NUMERICAL ANALYSIS OF INITIAL AND BOUNDARY CONDITIONS INFLUENCE ON THE CREW OF TRACKED VEHICLE AND THE GROUND

Wiesław Barnat, Robert Panowicz
Tadeusz Niezgoda, Paweł Dybcio

Military University of Technology, Faculty of Mechanical Engineering
Department of Mechanics and Applied Computer Science
Gen. S. Kaliskiego Street 2, 00-908 Warsaw, Poland
tel.+48 6839849, 683 9849, fax: +48 6839355
e-mail: wbarnat@wat.edu.pl, rpanowicz@wat.edu.pl

Abstract

The problem of vehicle's impact resistance is broadly discussed in many articles and standardizations concerning special structures. In this paper, the numerical analysis results of an armoured vehicle loaded with blast wave are presented. Effects of ground proximity such as wave reflection are also taken into account. What is more, the tracking system was also included in calculations.

The ground was modelled using Mie-Grüneisen equation of state. In the research an ALE coupling algorithm was used to model interaction between fluid (Euler domain) and structure (Lagrange domain). Euler description is used for air and blast wave propagation modelling, whereas structure is described by Lagrange equations of mass, momentum and energy conservation. The ALE coupling algorithm is implemented in MSC Dytran software. The problem was solved using explicit integration of movement equations over time.

The research showed that ground and wheels considerably affect the simulation results. The pressure impulse on the vehicle's bottom increased by 40% compared to the model in which these effects were not considered. Furthermore, the quality of the results increased as the solution obtained is more physical. Proposed method is a useful tool in hull design process. As well as that, the method will be further developed to include more detailed model of the vehicle.

Keywords*: hull design, tracked vehicle*

1. Introduction

High mobility in all terrain and weather conditions is one of the most significant features of the light armoured vehicles. As well as that, such vehicles have good independence, setting them as a primary military equipment to be used by stabilization forces of many countries. However, they are exposed to many threats among which are improvised explosive devices (IEDs). As a consequence, contemporary technical and tactical requirements put strong emphasis on proper layout of the hull in order to provide a good cover for the crew. Such a layout consists of:

- hull geometry ensuring sufficient ballistic protection level,
- crew and equipment protection from different classes of explosives (different types of mines, mass of explosives, placement under the vehicle).

One of the main problems in structure design is to provide effective protection for the crew and external equipment [1], especially against Improvised Explosive Devices (IEDs).

The contemporary development of numerical methods and computational capabilities allows modelling many physical phenomena. As well as that, steady progress of passive protection techniques [2, 3] goads the research into new design solutions. This goal can be achieved with both physical and numerical experiments. One of the most difficult problems is to simulate the blast wave multiple reflections between the flat bottom of the vehicle and the ground. An example of wave reflection is depicted in Fig. 2.

Fig. 1. An example of IED detonation under different vehicles [US ARMY photo]

Such a reflection results in the creation of a Mach's wave. It arises from intersection of incident and reflected wave (point a in Fig. 2). Reflected wave propagates as secondary wave front and can do similar damage as the primary, however, it moves in other, usually the opposite, direction. Since the propagation of primary wave changes the properties of the gas (density, temperature), the reflected wave is able to move faster than the primary wave. Quite often the secondary wave catches the primary wave and the overpressures of each wave sum up. As a result, single strong wave arises. Firstly, the described phenomenon occurs in ground proximity but if the conditions allow further propagation such a wave can be a few kilometres high. The wave is flat and perpendicular to reflecting surface. Mach waves are rare phenomena and have been used in strong nuclear explosions to enhance destructive power.

