NUMERICAL INVESTIGATION OF THE INFLUENCE OF A RIGID OBSTACLE ON THE MULTIPLE REFLECTED PRESSURE IMPULSE

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Abstract

The article presents the case of multiple reflection of a blast wave from a rigid obstacle. The pressure impulse was generated in the Euler domain according to Taylor-Sedov theory. Additionally, there the results of numerical and analytical investigations on the behaviour of the reflected pressure impulse from the flat stiff obstacle were discussed. The analytical considerations are pursuant to the accessible literature

This case is identical with the explosion under a flat bottom of the tank-type vehicle or BWP. All the considered obstacles which are influence by the pressure impulse are similar to the construction of the vehicles used by Polish Army. As it was mentioned above, the numerical investigations were supported by analytical models from the scientific literature.

In the previous papers, the authors conducted the numerical and experimental investigations on the flat blast wave. Those papers concentrated on the selection of the Euler domain parameters and parameters describing an explosive charge for numerical analyses. Additionally, the parameters of the boundary elements of the Euler domain were selected in order to unable the uncontrolled influence of gases.

The innovation presented in the paper is the description of the issue of the numerical problem of multiple pressure impulse reflection from a rigid obstacle. The presented papers aim at increasing the safety of the military vehicles crews during the stabilisation missions in Iraq and Afghanistan.

Keywords: *pressure impulse, analytical model, FE analysis, influence of the obstacle on the reflected wave*

1. Introduction

Many authors dealt with the blast wave's propagations problems in the continuum medium. Contemporary papers developed by such scientists as: Redwood [1], Kaliski [2], Włodarczyk [3], Malecki [4], Siepanow [5], Łęgowski and Rafa [6], Berker [7], Borkowski [8] include information on this subject.

The present paper deal with numerical implementation of the phenomena described in the above mentioned papers. General formulating of the problem is based on the fact that a blast wave generated by a source placed in any point of space propagates in the fluid (air) and interacts on the considered object. In analytical investigations the Taylor-Sedov theory was used with energy E_o determined on the base of the known mass of charge W and explosion heat Q. An example of the contact type explosion is presented in Fig. 1. The contact occurs on the boundary between ground and air.

During analyses of the phenomenon of blast waves propagations the following simplifications are assumed:

- a blast wave is considered as a flat one, characterised by a normal vector,
- a construction element is assumed as a flat and rigid one,
- a problem is considered as stationary one, that is, all the surfaces of discontinuity constitute planes, and a flow in each area limited by these discontinuities is homogenous.

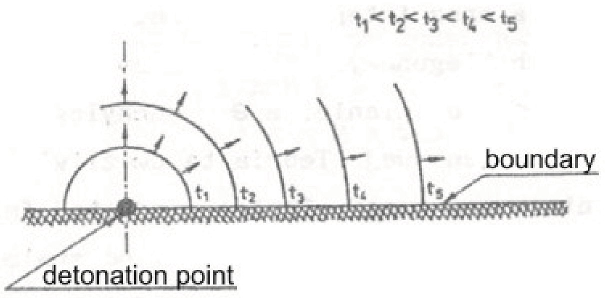

Fig. 1. Initial pressure wave originated as the result of the explosive material detonation [6]

Each of the analysed blast waves is reflected from the examined construction or ground surface. According to the authors of above mentioned papers, these surfaces are considered as rigid partitions. In the case of a deformable partition, the solution of the above mentioned problem is possible only through applying numerical methods.

During the examination of the reflection phenomena, we can distinguish:

- reflection of a flat perpendicular wave from the stiff partition,
- interaction of a flat wave falling on the stiff obstacle with an angle different then 90^o,
- Mach-type reflection,
- multiple reflection.

2. Reflection of a flat perpendicular wave from a stiff obstacle

The simplest case of reflection is regular reflection of a blast wave from a stiff obstacle. This phenomena is presented in Fig. 2.

