Numerical Analysis of the Composite-Foam Panels Applied to Protect Pipelines Against the Blast Wave

W. Barnat, T. Niezgoda,
P. Szurgott, R. Panowicz

Military University of Technology

Introduction

The tremendous progress of the computational techniques allows to study of more and more various physical phenomena as detonation and blast wave interaction with different structures. A concern for passive protection of the structures [1, 2] causes necessity of searching the completely new solutions in the form of additional protective layers. Additionally mathematical description of the detonation process and the blast wave propagation is very difficult, hence many scientific publications on this phenomena can be found [3, 4, 5].

In current work, an attempt was made to simulate interaction of the blast wave with structures using a method that couples these elements. The Arbitrary Lagrangian Eulerian (ALE) method was used to couple an effect of the fluid on the structure. The fluid is described in Euler formulation, whereas the structures – in Lagrange one. Such method is applied in the standard implementation of the MSC. Dytran software [6]. An explicit scheme was selected to integrate the equation of motion in performed analysis.

General description of finite element models

Numerical analysis was carried out for two pipeline finite element (FE) models – with and without a protective panel. The pipeline—the main object of conducted research—was made of the L415MB steel. Its material properties based on the strength test [7] are provided in Table 1. One meter long fragment of the pipeline with inside diameter of 400 mm and the wall thickness of 7 mm was taken into consideration. Deformation effects of the protective panel and composite outer plate were also taken into account during the simulation.

The fluid domain has a cylindrical shape. It was simulated in the Eulerian domain using Hex 8 elements with the properties of the ideal gas – mass density of 1.2829 kg/m^3 and g = 1.4. A free flow of fluid through the boundary faces of the elements was assumed as initial condition. The Eulerian domain was limited by two planes of symmetry to reduce the CPU time.

The pipe and the protective panel, which is made from composite and aluminum foam, were modeled in the Lagrangian domain formulation. The Quad 4 shell elements were used for the pipe FE model, whereas the Hex 8 solid ones – for the panel. The two different the FE models (Figure 1 and 2) were used in analysis:

- Model 1 without the protective panel (in Lagrange domain is only pipeline),
- Model 2 with the 60 mm thick composite-foam protective panel (50 mm foamed aluminum and 10 mm reinforced polymer composite).

For both models, high explosive HE was located 100 mm from the pipe surface. Detonation of HE was modeled by defining appropriate initial conditions for selected elements in the Eulerian domain. Material properties of these elements based on the typical parameters of explosive materials and they are provided in Table 2. The initial values correspond with 100g of TNT. The Initial constraints were not declared in Lagrangian domain Therefore, velocities and displacements at the beginning (t = 0) were zero.

Table 1. Material properties of the L415MB steel [7]

Young's modulus	Poisson's ratio	Ultimate strength	Yield strength
E (MPa)	ν (–)	R_m (MPa)	$R_{0.2}$ (MPa)
195300	0.285	476	387