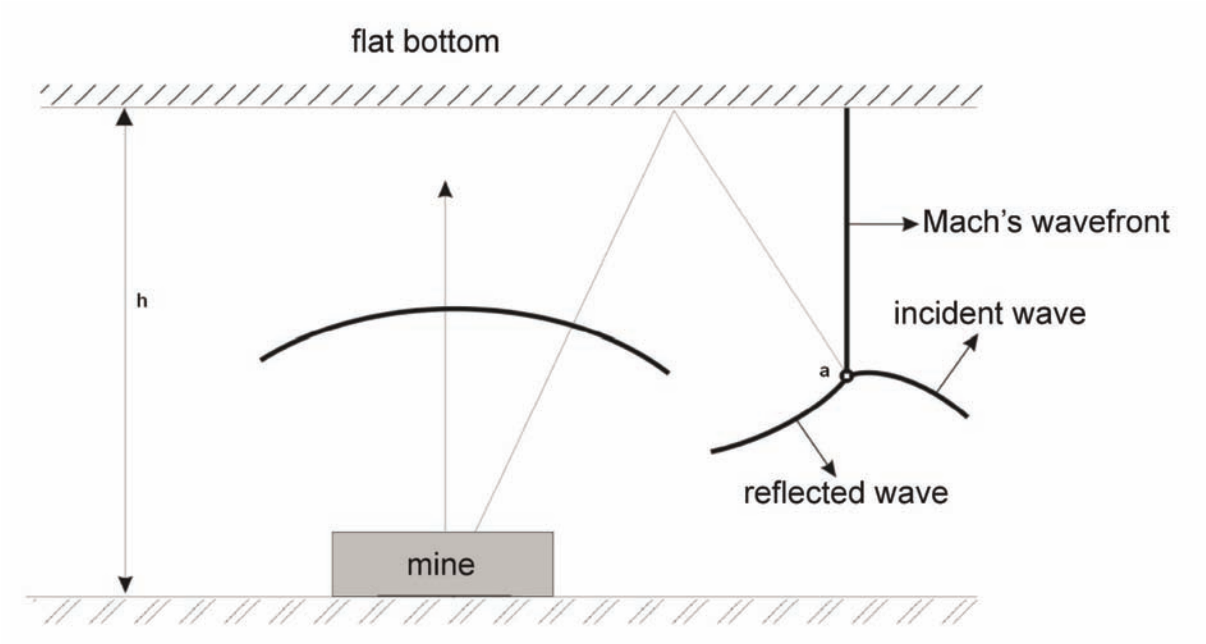


Fig. 2. Wave reflection from vehicle's bottom

Another phenomenon that complicates the right evaluation of the explosion effects is the strengthening of the incident wave by the reflected one. Depending on the obstacle stiffness [6, 8] the amplification can be up to ten times. In 1970 Richmond presented a relation between incident and reflected pressure. That dependence is depicted in Fig. 3 and Fig. 4.

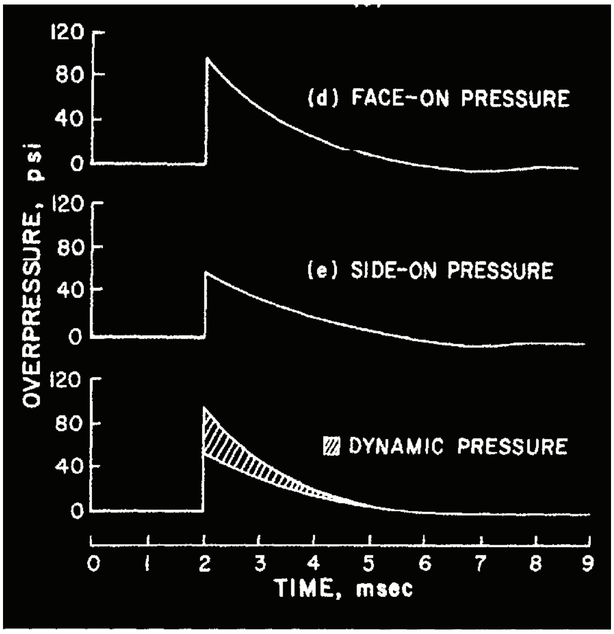


Fig. 3. Static and dynamic pressure for near ground explosion [D. R. Richmond 1970]

Figure 4 depicts pressure impulse of incident and reflected waves obtained numerically [11]. Overpressure can be observed (Dpc > Dpo) which means that wave front pressure is higher that in the surrounding domain. Both analytical calculations and numerical results shown in Fig. 4 confirm, that the reflected wave's pressure is 5 times higher that the free wave.