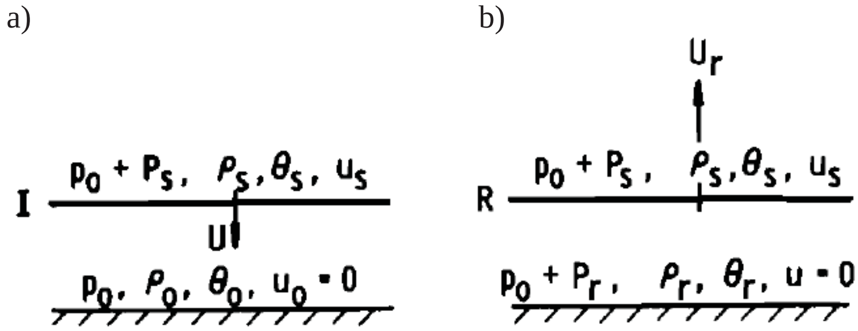

Fig. 2. An example of reflection of a flat wave falling on the stiff obstacle

Figure 2a presents the flat wave falling on the stiff obstacle immediately before reflection and Fig. 2b presents the flat wave immediately after reflection. In the first case, the pressure impulse moves in the area of undisturbed air with velocity U (all physical quantities describing undisturbed possess index 0). Fig. 2b illustrates the wave after reflection from a stiff partition. The reflected wave moves out of boundary with velocity U_r. Due to a momentum conservation pressure, density and temperature of the reflected wave are greater than the values of the falling wave. Pressure of a reflected wave P_r for a very weak incident waves is twice as much strengthened. An eightfold increase of reflected pressure values for a perfect gas occurs for stronger waves. Some sources state that pressure increases even 13-20 folds for a real gas. To sum up, the essential feature of a perpendicular reflection of a flat wave is strengthening of a reflected pressure impulse. This feature is applied to constructional calculations in compliance with norms.

3. Reflection of a flat wave falling on a stiff obstacle with other angle

The broad case describing these phenomena is reflection of a flat wave falling on the stiff obstacle with other angle than 900. During regular reflection the influence of the wave on the construction is reduced to the analysis of reflection of stationary blast wave from the stiff partition (wall). The angle of falling αI is essential in this case.

In the variability range of angles of falling (0, π/2) there is a certain boundary value αI = αgr which divide the reflection problem into so called regular and irregular reflections for angles αI > π/2, we will assume that a given element of the construction is placed in the area of so called geometrical pressure and the reflection phenomenon doesn't occur on it. In the scope of regular reflection αI = αgr a falling wave and a reflected wave always cross on the construction surface (Fig. 3). In the scope of irregular reflection for angles αgr <αI ≤ π/2 the crossing point of a falling wave and a reflected wave moves back for a certain distance from the wall.

The regular reflection of a blast wave from a stiff partition is illustrated in Fig. 3.

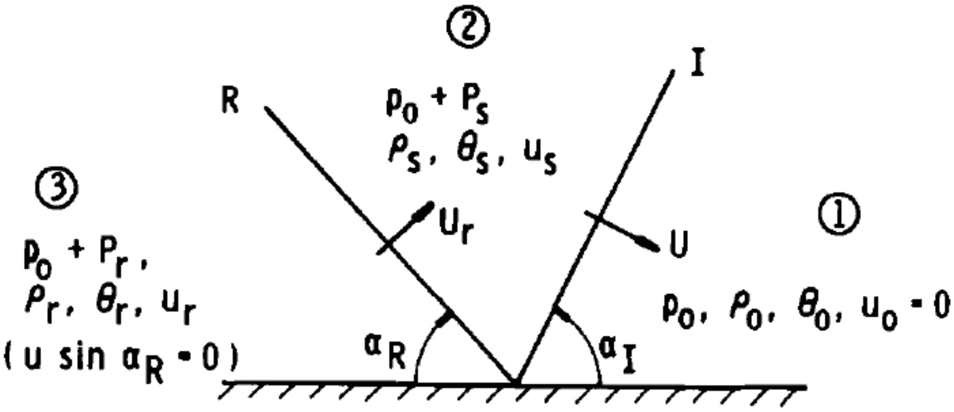

Fig. 3. The wave configuration near the wall in the scope of regular reflection [7]

Figure 3 illustrates the three areas describing regular reflection. The first area is undisturbed. In this area, the boundary surface with velocity vector U creates falling angle αI. Area 2 describes a falling wave and 3 describes a reflected wave.

A certain critical angle related from gas constant γ occurs for strong waves. In the case of value γ = 1.4 the regular reflection takes place for angle from 90 to 39.97 degrees.

4. Mach-type reflection

The other important phenomenon is Mach-type reflection. It was described in 1877 by Ernst Mach and was observed during huge charges explosion.

