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EXPLOSIVE CHARGE IMPACT ON THE OPENWORK STEEL SHIELD

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Abstract

The article presents the issue of increasing the passive safety of soldiers in a military vehicle, which is subject to loads resulting from an explosion IED or mine. Traditional methods of increasing security involve the application of additional layers, which are made using materials with high density. This approach contributes to the reduction of mobility and efficiency of a vehicle on the battlefield. For these reasons, it is necessary to search for a new structural design, which will benefit from a solution, which will not worsen the driving parameters of a vehicle in combat. Therefore, we propose a novel solution of openwork panel with dividers.

The effectiveness of the system will be checked by 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 test 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.

The problem considered in the study was solved numerically with the FEM using the following CAD-CAE systems: CATIA (to prepare a surface model), HyperMesh (division into finite elements), LS-Dyna (a solver), LS-PrePost (pre and post processor).

Keywords: *protective shield, passive safety, shock wave*

1. Introduction

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

The literature studies have shown that dissipation of the blast wave energy can be increased reasonably by geometrically advanced energy–absorbing structures, e.g. cylindrical or conical tubes, semi–spherical shells etc. [3, 4]. However, protective shields with cores composed of such elements are expensive and technologically difficult to manufacture, e.g. [1, 2, 5, 6]. Hou et al. [1] present quasi-static and impact perforation tests carried out on metallic sandwich panels composed of the CYMAT aluminium foam core and 5005H34 aluminium facings, joined together with 3M Epoxy adhesive. Rybak [5] presents experimental and numerical investigations on the 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 the new design of the shield structure.

2. Description of the openwork steel shield

The openwork steel shield is applied to increase the protection of the crew of LAVs with the flat-shape bottom. The proposed protective structure was built with the use of structural steel. The visualization and individual parts are shown in Fig. 2. The essential parts of the system are the following: perforated metal exterior and two types of perforated inserts designed to increase the stiffness of the system. The proposed system is attached to the witness sheet with the use of a welded joint.

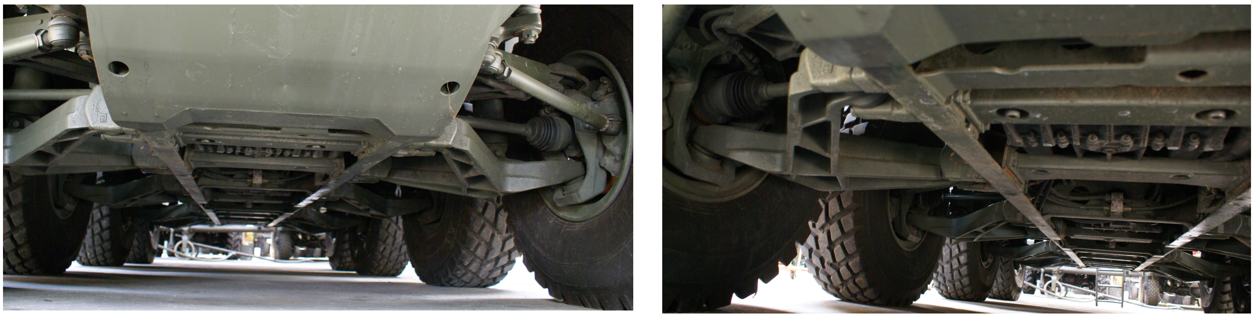

Fig. 1. Integrated bottom frame for the suspension and drive in the ROSOMAK-type LAV vehicle