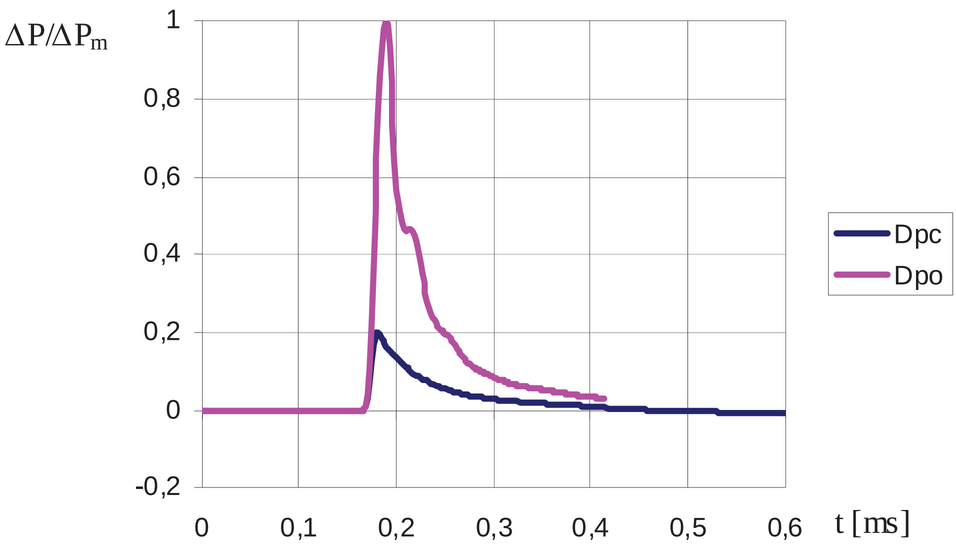


Fig. 4. Comparison of pressure impulse of free wave Dpc and reflected wave Dpo for 125 g TNT charge

Important factor that should be taken into consideration is the material model of the ground, as it has an influence on the shape and the size of the crater. This topic is discussed in the literature. Some authors consider the crater as another factor affecting the pressure impulse, while others treat them as a way to dig hidings. Both approaches conclude as a tabulated relation between the crater type/size and used explosive [10]. Typical crater is depicted in detail in Fig 5. Due to all the effects mentioned above, the standardization NATO STANAG 4569 describes the test of anti-tank mine resistance with the explosive placed on a concrete base preventing the change of the pressure impulse by ground deformation.

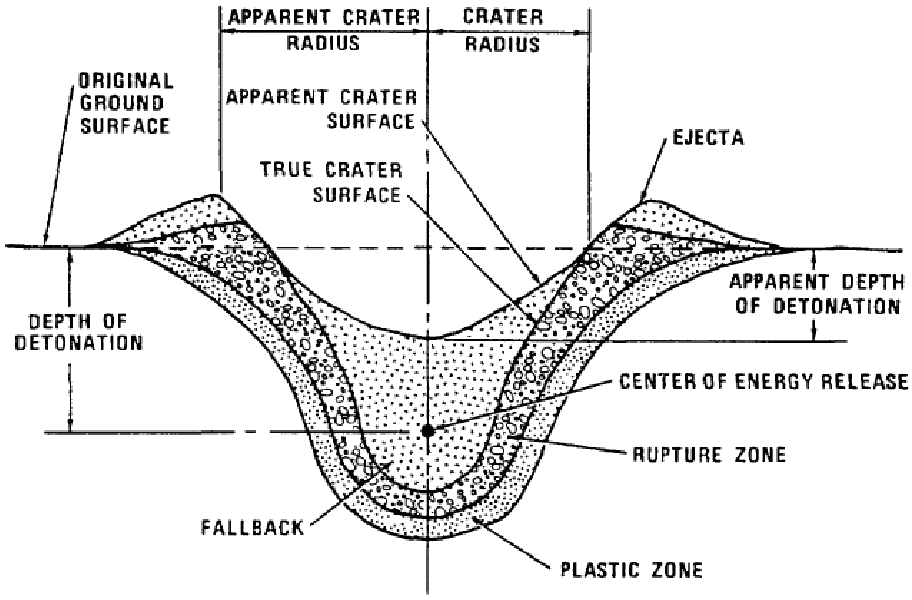


Fig. 5. Crater scheme [Kinney and Graham, 1985]

In this research, an ALE coupling algorithm was used to model interaction between the fluid (Euler domain) and the structure (Lagrange domain). Euler description is used for air and blast wave propagation modelling, whereas structure is described by Lagrange equations of mass, momentum and energy conservation.

The process of detonation and blast wave propagation is a complex problem. It forced the development of special computational techniques that are discussed in the literature [4, 5, 6]. During this study, a uniform integration scheme of movement equations for both fluid and structure is used. The aim of the research was to investigate the ground model influence on results of numerical analysis.

