Investigation of steel-elastomer panel with carbon fibres loaded with blast wave

Wiesław Barnat, Robert Panowicz, Tadeusz Niezgoda and Roman Gieleta

Department of Mechanics and Applied Computer Science, Jarosław Dąbrowski Military University of Technology
2 Gen. Sylwester Kaliski, 00-908 Warsaw 49, Poland
tel. +48 22 683-98-49, fax: +48 22 683-93-55
e-mail: kmiis@wat.edu.pl

Abstract

Terrorist attacks are directed against the most important elements of infrastructure and human life. Therefore crews of combat vehicles as well as gas, oil and electrical energy transmission installations are the first to be exposed to such operations. Such situation resulted in striving for increasing the construction resistance to the blast waves. The object of the presented investigations was a numerical analysis of the elastomer protective layer combined with an experimental verification. The developed elastomer structures constitute perspective materials and will be applied to increase the safety of military vehicles as well as of neuralgic constructions of pipelines and gas-pipelines, especially in such dangerous places as crossings over rivers etc. A steel plate with a layer of elastomer strengthened with carbon fibres and loaded with a 100g TNT charge was analyzed. The numerical analysis was verified experimentally.

Keywords: blast waves, experiment, FEM analysis, elastomer layer

1. Introduction

The article deals with one of the possible ways of increasing the resistance of military vehicles and infrastructure structures. There are presented the possibilities of application of hiperelastic elastomer material with the addition of carbon fibres as a protective layer. Such type of layers are widely applied in the modern technology. They are mainly used to dissipate energy resulting from the interaction of body impact or pressure (for example, caused by detonation) on the construction [1, 2, 3].

2. Description of examined energy absorbing structures

Two research systems were subject to numerical investigations:

- Model 1 – a square steel plate (500x500 mm) made of alloy St3 of 2 mm thickness
- Model 2 – a square steel (500x500 mm) made of alloy St3 of 2 mm thickness with an elastomer layer with an addition of carbon fibres of 9 mm thickness.

Both systems were loaded with the blast wave from the detonation of 100 g cylindrical-shaped TNT charge. The numerical tests results were compared with experimental studies. The numerical model used in the simulation is shown in Figure 1.

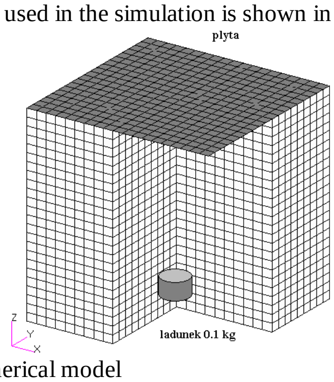


Figure 1: Numerical model

In the research the protective layer was made of PNMU elastomer. The macroparticles of this polymer are built of elastic and stiff segments, consisting of flexible and stiff mers. This polymer is self-extinguishing, it shows low water absorption and high hydrolytic resistance. Thanks to these properties, elements made of such polymers can work a long time in water environment. They exhibit also high wear resistance. So far, the industrial applications of such polymers include a wide range of parts, especially those working in raw materials processing, e.g. in mining.

The PNMU's remain in the high-elastic state, which means that the energy of thermal vibrations is higher than the energy barrier to rotations about the bonds and, as a result of that, even under a small loading, they exhibit considerable elastic deformation, which can be easily and quickly reversed under the influence of the loading.

The elastic and plastic deformations are small. Under deformation, the volume and internal energy of the elastomer undergo no change and its entropy decreases.

3. The results of numerical analysis

In the previous papers, for example [1], there were presented the results of investigations concerning, among others, the influence of parameters of Euler mesh, values of initial energy of explosive material as well as selection of coupling between Euler domain and Lagrange domain on the results of analyses of the considered constructions. On the basis of the obtained experiences, there were built models applied in the present considerations.

In the numerical model a JWL equation was used to simulate the detonation products propagation. The method is a programming burn model of complex processes in the explosive and the detonation front. It is based on determining the initial values of the detonation's velocity, initial coordinates, Chapman – Jouget point parameters and the equation describing the parameters of detonation product.. In this approach, the detonation front moves with constant velocity forming a surface of strong non-linearity. Due to this non-linearity, only cells with reacted material can be considered. The cells through which the front passes, have constant values of pressure, density and energy corresponding to the values in C-J point. The method allows large element size which enlarges the minimum timestep without affecting the results of the simulation. The equation commonly used to obtain the pressure of the products is a JWL (Jones, Wilkins, Lee) equation.

$$p = A\left(1-\frac{\omega}{R_1V}\right)^{-R_1V} + B\left(1-\frac{\omega}{R_2V}\right)^{-R_2V} + \omega\rho E \tag{1}$$

where:
$V=\rho_0/\rho$, ρ_0 – initial density,
ρ– density of detonation,
a A, B, R_1, R_2, ω – constants.