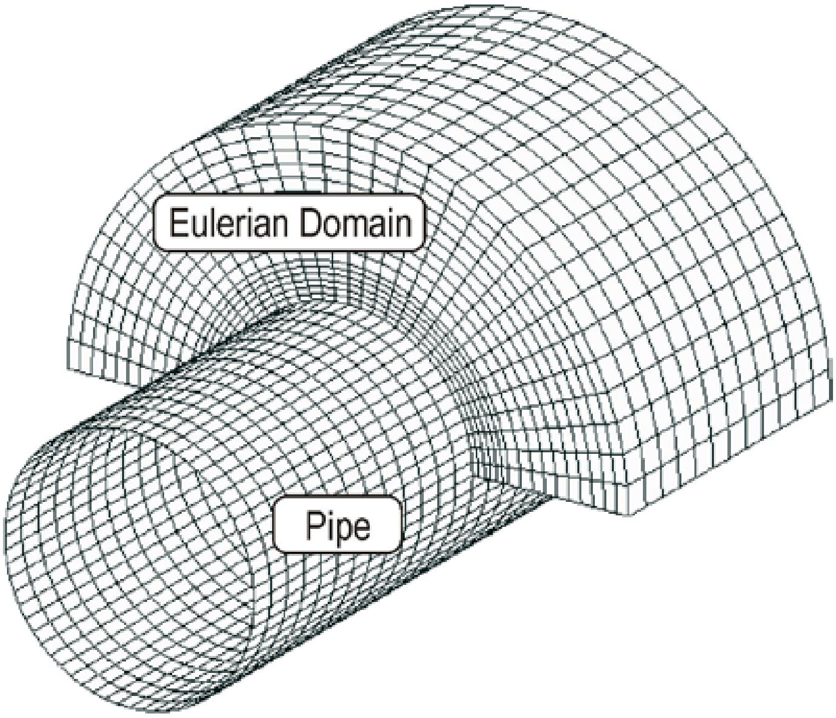

Figure 1. FE model of the pipe (Lagrange domain) and fluid – air (Euler domain)

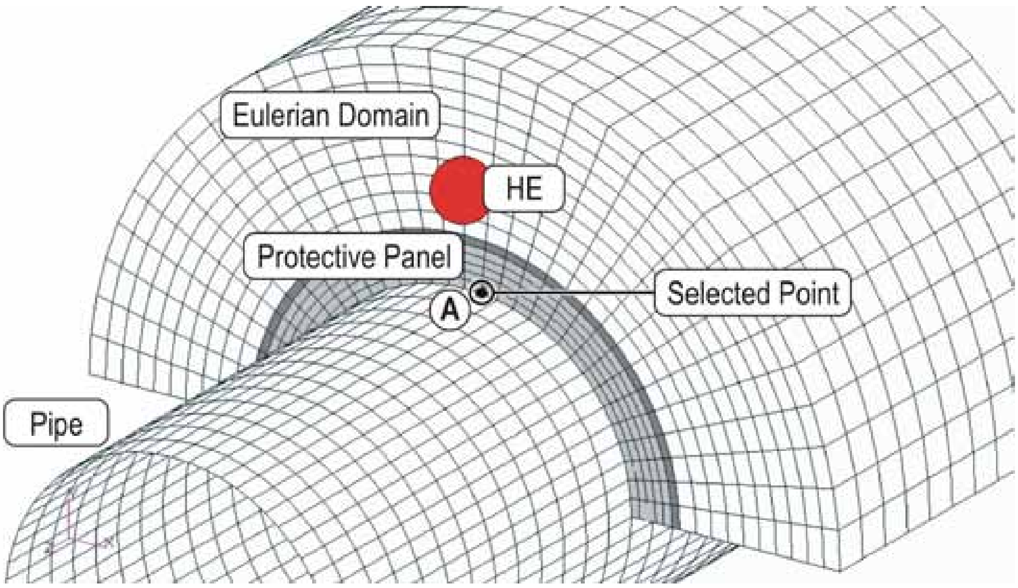

Figure 2. FE model of the pipe with the protective panel and fluid. Location of the HE and the selected point A is presented

Table 2. Material properties of the HE material

Mass density	Internal energy density
ρ (kg/m^3)	E (MJ/kg)
1600	4.2

Appropriate constrains were applied in the pipe FE model on the bottom edge.

The phenomenon of a detonation process was not simulated itself. However, there are some publications on modeling such phenomenon. The results presented in available publications reveal that taking above-mentioned phenomena into consideration has slight influence on the quality of obtained results.

The simple analytical model of the point charge detonation was made use of describing blast wave propagation. It be described by Taylor's so-called "similarity solution", which after transformation can be given as

$$p(r) = 0.155 E_0 \, r^{-3} \qquad (1)$$

where E_0 is the initial internal energy; r is the current radius of the blast wave.

The initial propagation of the blast wave is spherical. Values from the presented analysis correspond to those calculated analytically. The phenomena of the blast wave propagation in the FE model is shown in Figure 3.