2. Numerical model

The numerical analysis was conducted using numerical model of a hull of a tracked vehicle (light tank) loaded with blast wave from detonation of a large explosive. The pressure wave caused by the detonation (modelled as a point-source detonation) propagated in cubic shaped domain. Such an approach allows simulating the process by applying proper boundary and initial conditions (such as density, energy and pressure) to selected Euler cells. Then, the conservation equations can be solved. Typical values for explosives used in the calculation are density – 1600 kg/m^3 and internal energy - 4,2 MJ/kg.

In the calculations, the changes caused by hull deformation were also considered. What is more, the transmission system (wheels) was also included in the analysis. Layer in which the blast wave propagated was meshed using Euler elements type HEX8. They are characterized by properties of air in standard conditions: $\gamma = 1,4$ and density $\rho = 1,28$ kg/m^3. Ground was modelled with Mie – Grüneisen equation of state with the following parameters: $\gamma = 2$, density $\rho = 2,35 \cdot 10^3$ kg/m^3. An assumption was made that beneath the ground there was a solid (rigid) rock. Hull was modelled using Lagrange elements type Shell Quad 4 with properties as follows: $E = 2,1 \cdot 10^9$ MPa, $\nu = 0,31$. Material model used in the simulation was bilinear elastoplastic DYMAT 24. A maximum strain failure criterion was used [7].

Preliminary material tests were conducted in Department of Mechanics And Applied Computer Science in order to obtain mechanical properties of armour steel. Subsequently, the full size vehicle model was developed. Model section is depicted in Fig. 6.

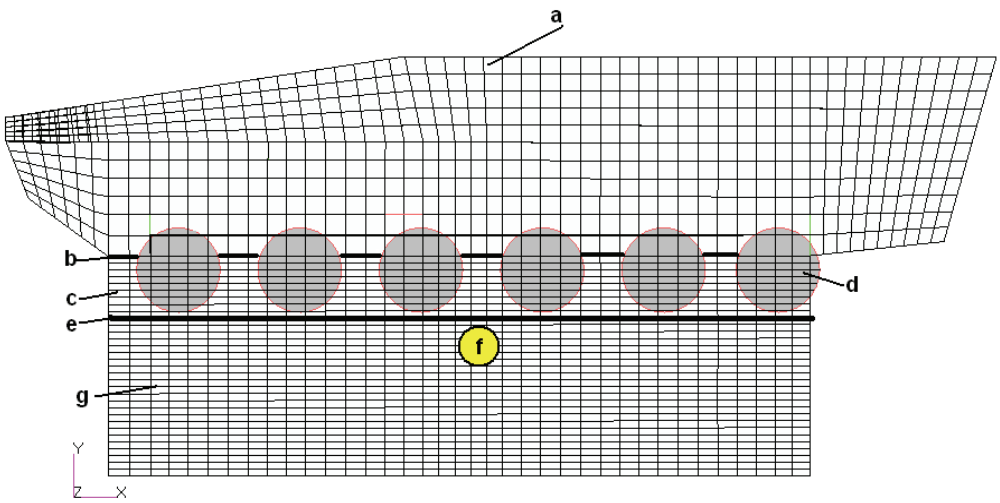


Fig. 6. Scheme of analyzed vehicle: a – hull, b – ALE coupling surface, c – air area, d – wheels, e – border of two domains, g – ground, f – explosive

