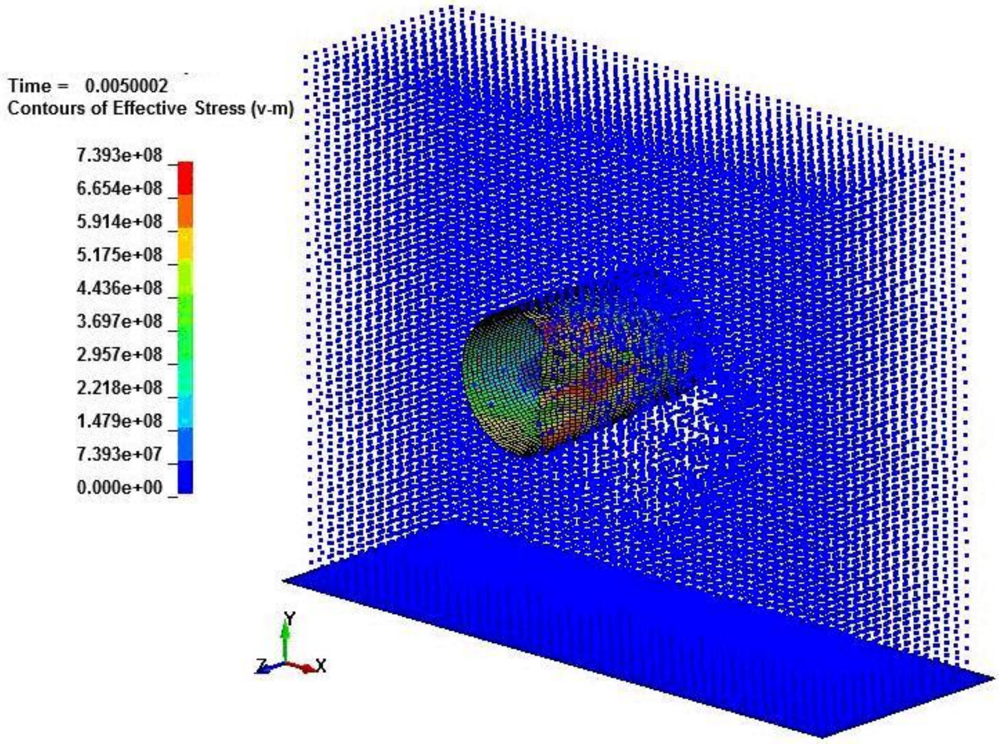


Fig. 10. Fluid structure interaction

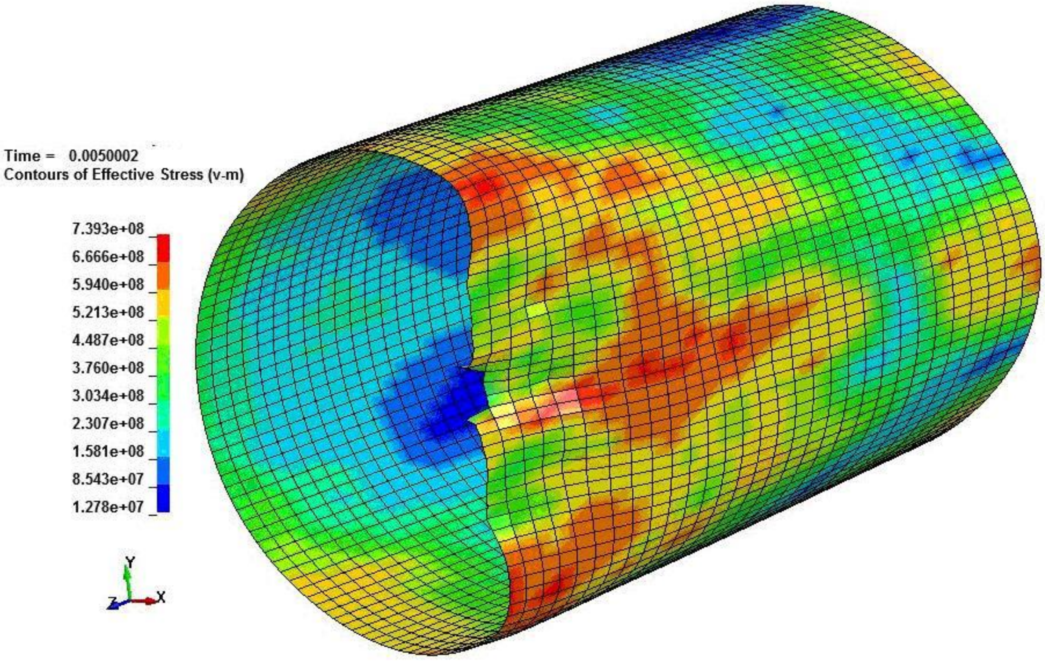