It is generated in the case of blast wave reflection from the ground surface. The reflected wave moves as the second front of the blast wave and it can do similar damages as the initial wave. Due to the fact, that the passage of the first front of the wave causes the change of gas properties (temperature, pressure, etc.), the reflected wave moves with a greater velocity than the initial wave and often catches up with it. When the faster wave catches up the first wave they interact and originate a flat wave perpendicular to the reflection surface. The pressure value of a new wave is greater than pressure of component waves.

This phenomenon the fastest occurs the closest to the reflected surface, however, along with the time and distance course such a strong single wave can be a few kilometres high. This wave is also called Mach column (Fig. 4).

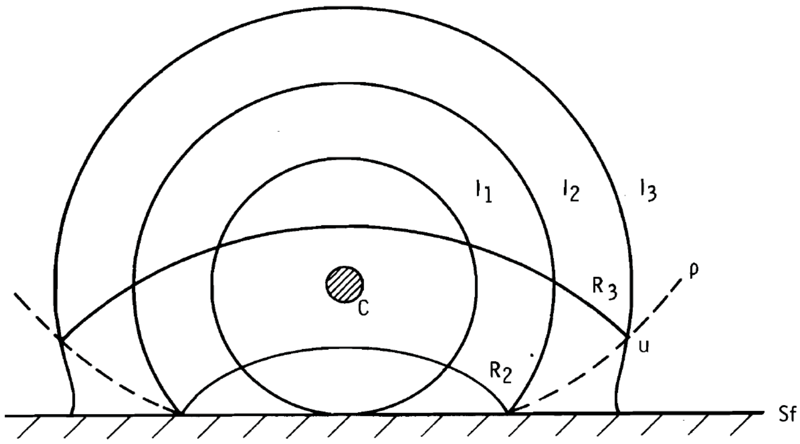

Fig. 4. Reflection of waves generated by detonation of strong charges from a rigid obstacle [7]

Superposition of waves creates a Mach wave is presented in Fig. 5. The Mach wave, as it was mentioned before, originates as a result of superposition of two waves: falling I and reflected R. The Mach waves is determined by crossing point T of the above mentioned waves and a straight line passing through this point perpendicular to the reflected surface.

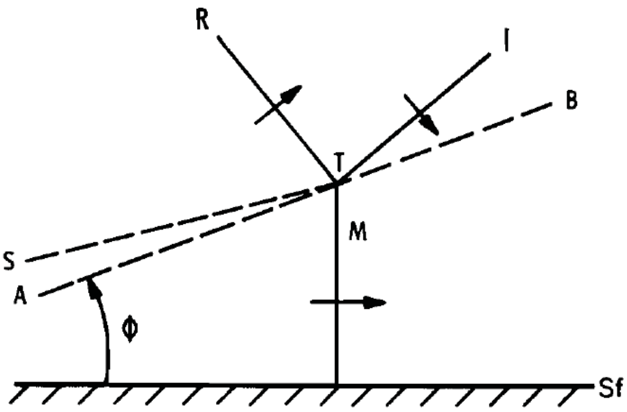

Fig. 5. Mach-type reflection [7]

5. Multiple reflection

The analytical analysis of the multiple reflection phenomena is a very complex issue. For a spherical wave spreading in the air and interacting with the construction some simplifications must be done.

Accessible literature [6] assumes that the object surface is a plane parallel to the ground located in distance h An additional assumption is that reflection initially has a regular character (Fig. 6).

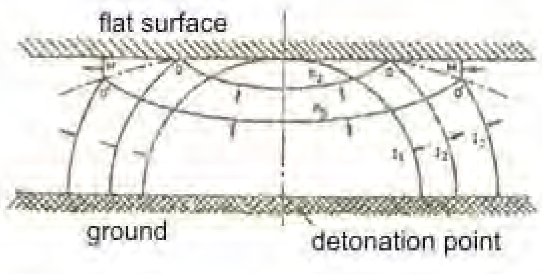

Fig. 6. The reflection of a spherical blast wave from a flat surface [6]

After some time, a reflection phase comes into an irregular case (during the wave propagation its falling angle grows). At results, the wave's configuration becomes more complicated.

A method of a mirror image was used during analytical consideration. It was assumed that reflected blast wave front coming from the point source, which is a mirror image of the real. The reflection face is the mirror surface.