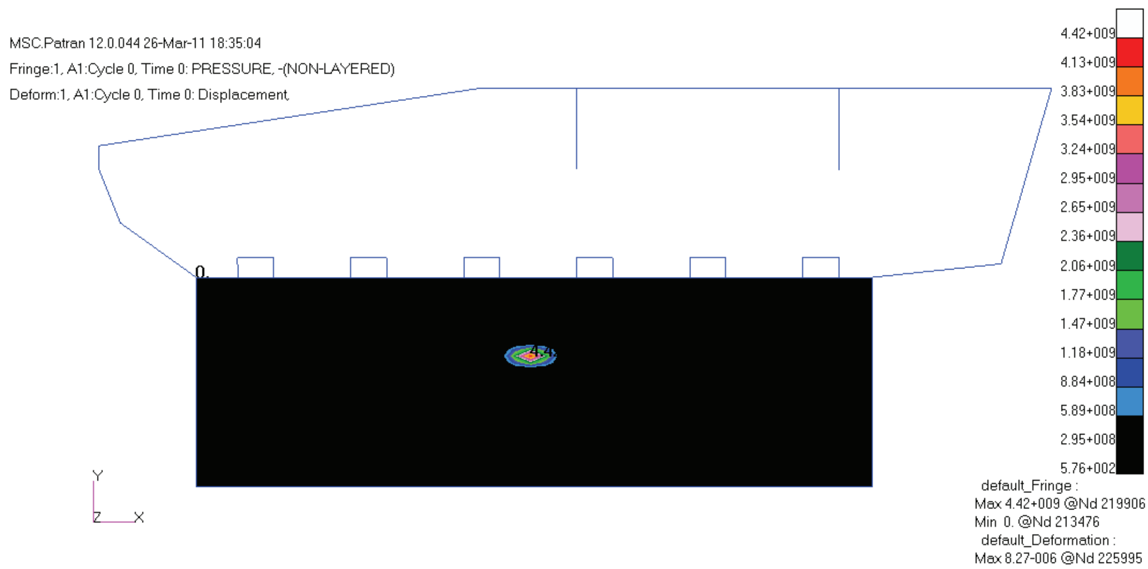
In all considered models there were no initial conditions applied to structural nodes. This means, that initial velocities and displacements for those nodes were equal to zero.

The military tests of armoured vehicles are conducted according to the NATO STANAG 4569 standardization. One of possible tests of mine resistance is the detonation of TM–57 anti-tank mine containing 6,34 kg of TNT. However, mass of explosive material in IEDs greatly exceeds the mass of explosive used in mines. Therefore, in the simulation a few models were loaded with larger charges that the standard TM-57 mine are considered Most of the tests were conducted, however, for charge equal to TM-67 mine.

3. The results of the numerical analysis

In the analysis the vehicle was loaded with the detonation blast wave larger than produced by TM-57 mine. The charge was placed under the vehicle's centre. Other possible charge localizations were also considered. As a result, graphs of displacements, accelerations and velocities of selected points were obtained. Figure 7 presents distributions of pressure (a) and densities of ground and air (b) for the time t = 0s.

(a)



(b)

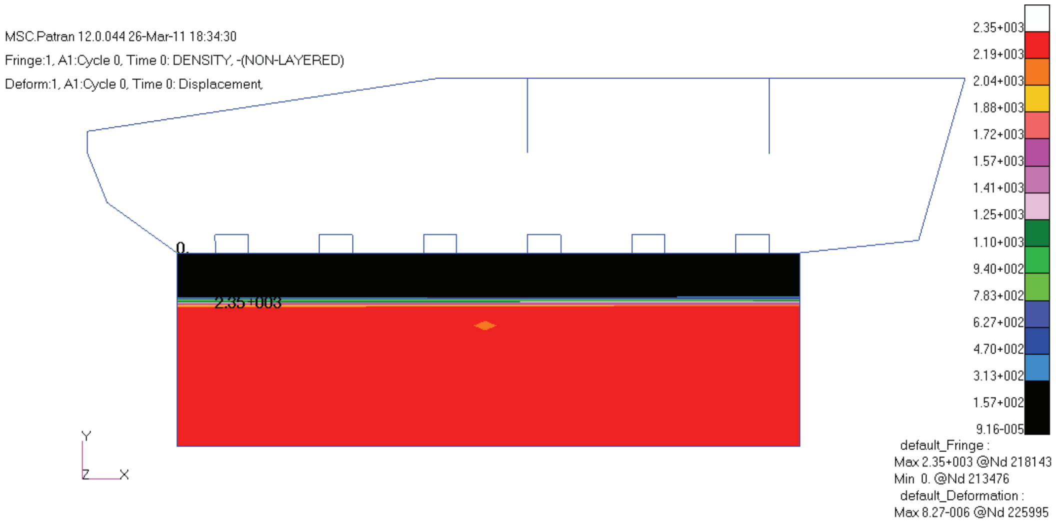
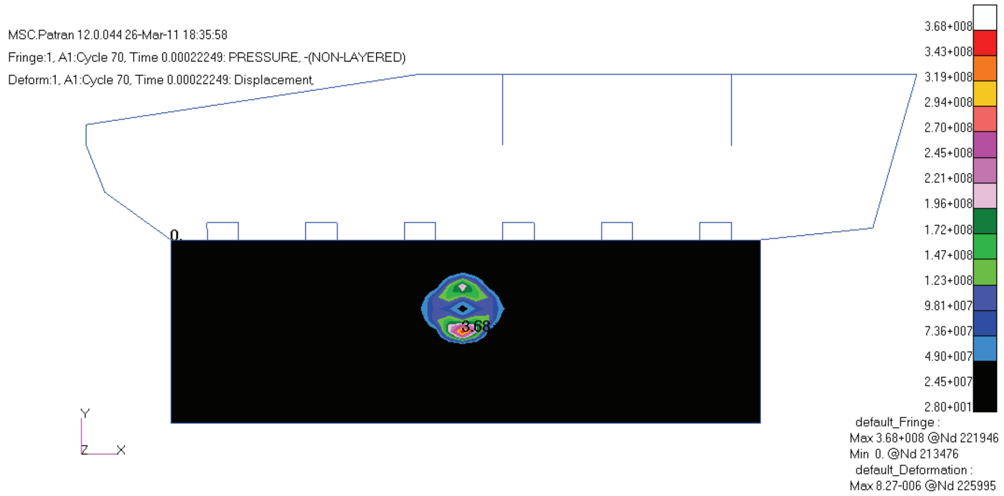