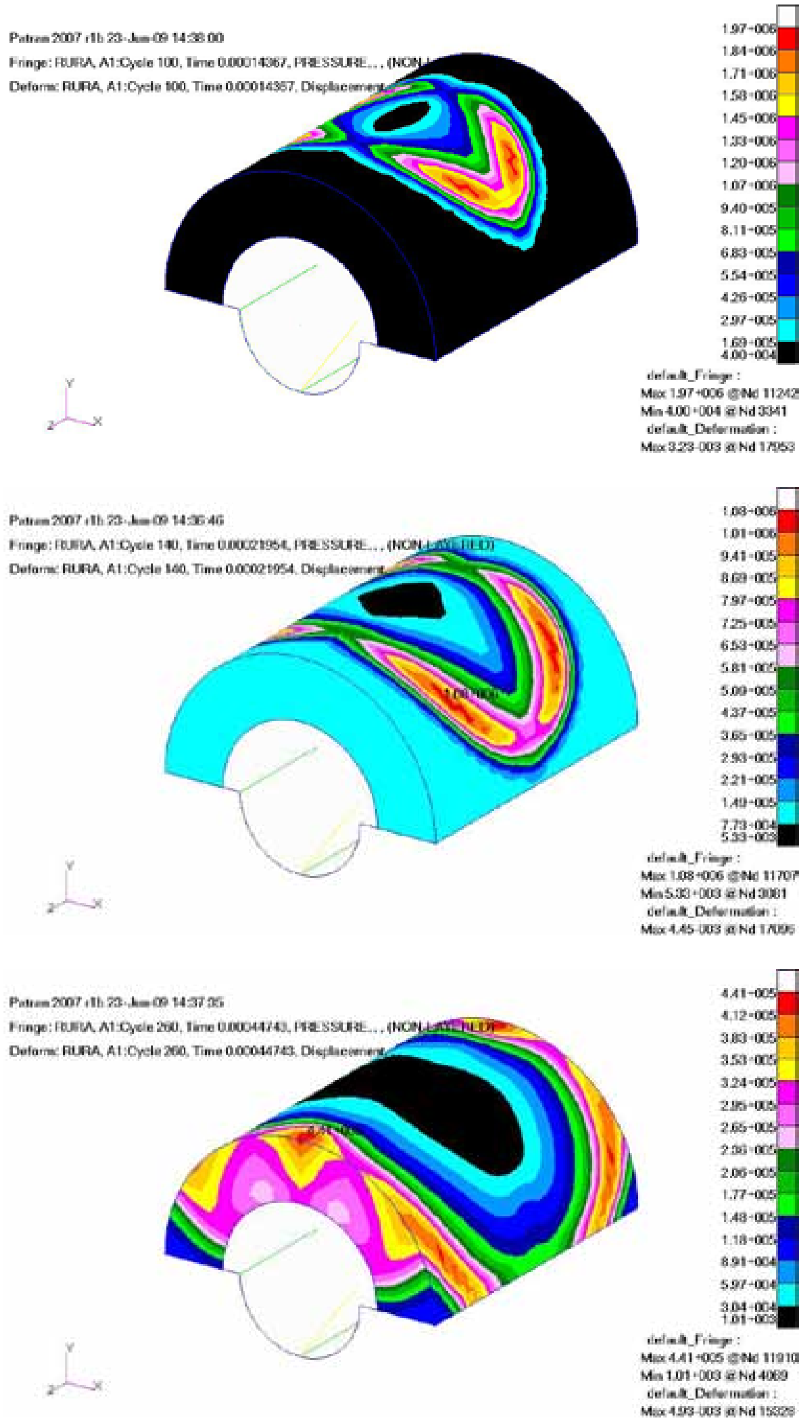

Figure 3. Distribution of the pressure inside the Eulerian domain for different time instants

FE Analysis and Results

Node A in the pipe FE model (see Figure 2) located on its top surface was selected for describing the results. Numerical analysis was performed for the time of 0.07 s. This time provided sufficient the blast wave interaction with considered structure to obtain an visible effect and decay of the pressure in the Eulerian domain, simultaneously.

The goal of conducted analysis was to assess the level of energy absorbed by each component of the tested structure. The graph of the deformation energy vs. time is presented in Figure 4. The maximum deformation energy of the pipe without the protective panel is equals to about 1750 J.

