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RESEARCH PROTECTIVE SHIELD, ELASTOMER-LIQUID AGAINST IMPACT SHOCK WAVE

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Abstract

An article describes an issue of increasing the passive safety of soldiers in a military vehicle subjected to loads resulting from explosion mine or IED. Traditional methods to increase security involving the application of additional layers made using materials with high density. This approach contributes to a reduction mobility and efficiency vehicle on the battlefield. For these reasons, it is necessary to search new design solution, which will benefit low-density material through which driving parameters of vehicle in combat do not worsen. Mentioned reasons led to propose a new concept protective shield made of elastomer with inclusion in form of a liquid.

Effectiveness of the proposed protective shield will be verified on the bench traverse. The blast shock wave will be induced by detonation of HE charge at the central point over 430 mm from the top surface of the range stand. Experimental tests will be used to validate the numerical model. After positive validation and verification, numerical model it can be used for other blast conditions or optimize protective shield.

FEM numerical modelling, dynamic simulations and postprocessing were carried out using the following CAE systems: CATIA, HyperMesh, LS-DYNA (a solver), LS-PrePost.

Keywords: *protective shield, multilayer system, passive safety, shockwave*

1. Introduction

Light-armoured vehicles (LAV) are exposed to shock wave obtained from explosion charges in the form of AT mines or IED devices. Modern LAVs commonly have flat-shaped bottoms, which should be equipped with energy-absorbing and armoured shields against AT/IED charges (Fig. 1).

Fig. 1. Integrated bottom frame for suspension and drive in ROSOMAK-type LAV vehicle

To date, a number of passive protection solutions were developed, e.g. [1-4]. Hou et al. [1] present quasi-static and impact perforation tests carried out on metallic sandwich panels composed of CYMAT aluminium foam core and 5005H34 aluminium facings, joined together with 3M

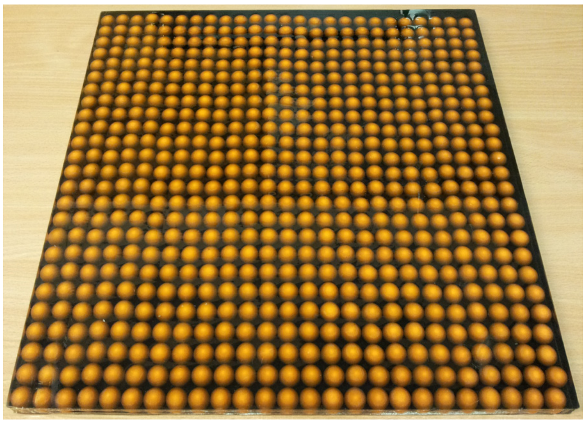
Epoxy adhesive. Rybak [2] presents experimental and numerical investigations on passive protection of combat vehicles exposed to impact blast of explosive material charges. An energy-absorbing shield is composed of distanced steel pipes connected with the top and bottom steel plates by means of screw connections.

These works confirm the correctness of research on new lightweight composite structures.

2. Description of elastomer-liquid shield

An elastomeric-liquid shield is applicable to protect occupants of LAV vehicles. This shield is composed of two materials, elastomeric matrix and liquid inclusions. The materials used to build the shield provide resistance to weather conditions and chemical factors. Location liquid beads are presented in Fig. 2. The thickness of each of the variants is 20 mm. Elastomer-liquid shield is joined with steel sheet by Soudaseal 2K glue exhibiting good adherence to metals and composites. It is characterized by high hardness (55 in Shore A scale), good mechanical properties, good resistance to atmospheric factors and limited chemical resistance. This glue is designed to make elastic connections exposed to heavy vibrations, which are well damped.

a)



b)