Basic constants of JWL equation for TNT are presented in Table 1.

Table 1. Contacts for JWL equation for TNT

A	B	R_1	R_2	ω
[GPa]	[GPa]	[-]	[-]	[-]
373.8	3.747	4.15	0.9	0.35

Remaining parameters: D – detonation velocity, p_{CJ} – pressure in Chapman – Jouget point, ρ_{CJ} – density in C-J point, required In the analysis of the detonation are show in Table 2.

Table 2. Additional parameters for TNT model

ρ_0	D	p_{CJ}	ρ_{CJ}
[kg/m^3]	[m/s]	[GPa]	[kg/m^3]
1630	6930	21	2230

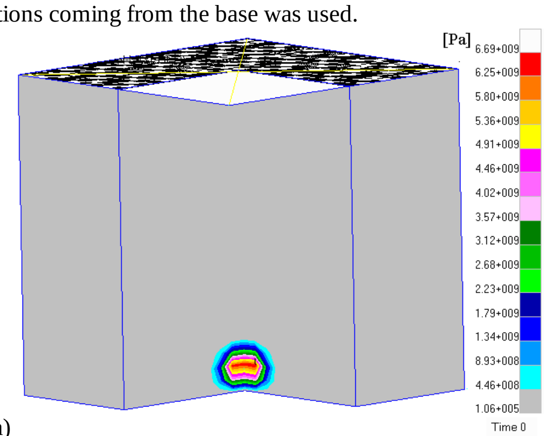
The proposed solution is the most complex one available among the used software. In this method, both the blast wave propagation in air and the propagation of the detonation products are considered.

The ideal gas equation was used to describe pressure in air:

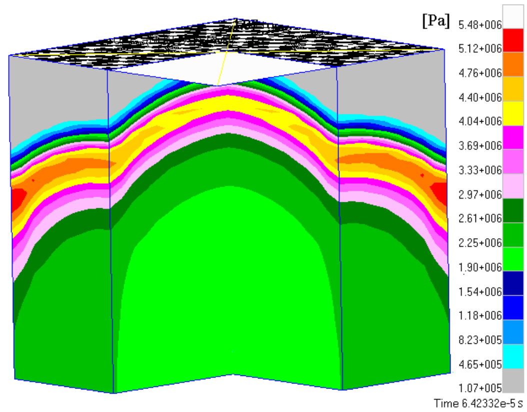
(2)

where:
E – specific internal energy,
γ – ratio of specific heats.

Propagation of blast wave coming from detonation of explosives in the Euler domain is presented in Figure 2. This wave interacts with the structure. To compare the results of the blast waves interaction on model 1 or 2, the estimation of displacement of a central node located in symmetry planes and reactions coming from the base was used.



(a)



(b)

Figure 2: Blast wave for: a – time t = 0 s, b – time t = 64.233μs

After the pressure wave reached the object it was reflected. The reflected waves are stronger from 2 to 8 times than the incident waves. The wave obtained numerically in the simulation is depicted in Figure 2.

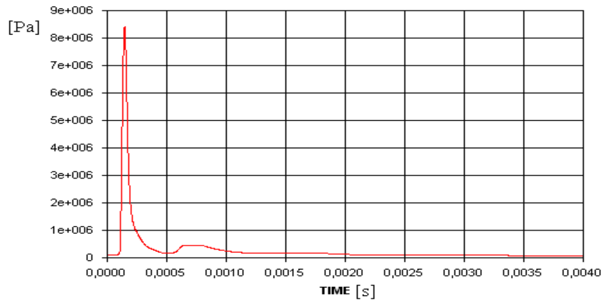


Figure 2:Pressure of wave reflected from a steel plate

The character of displacements of the central node in the function of time is presented in Fig. 3.