Fig. 11. Von Mises Stress field upon deformation state of the pipe

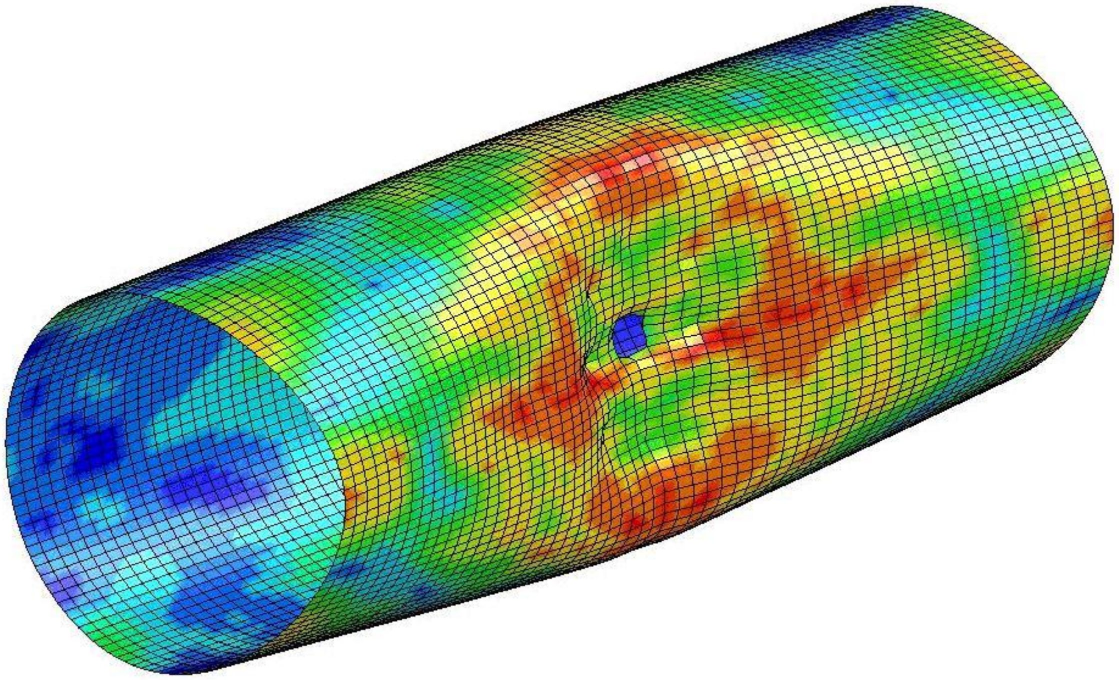
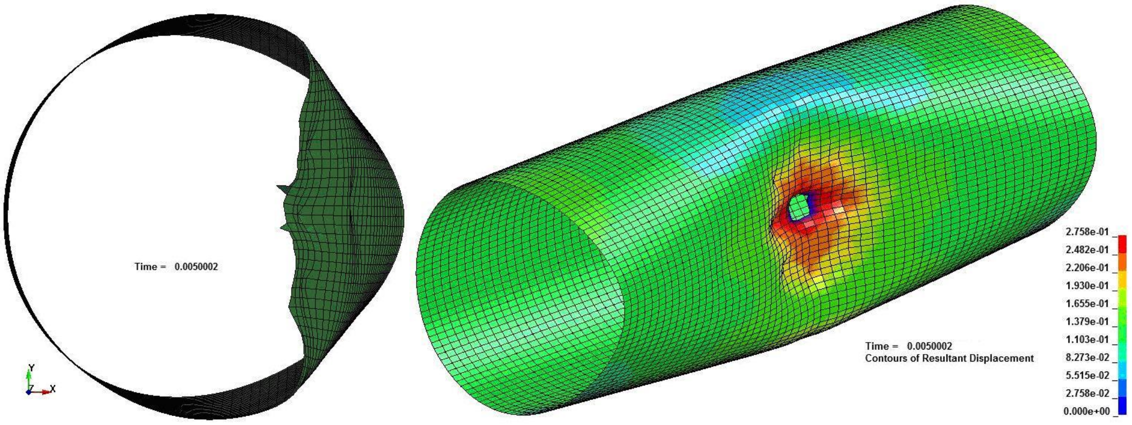