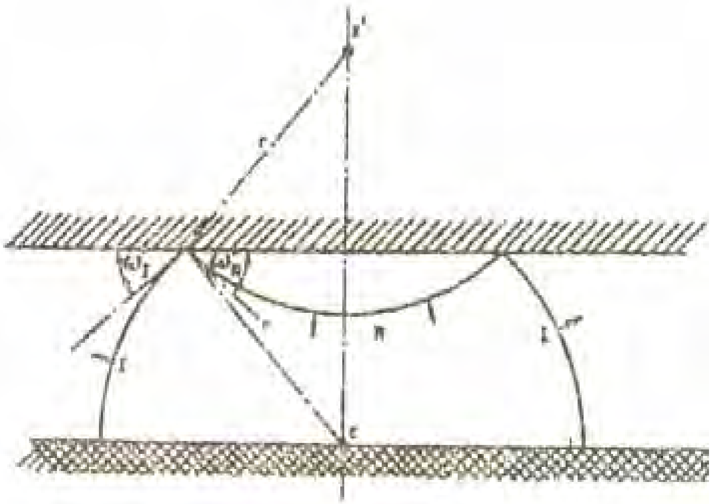

Fig. 7. Constructing the reflected wave front [6]

The apparent source, assumed in such a way, fulfil the fundamental feature of reflection of a spherical wave (an incident angle equals to a reflected angle).

Fig. 8 presents the propagation of the initial wave along the plate of the object bottom (of a mechanical system: ground – vehicle – explosive charge) as well as the front of the subsequent blast waves. The figure presents a typical wavy image of motion at the selected moment of time. From the given geometrical relations, it can be seen that in the fixed moment of time the radiuses of all the reflected waves are identical and equal to the radius of the initial wave.

The accessible literature [6] presents the results of the test calculations for the mine explosion containing an 8 kg charge and channel high 0.5 m. For the analytical investigations it was assumed that the explosion takes place in the dry air of isentropic index $\gamma = 1.4$.

The obtained pressures distribution on the object surface in the function of distance from the explosion epicenter for a few time moments is presented in Fig. 9.

