Modelling explosions using ALE meshes: the influence of mesh refinement in pressures and in efforts induced by blast/structure interaction

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Abstract

Hydrocodes are becoming a very important tool for simulation of explosive loads and the interaction between the shock wave and possible structures stroked. Landmine explosions and the damage induced when they explode under an armoured vehicle are good examples of this. However this type of simulation usually requires very complex meshes, which must also be able to reproduce a large number of elements involved in the simulation, such as the explosive, the air, the wheels, the transmission…etc. Furthermore, the problem worsens if we take into account that very small size element meshes are required if we are looking for a good accuracy of the calculations, especially when we want a good approximation for the sharp pressure peaks that appear during an explosion. In this work, numerical results are presented from a research focused on the study of the mesh refinement influence in this type of problem. The study has been focused specially in two fundamental variables: time-pressure history and the time-integral of pressure with respect to time history.

Keywords: explosives, ALE meshes, mesh refinement and element size, pressure history.

1 Introduction

Nowadays, there is a very big concern about protection of vehicles against landmines explosions. The current scenario, with a wide expansion of peacekeeping forces on low intensity conflict areas involves a high risk of vehicle losses [1].
The Department of Materials Science of the Polytechnic University of Madrid, Spain, is collaborating in an International Research Team to develop an EUCLID project named "Protection of light armoured vehicles against mines" [2].

The analysis of the damage produced on a vehicle by a landmine explosion and especially the benefits obtained from different protection solutions involves a high experimental budget, since each test is very expensive. Numerical simulation is therefore a clever approach to reduce the required expenses of the research.

This paper summarizes the first numerical simulations of landmine explosions carried out at the Department, focusing on the influence of mesh refinement on the results.

2 Problem simulated

The problem simulated numerically is sketched in fig. 1. It corresponds to the explosion of a cylindrical landmine of 5.5 kg. of C4 explosive with a cylindrical confinement. The blast wave is propagating into the air, once the confinement being over passed. Only the region placed inside and above the confinement has been simulated as can be seen in figs. 2.

The top surface of the region is assumed to be impermeable to simulate the blast action on a plate placed there. Taking into account the symmetries of the problem, only one fourth of the body has been modelled. All numerical simulations have been performed with the commercial hydrocode LS-DYNA 3D version 960 [3].

3 Material properties

The body simulated includes two materials, the air and the explosive.
The air has been modelled by an equation of state of gamma kind:

\[ p = (\gamma - 1) \left( \frac{P}{\rho_0} \right) e \]  

(1)

where \( p \) is the pressure, \( \gamma \) is the adiabatic coefficient, \( \rho \) the actual density, \( \rho_0 \) the initial density and \( e \) the specific internal energy (internal energy per unit of mass). The following values of parameters and initial values were used:

\[ \gamma = 1.4 \]
\[ \rho_0 = 1.225 \times 10^{-3} \text{ kg/dm}^3 \]
\[ e_0 = 0.00025 \text{ GPa} \]

For the C4 explosive, the JWL equation has been used [4]:

\[ p = C_1 \left( 1 - \left( \frac{\omega}{r_1 v} \right) \right) e^{-n v} + C_2 \left( 1 - \left( \frac{\omega}{r_2 v} \right) \right) e^{-n v} + \left( \frac{\omega e}{v} \right) \]

(2)

where \( p \) is the pressure, \( v \) is the specific volume, \( e \) the specific internal energy and \( C_1, C_2, \omega, r_1 \) and \( r_2 \) are material constants that depend on the explosive type. Following [5], the values used for these parameters were:

\[ C_1 = 609.8 \text{ GPa} \]
\[ C_2 = 12.95 \text{ GPa} \]
\[ \omega = 0.25 \]
\[ r_1 = 4.5 \]
\[ r_2 = 1.4 \]
\[ e_0 = 9.0 \text{ GPa} \]

Other parameters used were: explosive density, \( \rho_0 = 1.6 \text{ kg/dm}^3 \); detonation velocity, \( D = 8193 \text{ m/s} \) and Chapman-Jouguet pressure, \( p_{CJ} = 28.0 \text{ GPa} \).

4 Meshes utilized

In all computations, ALE meshes (Arbitrary Lagrange Euler) have been utilized. All elements are hexaedrical with 6 faces, 8 nodes and constant stress, e.g. with one single integration point.

Five different element sizes have been used to analyze the influence of mesh refinement on the results. As can be seen in fig. 2, meshes used for both the explosive and the confinement were the same for all computations performed, because the aim was the analysis of mesh influence on the blast propagation into the air. If mesh sizes of explosive and air inside the confinement were also changed, other parameters like detonation times and reflections inside the confinement would be affected. By keeping these meshes unaltered, the only differences between all computations are the blast propagation into open air.
Figure 2: Different element height meshes used to model the problem: a) element height of 44.625 mm; b) element height of 14.875 mm; c) element height of 6.375 mm; d) element height of 3.75 mm; e) element height of 2.23 mm.
Figure 3: Pressure histories obtained with the different element height meshes: a) element height of 44.625 mm; b) element height of 14.875 mm; c) element height of 6.375 mm; d) element height of 3.75 mm; e) element height of 2.23 mm.
Figure 4: Integral of pressure with respect to time histories obtained with the different element height meshes: a) element height of 44.625 mm; b) element height of 14.875 mm; c) element height of 6.375 mm; d) element height of 3.75 mm; e) element height of 2.23 mm.
Also, since the main parameter of analysis is the pressure on the top surface of the air cylinder, the size of the upper layer of elements was kept constant in all computations, so that the integration point where stresses were determined was the same in all cases. The element in which pressures were recorded was that adjacent to the symmetry axis.

Taking into account all those requirements, the only possibility of mesh refinement was the change of element height. Therefore, five element heights have been used, that is 2.23, 3.75, 6.375, 14.875 and 44.625 mm. The size of the base of elements was slightly different but in all cases around 7.5 mm.

### 5 Numerical results

Fig. 3 illustrates the pressure vs. time plots obtained for the different models. As can be seen, the finer the mesh, the higher is the pressure peak achieved. It is also observed that for coarser meshes, the pressure peak appears later.

On the other hand, in fig. 4 the integral of pressure with respect to time is depicted for the same position of pressure measurements as before. It can be
pointed out that the differences observed between the five computations performed are much smaller than those obtained with pressure histories.

The parameter used in the abovementioned plot integral of pressure with respect to time, is the impulse per unit of area applied to the top surface at the point of analysis. The momentum applied by the blast wave to the whole surface is then the integral of that parameter over the surface.

For a better understanding of the effect of mesh refinement, fig. 5, illustrates the comparison for three element heights (2.23 mm, 6.375 mm and 44.625 mm) of the pressure versus time and the integral of pressure versus time histories obtained.

As can be seen, plots show that both parameters decrease when element size increases, but its influence is much more important on maximum pressure than on momentum.

6 Conclusions

This paper demonstrates that a fine mesh is beneficial for an appropriate numerical simulation of a landmine explosion. Finer meshes improve the results of momentum applied to the vehicle, which is the main parameter to determine stresses, damage and vehicle motion.

However, a detailed description of pressure histories on the vehicle surface requires an extremely fine discretization of the blast wave propagation which may be too costly in CPU times.

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References

[2] EUCLID RTP 3.27 "Protection of lightarmoured vehicles against mines".