Fig. 12. Von Mises stress field on the deformation state of the entire pipe



a) b)

Fig. 13. Deformation state of the pipe

The Figures 11...13 show the effects of the explosion upon the pipe. This is strongly deformed, even perforated in its nearest part of explosion. Maximum displacement has a value of 0.275 m. The Figures 12 and 13 are obtained by graphically post processing using symmetry effect.

Conclusions

This paper comes with some very important information for those interested in determining of explosion effects upon a pipe, in under water conditions. These conditions make the explosion to also present specific characteristics, which have to be known and taken into account in numerical simulation.

The under water explosion calculus presents some calculus issues, which can be watched and evaluated: explosion parameters, effects upon structures, gas bubble and water evolution.

The main target of this paper was to determine the explosion effect upon a pipe, without internal pressure, in a limited water domain without reflected waves, which as a rule, amplify the explosion effects.

There are many other aspects, like local cavitation in some conditions, the effects of water masses in moving and others. Everything can be numerical simulated and quantitative evaluated.

First of all, this paper brings in our attention the using of SPH method; this is the simplest way for FSI interaction and recognized to be the best numerical method for fluid mechanics, especially for solving the most difficult problems, like the evolution of free water surface etc.

Calculus models presented in this paper are available in many other conditions as underwater explosion is concerned.

References

1. Kingery, C.N., Bulmash, G. – *Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst*, Technical Report ARBRL-TR-02555, 1984.
2. Lee, J.H.S. – *The Detonation Phenomenon*, Cambridge, 2008.
3. Năstăsescu, V., Bârsan, G. – *Metoda SPH*, Editura Academie Forţelor Terestre, Sibiu, 2012.
4. Năstăsescu, V., Bârsan, G. – Numerical Analysis Ways for Determining of the Blast Effects and Parameters, *The 19th International Conference The Knowledge-Based Organization (KBO), Conference Proceedings 3, Applied Technical Sciences and Advanced Military Technologies*, Sibiu, 2013.
5. Ngo, T. et al. – Blast Loading and Blast Effects on Structures - An Overview. *Electronic Journal of Structural Engineering*, Special Issue: *Loading on Structures*, pp. 76-91, 2007.
6. Schwer, D.A., Kailasanath, K. – Numerical simulations of the mitigation of unconfined explosions using water-mist, *Proceedings of the Combustion Institute*, 2007.
7. * * * – *LS-DYNA Theory Manual.*
8. * * * – *LS-DYNA User's Manual.*

Modelarea numerică a unei explozii subacvatice lângă o conductă

Rezumat

In această lucrare, sunt prezentate efectele unei explozii subacvatice asupra unei conducte. Modelul numeric este unul bazat pe Metoda Elementelor Finite (MEF) şi pe metoda particulelor libere (MPL). Ultima metodă s-a folosit pentru modelarea apei şi a explozivului. MEF s-a folosit numai pentru modelarea conductei. Explozia se produce undeva în apă, fiind nici superficială (aproape de suprafaţă), nici de adâncime. La aceiaşi adâncime se găseşte centrul unei conducte cu diametrul de 1 m. Modelul numeric a folosit modele de material dedicate pentru fiecare component al său. Folosirea metodei SPH pentru modelarea apei a permis analiza împreună conductă şi apă, cu alte cuvinte, o rezolvare într-un singur pas a interacţiunii fluid-structură. In plus, prin utilizarea metodei SPH, s-a descris apariţia şi dezvoltarea bulei de gaze. Rezultatele cantitative şi calitative obţinute stau la baza concluziilor, dar reprezintă totodată date utile unor măsuri practice în situaţii speciale.