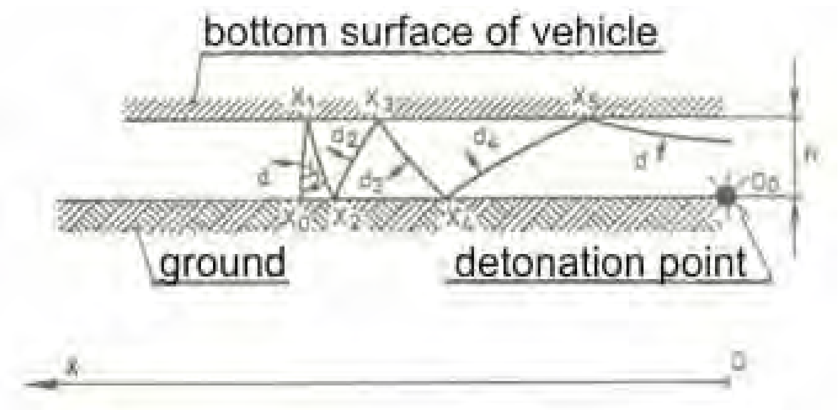

Fig. 8. The fronts of the subsequent blast waves

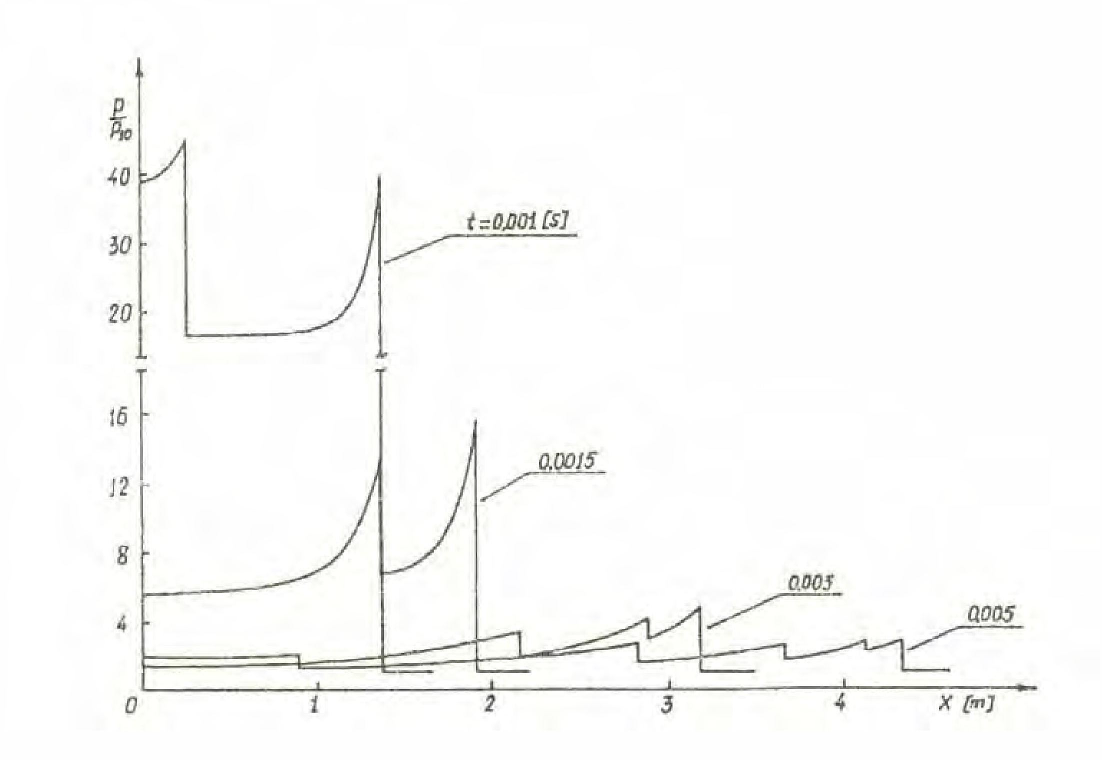

Fig. 9. The pressures distribution on the construction surface in the function of distance from the explosion epicenter, charge – 8 kg, channel height – 0.5 m

6. Numerical approach to the problem – a general description of numerical models

The numerical analysis was conducted for the example analytically considered and described above.

The pressure wave induced by detonation (simulated in approximation of instantaneous detonation) was propagating in the cubic - shaped area with given proper boundary conditions. A theoretical solution of propagation of strong spherical shaped discontinuity, initiated from the point source, exists in the form of analytical equations of the Taylor similarity which after transformation can be written as [9]:

$$p(r) = 0.155\, E_o\, r^{-3},$$

where:
E_o - initial internal energy,
r - current sphere radius.

It allows the computer simulation of the propagation process of a blast wave through giving the proper initial conditions (density, energy, pressure) to the certain selected elements from the Euler domain and the solution of conservation laws of mass, momentum and energy. Typical values for explosive substances are: density – 1600 kg/m3 and specific internal energy – 4.2 MJ/kg.

In the calculations, the blast wave was modelled with the use of Euler elements type Hex 8 characterised by ideal gas properties of $\gamma = 1.4$ and density corresponding to the atmospheric air density in regular conditions ($\rho = 1.2829$ kg/m3).

A general view of the model of the system with limited surfaces of the outflow ("channel") is presented in Fig. 10. The interested values were presented for cells marked with symbols A, B, C, D.

The case with the free outflow from the Euler area ("explosion") was additionally analysed.

In all models used in the present paper, no initial conditions were imposed on the nodes of structural elements. It means that all velocities and displacements for time t = 0 were zeroed. The size of the mesh elements was selected on the base of the previous numerical works [10].

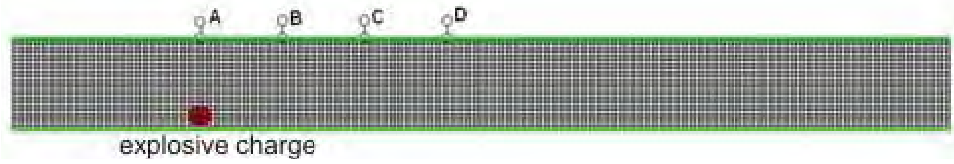

Fig. 10. A draft of a numerical model of a considered example. Green thick lines designate the surfaces limiting the gases outflow. Points A, B, C, D designate Euler cells in which the pressure values were charted

7. Results of numerical analysis

As a result of numerical analysis the pressures graphs and maps were obtained. At the first stage of the numerical analyses, the model was loaded with the pressure wave coming from detonation of the explosives. Fig. 10 presents the initial character of the pressure wave propagation for times 4 σs. In the initial period, the pressure impulse generated by an explosive charge interacts with the obstacle (lower wall) and reflects from it additionally, as a result of superposition of the falling wave with the reflected wave, the strengthening of the Mach-type pressure impulse occurs.