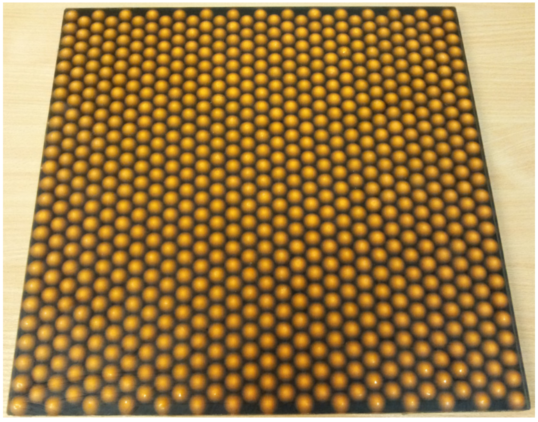


Fig. 2. Variants position liquid beads a) parallel rows, b) moved rows

3. Numerical modelling protective shield against impact shock wave

The FEM numerical modelling, simulation and postprocessing were developed using the following CAE systems: CATIA, HyperMesh, LS-DYNA, LS-PrePost. The geometrical models of the protective shield were built using CATIA system. The FE meshing in particular subsystems was generated automatically using HyperMesh platform. LS-PrePost programme was used as a pre-processor to define the boundary conditions, finite elements, material properties, the solution type. Complete FE model was exported as a key file with LS-DYNA preferences. LS-DYNA programme was used as a solver and LS-PrePost programme was applied as the post-processor.

Because of bisymmetry of variants protective shield, their numerical models were limited to respective quarters of the global systems. The boundary conditions in the planes of symmetry eliminate displacements perpendicular to these planes. The numerical models of the protective shield are shown in Fig. 3.

In the materials' description original notation of input data assumed in FE code LS-DYNA as well as a system of units used in the numerical modelling and simulation (kg, mm, msec, K, GPa, kN) have been saved.

To build the numerical model were used the following material models:

- MAT_JOHNSON_COOK for steel plate. The Johnson–Cook strain and temperature sensitive plasticity material, used for problems where strain rates vary over a large range and adiabatic temperature increases due to plastic. Material data for Armox 500T steel are collected in Tab. 1.

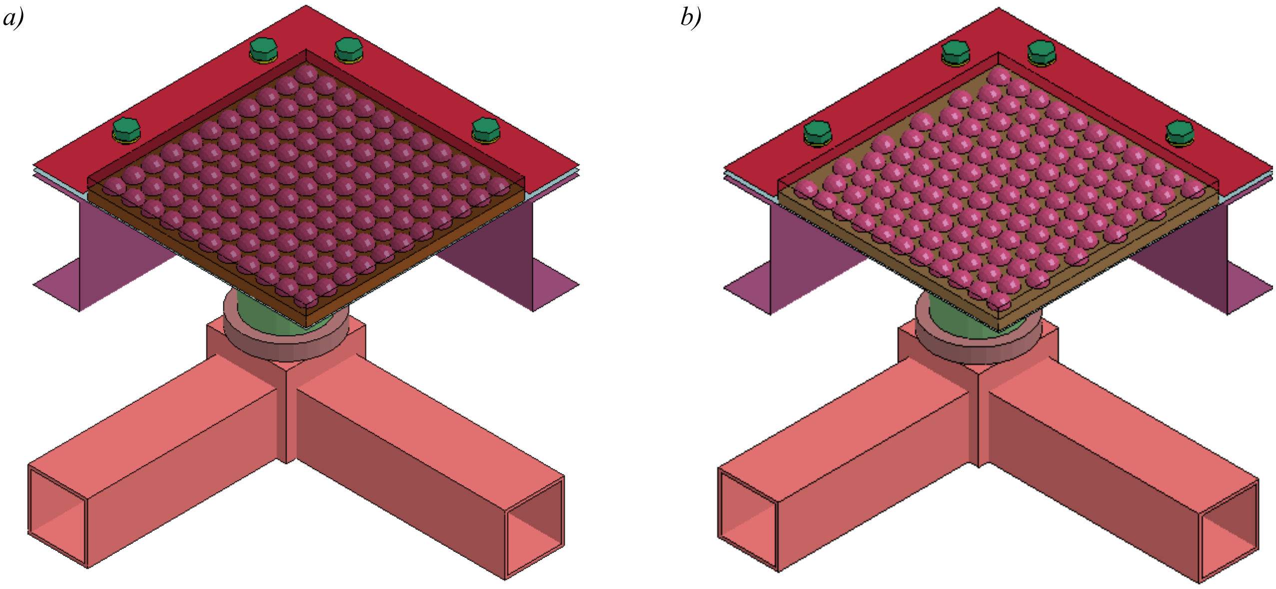


Fig. 3. An isometric view range stand with fixed panels for two variants a) parallel rows, b) moved rows