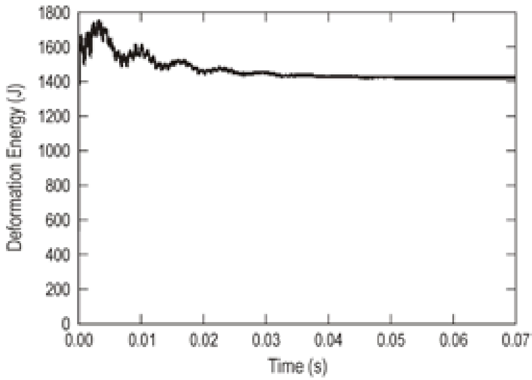

Figure 4. Variation of deformation energy for the pipe FE model subjected to blast wave

Displacements of selected node A from the pipe FE model is compared to those obtained for the model including the protective panel (Model 2), as presented in Figure 5. The maximum deflection for the Model 1 without the panel is 12 mm. The final form of deformation of the FE model with the contour of the deformation energy is shown in Figure 6. The contour of model deformation in the final stage is presented in Figure 7.

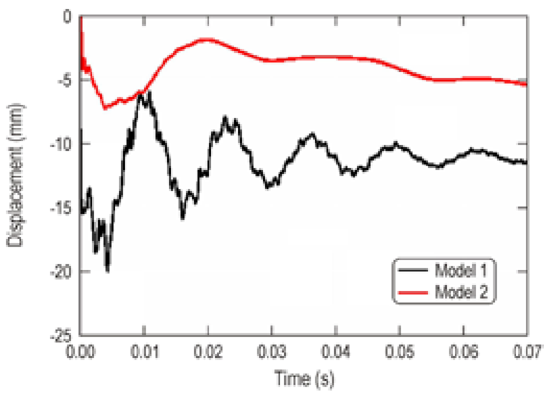

Figure 5. Displacements of the selected node A for the both FE models

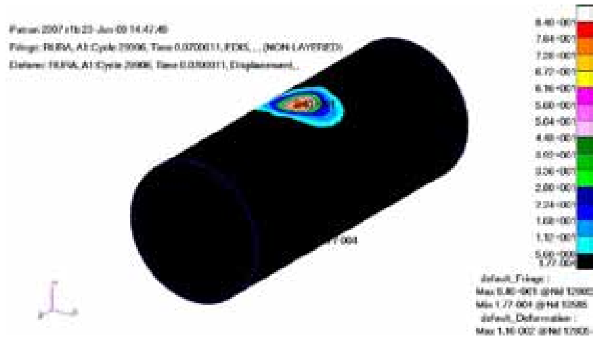

Figure 6. The final deformation energy (gradient) for the Model 1

Figure 7. The final deformation of the Model 1 – contour of the displacements (mm)

In the second model, with the protective panel, the energy of the blast wave was absorbed by each component – the composite plate, aluminum foam, and by the pipe. The energies absorbed by each component are compared in Figure 8. Maximum deformation energy—around 2,700 J—is absorbed by the foam layer. The pipe in Model 2 subjected to blast wave absorbs only 150 kJ of the energy—about ten times less than the pipe in Model 1 (without protective panel). The composite plate absorbs merely about 50 J. Contours of the deformation energy and displacement in the final stage are presented in Figure 9 and 10, respectively.

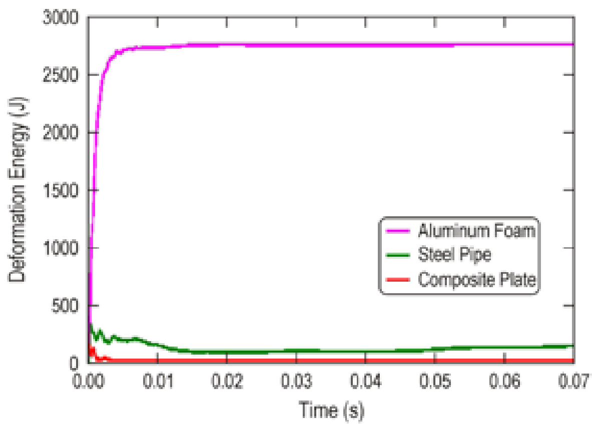

Figure 8. Comparison of the deformation energy for each component of the structure including the protective panel