Fig. 11. The initial pressure impulse

Figures 12 and 13 present the strengthening of the pressure impulse through the reflection from the upper wall and the further wave propagation.

The interesting comparison of the pressure values in points A-D is presented in Fig. 14 and 15. In the first case, the blast wave propagated in the fluid without any limits. In such situation the maximum pressure values in points A-D are smaller by half than in the case of ”channel” (with the limited outflows).

8. Conclusion

The paper presented the results of researches into the phenomenon of the reflection of the pressure wave with the special consideration into the multi-reflection of the wave from an rigid obstacle. The discussed analytical solutions (accessible in literature) allow describing the phenomenon based on the assumption that the pressure impulse reflects from the unmemorable obstacle. In the case of a susceptible partition the analytical methods can bring incorrect results. In such a case it is necessary to apply numerical method like the finite elements method.

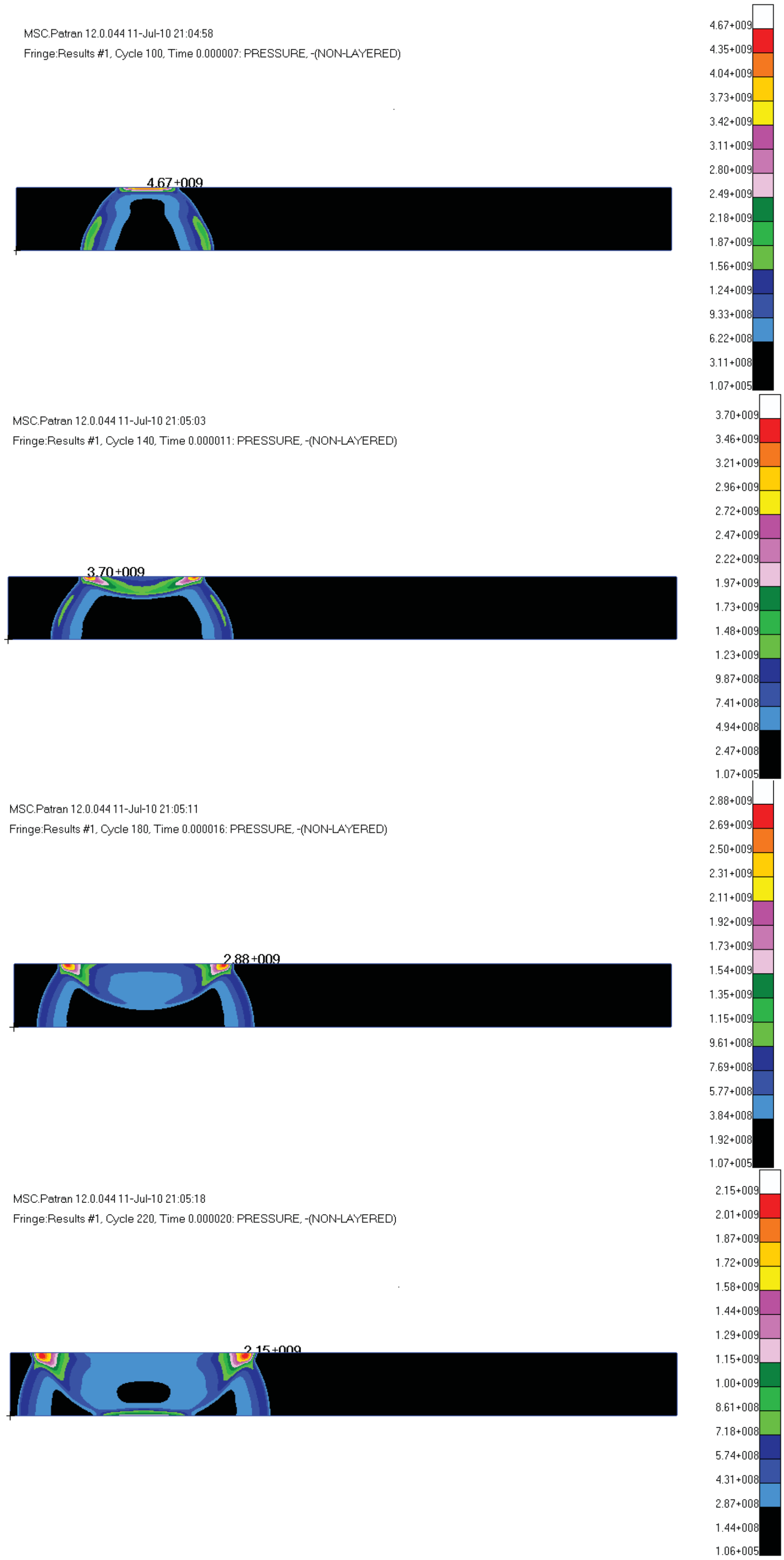

Fig. 12. Strengthening of the pressure impulse reflected from the upper wall and the further wave propagation