Tab. 1. Material constants for Armox 500T steel

Parameter	Armox 500
Mass density, RO	7.85e-6
Shear modulus, G	79.6
Scale yield stress, VP	0
Flow stress: A B N C M	0.849 1.34 0.0923 0.00541 0.870
Melt temperature, TM	1800
Room temperature, TR	239
Quasi-static threshold strain rate, EPSO	0.001
Specific heat , CP	450
Spall type , SPALL	2
Plastic strain iter. option, IT	1
Failure par.: D1 D2, D3, D4, D5	0.5 0
Intercept C	4570
Slope coeff.: S1 S2, S3	1.45 0
Gruneisen gamma, GAMAO	1.93
First order vol. correction, A	0.5
Initial internal energy, E0	0
Initial relative volume, V0	1

- MAT_SIMPLIFIED_RUBER/FOAM_WITH_FAILURE for elastomeric. Material data are collected in Tab. 2. For this material, it is necessary to defining the force versus actual change in the gauge length (Fig. 4).

Tab. 2. Material constants for elastomer

Parameter	Elastomer
Mass density, RO	1.25e-6
Linear bulk modulus, K	0.233
Define curve, LC/TBID	Fig. 4

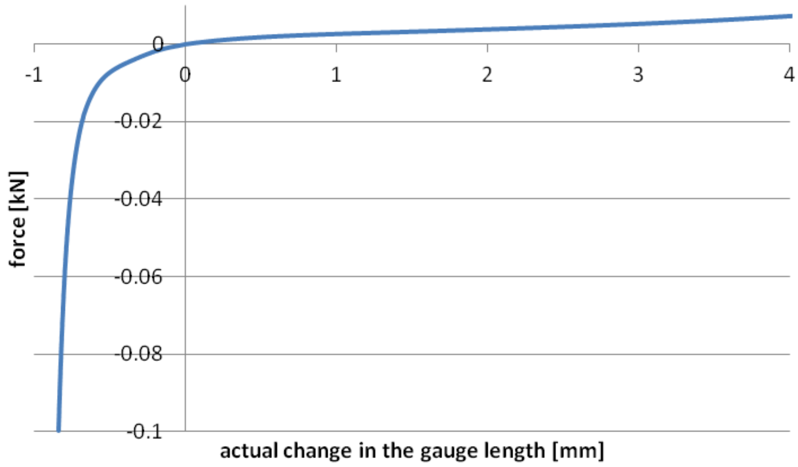


Fig. 4. Force versus actual change in the gauge length

- MAT_ELASTIC_FLUID for liquid bullets. For this material is defined only density. Other parameter remain the default (density, RO = 1e-6).

The blast shock wave induced by detonation of HE charge at the central point over the range stand (within 430 mm) is modelled approximately using the CONWEP model. This model approximates fluid–solid interaction based on the experimental data. Blast shock wave was modelled using the LOAD_BLAST_ENHANCED option offered by LS-Dyna system. This load model defines an air blast function for the application of pressure loads due to explosion of conventional charge, including enhancements for treating reflected waves, moving warheads and multiple blast sources. A type of blast source is spherical free-airburst (BLAST = 2).

4. Range tests of elastomer-liquid shield against 0.5 kg TNT blast shock wave

The main purpose of experimental performed on energy-absorbing panels is test effectiveness on the impact of the shock wave. For this purpose, elastomer-liquid shield was attached to a steel plate, which was then mounted on the range test.