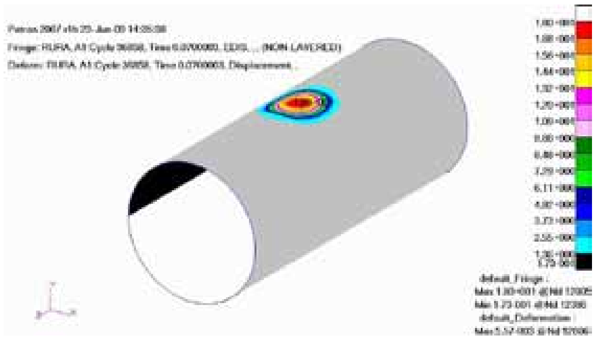

Figure 9. The final deformation energy (gradient) for the Model 2

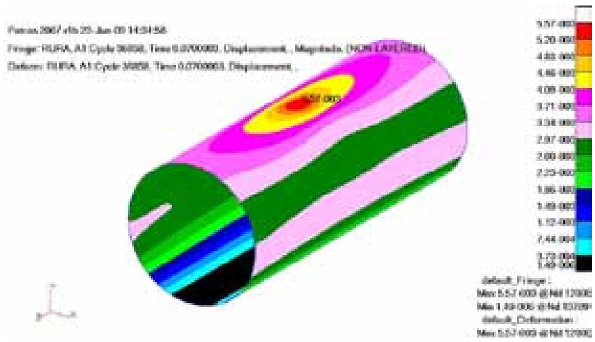

Figure 10. The final deformation of the Model 2 – contour of the displacements (mm)

The deformation energies for both models - with and without the protective panel - are compared in Figure 11. Performed analysis shows that the significant amount of the deformation energy is lost in the foam layer. Such disproportion of the energy absorbed by each component is caused by using the stiff composite plate and its surface-effect influenced on aluminum foam and the pipe.

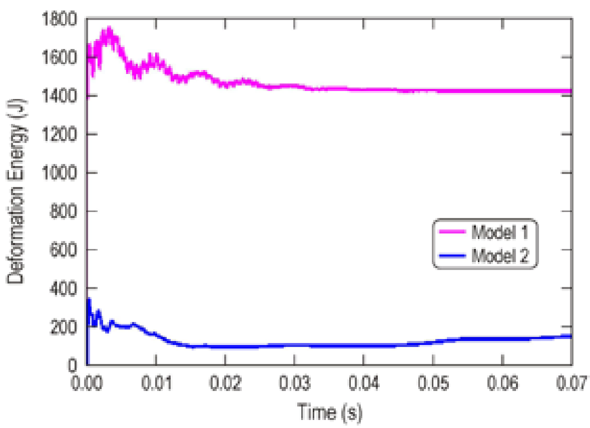

Figure 11. Comparison of the deformation energies for the pipe FE models subjected to blast wave

The blast wave causes an local effect on the pipe wall if the protective panel was not applied. It may caused large displacement of nodes, and a damage of pipe, consequently. The protective panel allows to reduce the displacement of the node A to 5 mm. Deformation energy for the Model 2 is about ten times lower in comparison with the Model 1, and its contour is different. In the Model 2 displacements of nodes are smooth and quite uniform due to surface-distribution of the blast wave on the pipe.

Conclusions

The results of preliminary analysis of the composite-foam protective panels are presented in the paper. Modeling of the dynamic loads generated by the explosives using the fluid–structure interaction - coupled Arbitrary Lagrangian Eulerian method applied in MSC.Dytran is much easier than the traditional approach. There is no need to generate the loads in external software and transfer them to the structural analysis software afterwards. Proposed approach is characterized by quite good conformity with the theoretical solutions. Applying the ALE methods allows to avoid transferring the loads onto modified mesh of the structural model. Deformations of the structure are taken into consideration automatically in the part of calculation regarding the fluid mechanics. In the traditional approach, considering of the influence of the shape changeability for the fluid channel is very time consuming and difficult to carry out.

Further work should be focused on a selection of properties of the foam and composite applied in the protective panels. Selection should be oriented on determining the optimal quantity of such panels. Furthermore, it is necessary to change the mass density of the used material to reduce the weight of the protection panel. Performed analysis allowed to determine the fundamental assumption to conduct the experimental test in order to verification and validation of developed FE models.

Literature

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