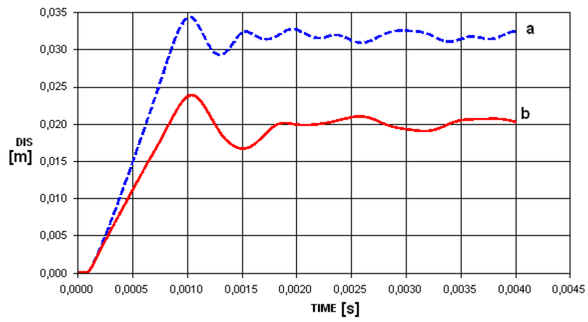


Figure 3: Displacements of the central node of the steel plate in the function of time, a-model 1, b-model 2

In both considered cases, from the moment t = 0 s to approximately 39.54 μs displacement of the plate central node doesn't occur. This time interval corresponds to the wave approach to the object. The duration time of the pressure impulse is relatively short in comparison to the plate movement, which is significantly longer and amounts to approximately 0.75 ms In the case of model 1, after time of approximately 1.5 ms there occurs stabilisation and damping of vibrations of the plate central node around the fixed level of 32 mm. A similar course of the central point displacements was recorded for model 2, however in this case the vibrations amplitude was greater, what was caused by an additional elastomer mass. The final deformation of the central node amounted to 0.02 m.

It is important to notice that the way of steel plates deformation in both considered cases is different. Difference in the character of deformation is related to an elastomer protective layer increasing the system stiffness and thereby causing load distribution on a greater surface of the considered system. In the case of the first model, values of equivalent stress are twice as much greater than in the case of model 2 and are equal to 402 MPa and 219 MPa respectively.

The deformation shape in both cases is different. Due to the application of elastomeric layer, final deformation is smaller than in the other system. It is caused by the increased stiffness and, therefore, better stress distribution. Deformation of plates is presented in Figure 4.

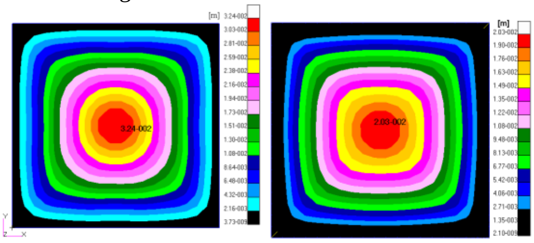
(a)  (b)

Figure 4: Deformation of the plate , a - model 1, b - model 2

As mentioned above, changing the stiffness affects the stress distribution. In Model 2, where elastomeric layer was applied, maximum stress value is twice lower than in the other case. Figure 5 depicts stress maps for both models. In Model 2 the maximum stress value is twice lower than in the other case.

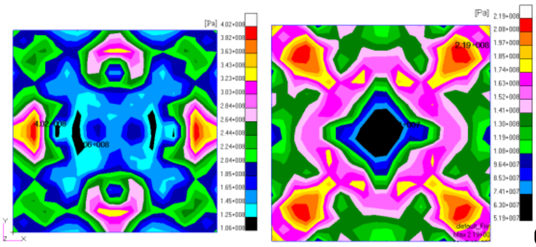
(a)  (b)

Figure 5: Stress map, a - model 1, b - model 2

4. Results of experimental investigations

In experimental investigations the set-up described in [4] was used. The stand is shown in Fig. 6.

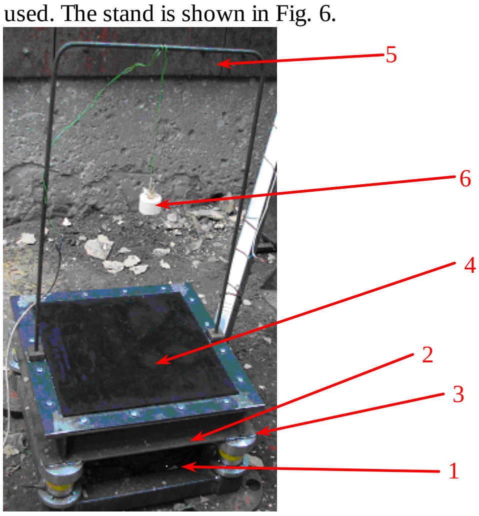
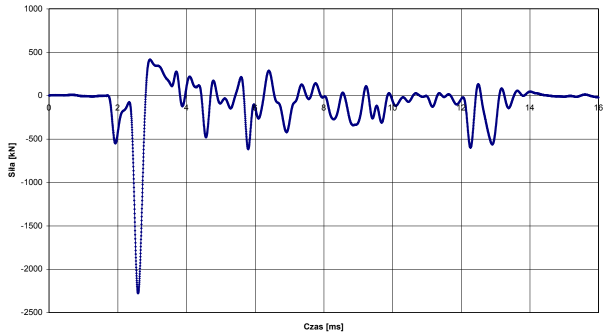


Figure 6: Test stand used in the experiment: 1 – base, 2 – attachment frame, 3 – digital force converter (x4), 4 – energy absorbing panel, 5 – mounting frame, 6 - TNT charge

The results obtained after conducting investigations on the testing stand were subject to calibration in order to draw the graphs of changes of force in the function of time. Fig.ure 7 presents the recorded results of force for the examined models. Difficulties in the measurement during such kind of experimental investigations caused the limitation to read out only the force acting on the frame and the shape of final deformation of the system.