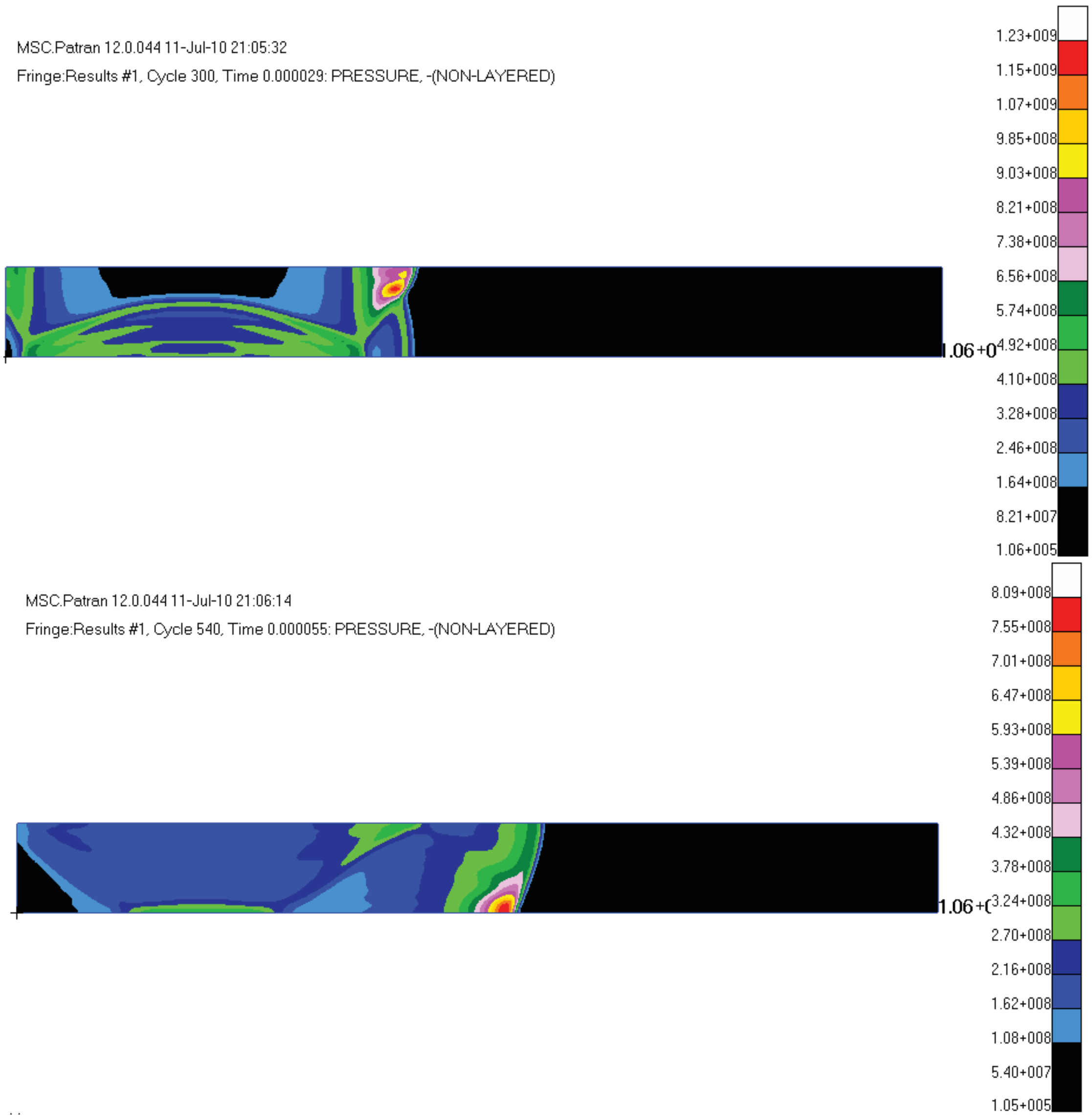

Fig. 13. Subsequent phases of multiple reflection of the pressure impulse

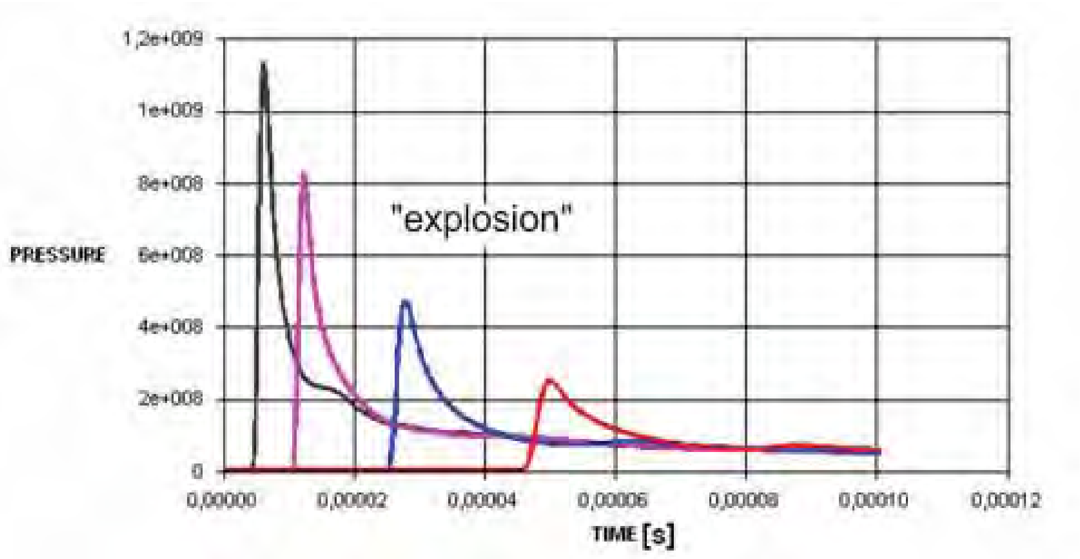

Fig. 14. The pressure of the free wave