Fig. 7. Pressure distribution (a), density distribution (b)

(a)



(b)

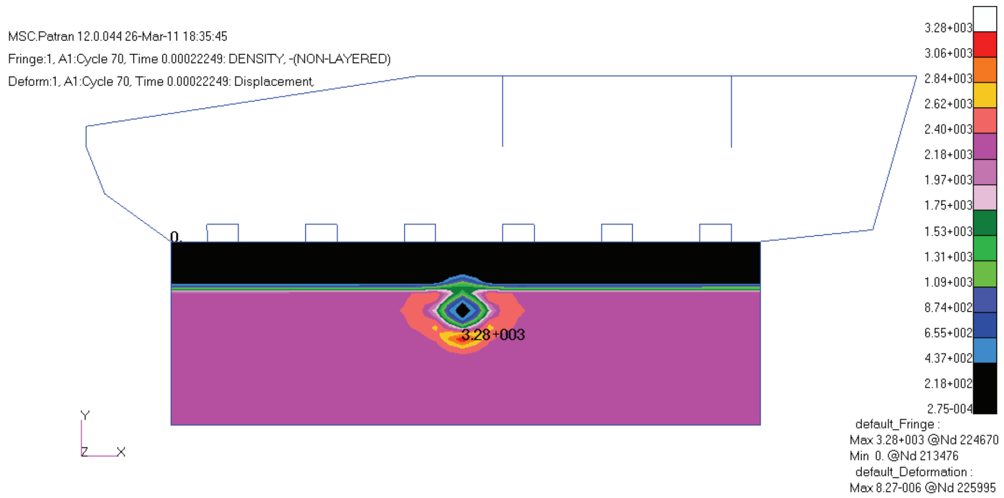


Fig. 8. Pressure distribution trough section of the vehicle (a), ground and air density (b) for the time t = 0.00022 s

Figure 8 depicts pressure and density distribution in symmetry plane section for the time t = 0.00022 s. The pressure value for the ground is slightly higher than for the air. It is due to the fact that these domains have different density. Figure 9 shows pressure and density distribution for the time t = 0.00051 s. As well as in Fig. 8, pressure in the ground is higher than in the air. Crater creation process is also visible.

(a)

(b)