(a)



(b)

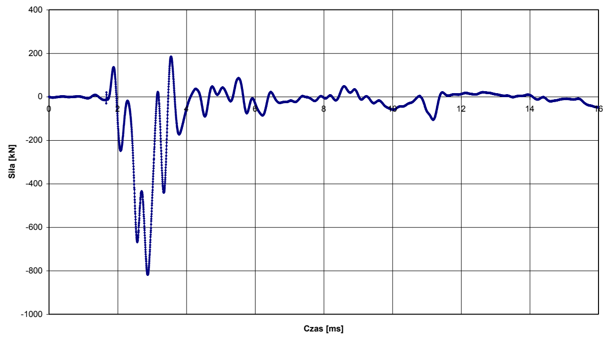


Figure 7: The results of load changes of the panel made of a steel plate: (a) without, (b) with an elastomer layer and filled with carbon fibres

Fig. 8 presents the photo of a base plate after the experiment (a deformed shape of plate). Comparing it to the plate in Figure 9, the deformation is smaller in the second case. It is due to the elastomeric layer used in Model 2.

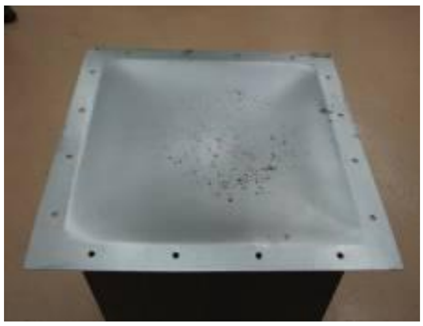


Figure 8: The deformed shape of the base plate

The measured permanent displacement of the central node of the steel plate amounted to 32 mm. Application of a protective layer (model 2) lowered the value of this displacement by 36.5% (displacement amounted to 20.3 mm). The maximum values of forces acting on the measuring system for the particular objects were additionally determined on the base of the recorded results.

Figure 9: The deformed shape of the base plate

After the numerical analysis and experimental trials both examinations were compared but evaluated. The comparison of final displacements of centre nodes is shown in Table 3.As can be seen, a good convergence of results was achieved.

Table 3. Comparison of numerical and experimental results

Sample		Steel plate 2 mm	Steel plate with elastomeric layer and nanotubes
Numerical displacement	[m]	0,032	0,027
Experimental displacement	[m]	0,032	0,0203
Mass of the sample	[kg]	4,4	6,5
Recorded reaction force	[kN]	2278,1	660

5. Conclusions

Constructions exposed to damages resulting from interaction of different kind of dynamic constrains such as impacts or interaction of a blast wave coming from detonation of explosive material should be characterized by the structure enabling absorbing the greatest possible part of energy interacting on them. One of the interesting types of materials possible to be used for this purpose is elastomer. Such materials characterised by capabilities of absorbing the energy of a blast wave coming from explosion allow a significant increasing of the protection level. Application of such materials causes the decrease of vibration frequency of the system loaded with a pressure impulse.

The maximum displacement of the protected plate was obtained for model 1. The lowest displacement of the central node was recorded for model 2 in which the elastomer layer strengthened with carbon fibres was applied. Experimental investigations also confirmed the fact that elastomer layers sufficiently absorb and dissipated impact energy thereby protecting the object against different kind of dangerous situations.

The authors presented a part of investigations executed in the Department of Mechanics and Applied Computer Science, Military University of Technology.

References

[1] Barnat W., *Wybrane problemy energochłonności nowych typów paneli ochronnych obciążonych falą wybuchu*, Belstudio, Warszawa, 2010.

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

[3] Zienkiewicz O.C. and Taylor R.L., *The Finite Element Method*, Vol. 3: *Fluid Dynamics*, Butterworth-Heinemann, Oxford, 2000.

[4] Niezgoda T., Barnat W., Gieleta R., Panowicz R., Eksperymentalno-numeryczne badania struktury kompozytowej w postaci półsfery obciążonej falą ciśnienia pochodzącą od wybuchu, *Proceedings of the XII Sympozjum stateczności konstrukcji*, 7-11 września 2009, Zakopane.