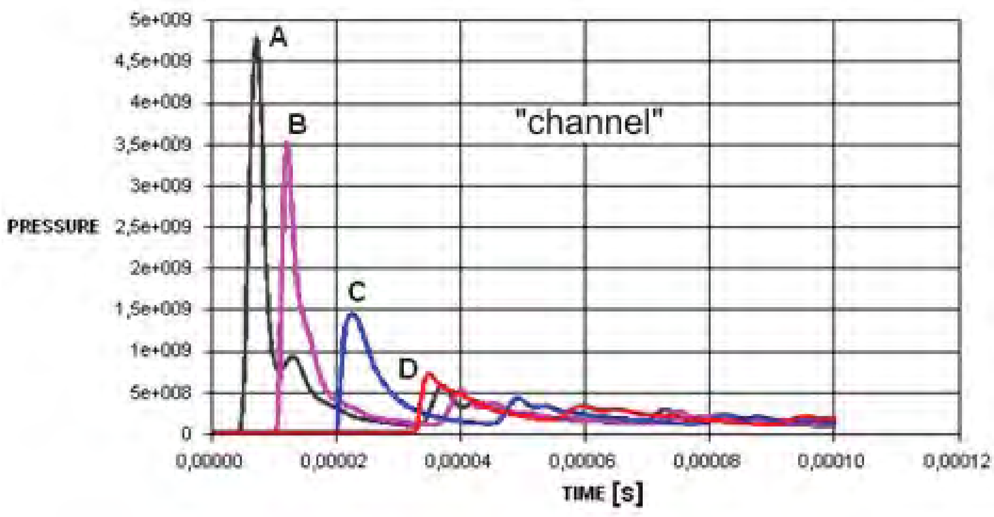

Fig. 15. The pressure of the multiple reflected wave

Acknowledgements

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