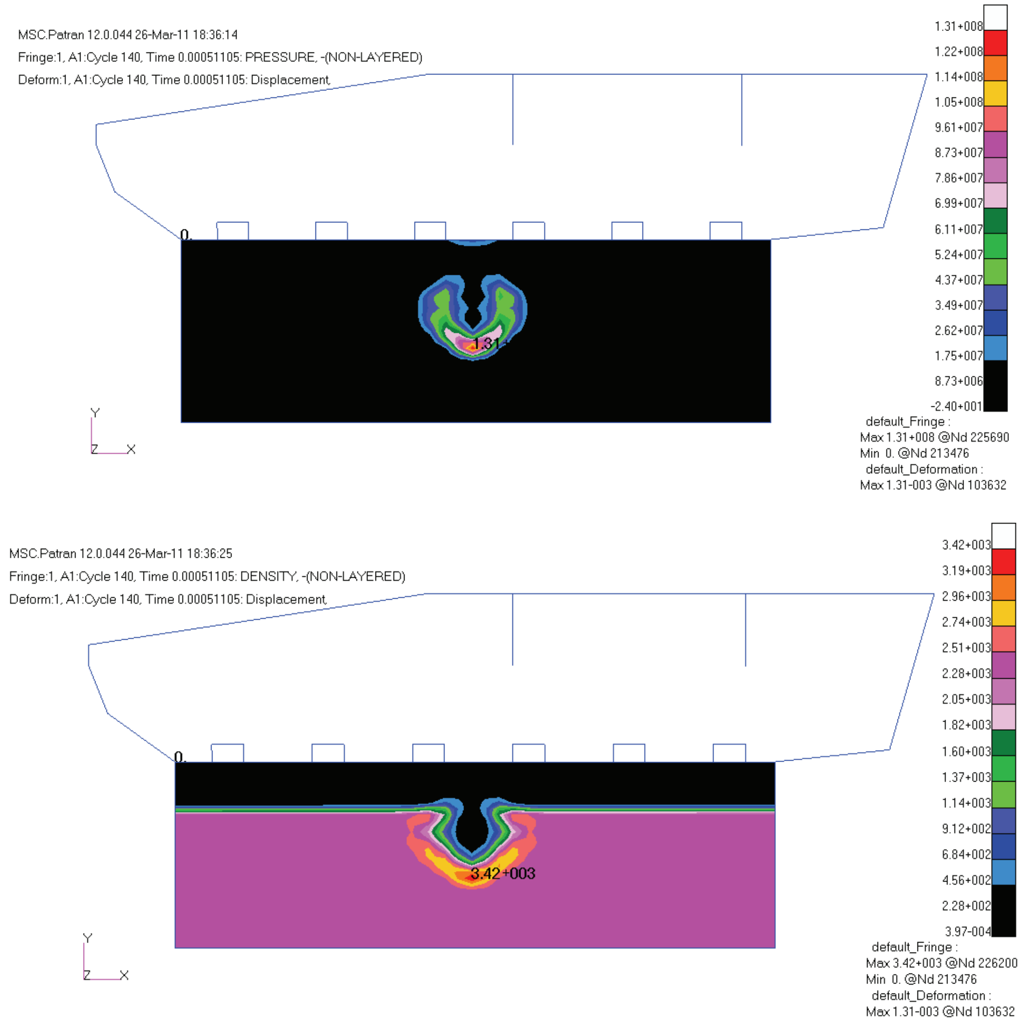


Fig. 9. Pressure distribution trough section of the vehicle (a), ground and air density (b) for the time t = 0.00051 s

The crater enlargement process is visible in Fig. 10. The influence of the wheels is shown in Fig. 11. The picture shows the difference of density resulted from pressure impulse propagating in the ground and unsettled pressure outflow through drive system.

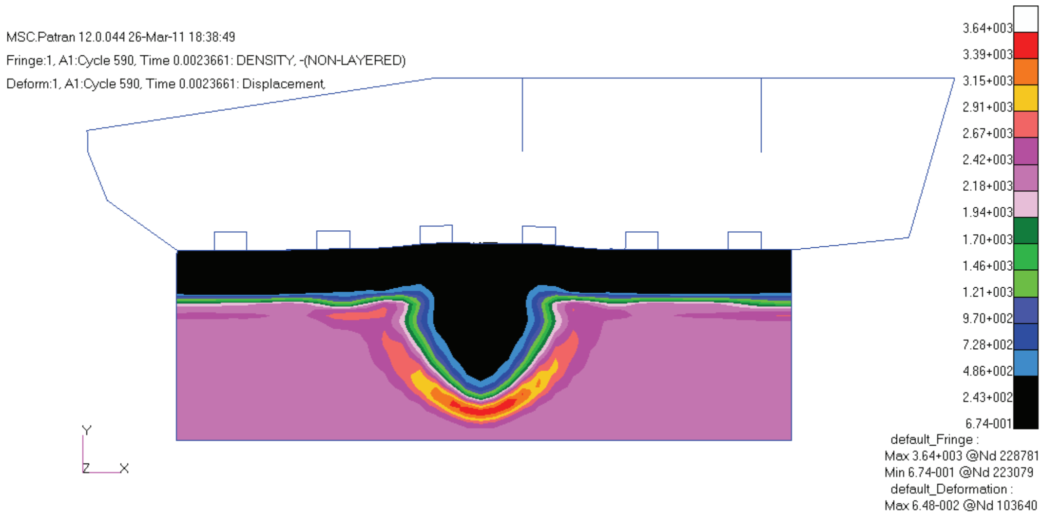


Fig. 10. Pressure distribution trough the symmetry plane section of the for the time t = 0.00236 s