The conditions for the experimental test are collected below:

- a spherical charge made of SEMTEX HE material equivalent 0.5 kg of TNT in reference to the pressure criterion,
- a detonator placed centrally in the sphere,
- central free suspension of HE charge at 430 mm distance from the top surface of the range stand (a typical distance of the vehicle bottom plate from AT mine hidden under the ground surface).

The photo documentation of the experimental blast test is presented in Fig. 5-6. Fig. 5 shows the shield before 0.5 kg TNT range test. Fig. 6 illustrates the shield after detonation of 0.5 kg TNT spherical charge hanged centrally over the stand at the 430 mm vertical distance.

The following damages have been observed:

- cracks and delamination of layers between elastomer and liquid boll,
- failure of glue layers between protective plate and protective shield,
- medium plastic deformations and no damages in the protected plate.

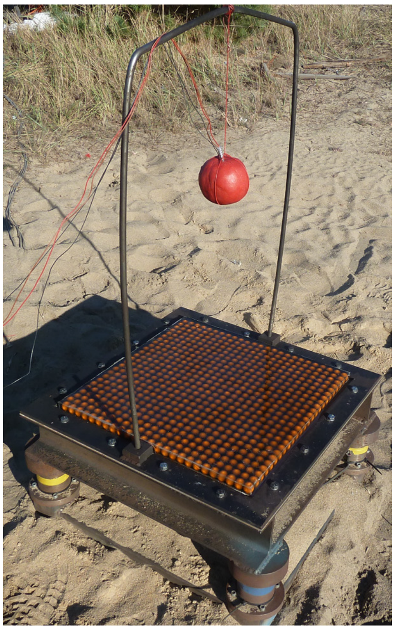


Fig. 5. The elastomer-liquid shield before 0.5 kg TNT blast test

a)

b)

Fig. 6. The elastomer-liquid shield after 0.5 kg TNT blast test: a) parallel rows, b) moved rows

Tab. 3. The plastic deflection of the steel plate d [mm] at the central point of the protected plate after 0.5 kg SEMTEX

Variant	*d* [mm]
Reference variant witness steel plate	16.0
Parallel rows	12.5
Moved rows	11.0

4. Simulations of dynamic processes

Impact in the form of the 0.5 kg SEMTEX blast shock wave induces plastic deformations in the Armox plate. The plastic deflection can be treated as the measure of these deformations. Respective numerical and experimental values of the plastic deflection are collected in Tab. 4.

Tab. 4. The plastic deflection of the steel plate d [mm] at the central point of the protected plate after 0.5 kg SEMTEX (N – simulation, E – experiment)

Variant	*d* [mm]		δ [%]
	N	*E*	
Reference variant witness steel plate	18.5	16.0	0.35
Parallel rows	13.8	12.5	0.30
Moved rows	12.9	11.0	0.44

Experimental validation of the numerical modelling is measured by the deviation of the numerical plastic deflection from the experimental one. The respective error is defined by the formula:

$$\delta = \frac{| d_N - d_E |}{L}, \tag{1}$$

where:
d_N – numerical plastic deflection,
d_E – experimental plastic deflection,
L – reference length equal to width of the square hole in the range stand, L = 430 mm.

Quantitative conformity of the numerical and experimental failure in the variants of protective shield is assessed positively. Summing up, experimental validation of numerical modelling has been assessed positively with possibility of further improvement of the numerical models. Attention should be put on better modelling connecting protective steel plate and elastomeric element. Moreover, the material models describing liquid inclusions.

5. Conclusions

Based on the experimental research developed in the study the following final conclusions have been formulated:

- The elastomer-liquid shield exhibit high relative energy absorption and have the key parameters competitive in the market, i.e. thickness, mass per unit area, price.
- The design assumptions made for the range stand have been confirmed experimentally.

The results corresponding to the selected protective panel and selected HE charge are useful for validation and verification of the numerical model of the protective shield. After positive validation and verification, one can realize numerical research for other blast conditions or optimize protective panels. Compared to the experiments the simulations are much cheaper and can predict displacement/velocity/acceleration time-histories, effective stress and plastic. Such approach enables fast and cheap design of protective shield for required protection level.

Acknowledgments

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