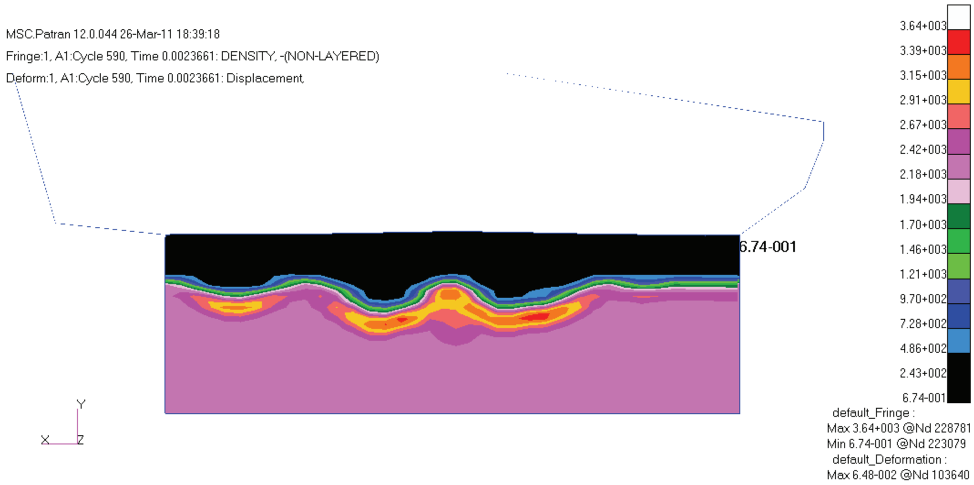


Fig. 11. Pressure distribution through right side section of the vehicle for the time t = 0,00236 s

4. Conclusions

The aim this study was to examine how inclusion of ground model affects the simulation of large explosive loading a structure of armoured vehicle hull with blast wave. What is more, wheels were also included in the model. The results showed, that adding the ground model to the simulation enlarged the impulse on the vehicle, resulting in 40% greater displacement of the bottom node. Furthermore, the ALE coupling method caused that all the explosion energy was transferred to the structure [11]. Both such coupling and taking into account the ground reflection effects have a significant effect on the quality of the results.

Because the mesh shape influence on the simulation of detonation front is rather small, in the analysis cubic mesh with sufficient cell size was used. The pressure wave caused by the detonation (modelled as a point-source detonation) propagated in cubic shaped domain. Theoretical solution of non-linear spherical wave front exist as a Taylor equation [9, 10].

Additional material study of armour steel was conducted in Department Of Mechanics And Applied Computer Science, Military University of Technology, in order to obtain suitable material model.

References

[1] Barnat, W., *Transporter Opancerzony Adi Bushmaster*, Myśl Wojskowa, 5/2005.

[2] Trzciński, W., Trębiński, R., Cudziło, S., *Investigation of the Behaviour of Steel and Laminated Fabric Plates Under Blast Wave Load*, Part I, Experimental Approach, V International Armament Conference, Waplewo 2005.

[3] Krzewiński, R., Rekrucki, R., *Roboty budowlane przy użyciu materiałów wybuchowych*, Polcen 2005.

[4] Thornton, P. H., Jeryan, R. A., *Crash Energy Management in Composite Automotive Structures*, International Journal of Impact Engineering, Vol. 7, No 2, pp. 167-180, 1988.

[5] Babul, W., *Odkształcanie metali wybuchem*, WNT, Warszawa 1980.

[6] Włodarczyk, E., *Wstęp do mechaniki wybuchu*, PWN, Warszawa 1994.

[7] Dytran Theory Manual, 2004; LS-DYNA theoretical manual, 1998.

[8] Ls_Dyna Theory Manual, Livemore, CA, 2005.

[9] Baker, W. E., *Explosions in Air*, University of Texas Press, Austin and London 1973.

[10] Instrukcja „*Prace inżynierskie i niszczenia*”. Sztab Generalny WP, Szefostwo Wojsk Inżynieryjnych, Warszawa 1995.

[11] Barnat, W., *Numeryczno doświadczalna analiza złożonych warstw ochronnych obciążonych falą uderzeniową wybuchu*, Bell Studio, Warszawa 2010.