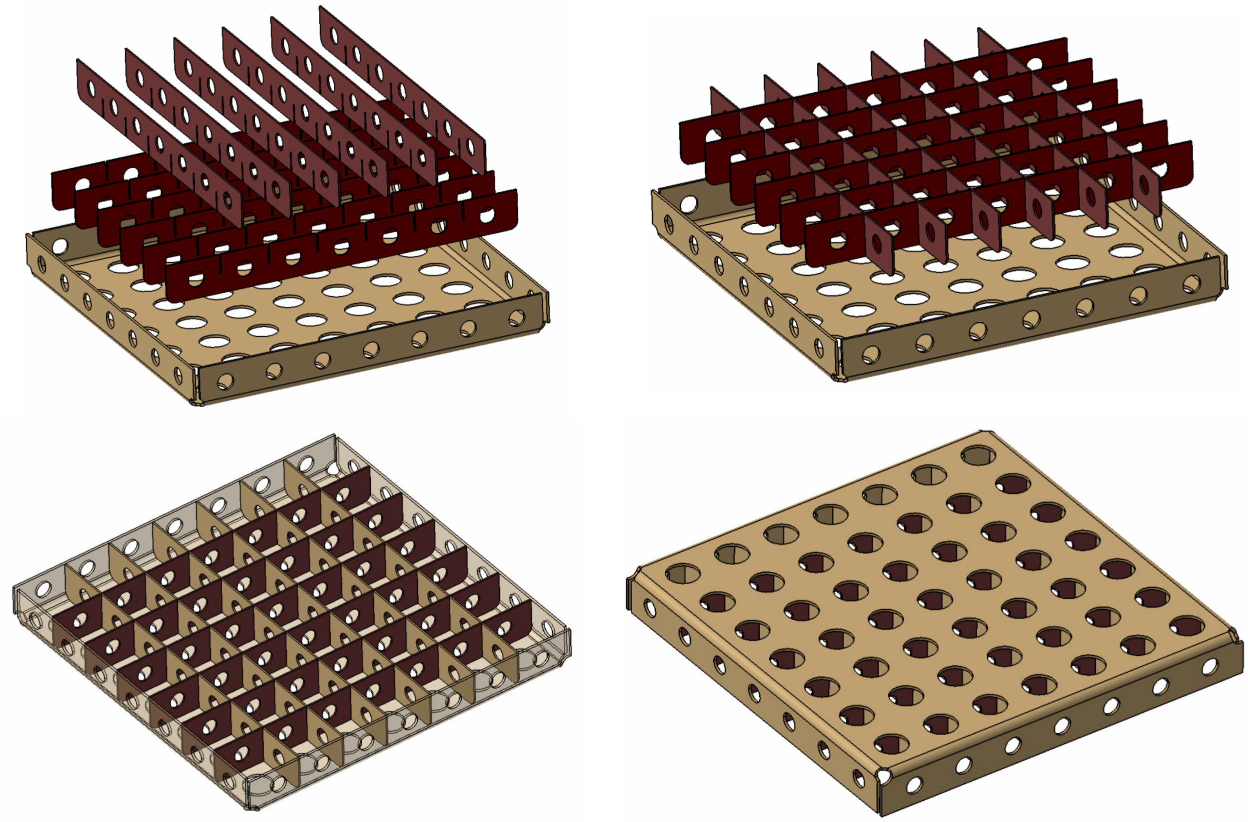

Fig. 2. Construction of the openwork steel shield

3. Numerical modelling of the protective shield against an impact shock wave

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

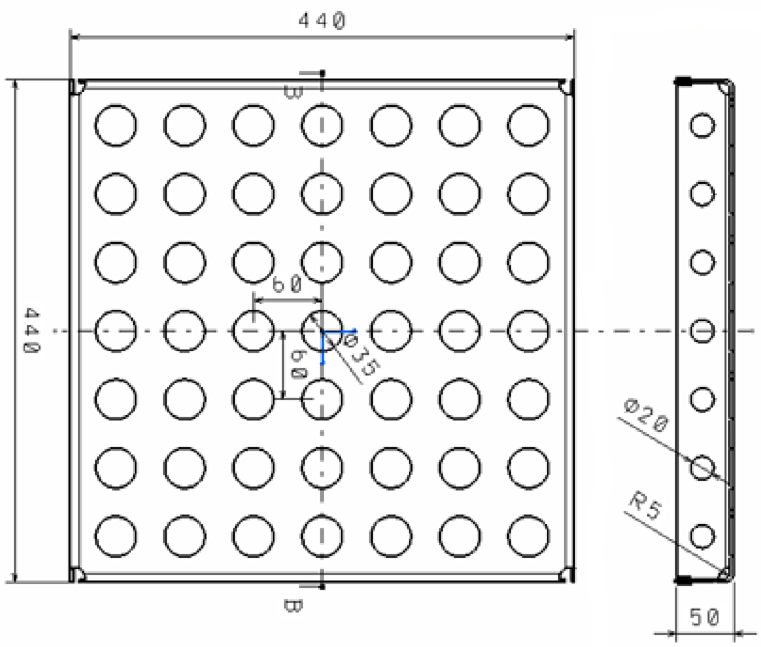

Fig. 3. Size of the protective shield

Due to the bisymmetry concerning the variants of the protective shield, their numerical models were limited to the respective quarters of the global systems. The boundary conditions in the planes of symmetry eliminate displacements, which are perpendicular to these planes. The numerical models of the protective shield are shown in Fig. 4.

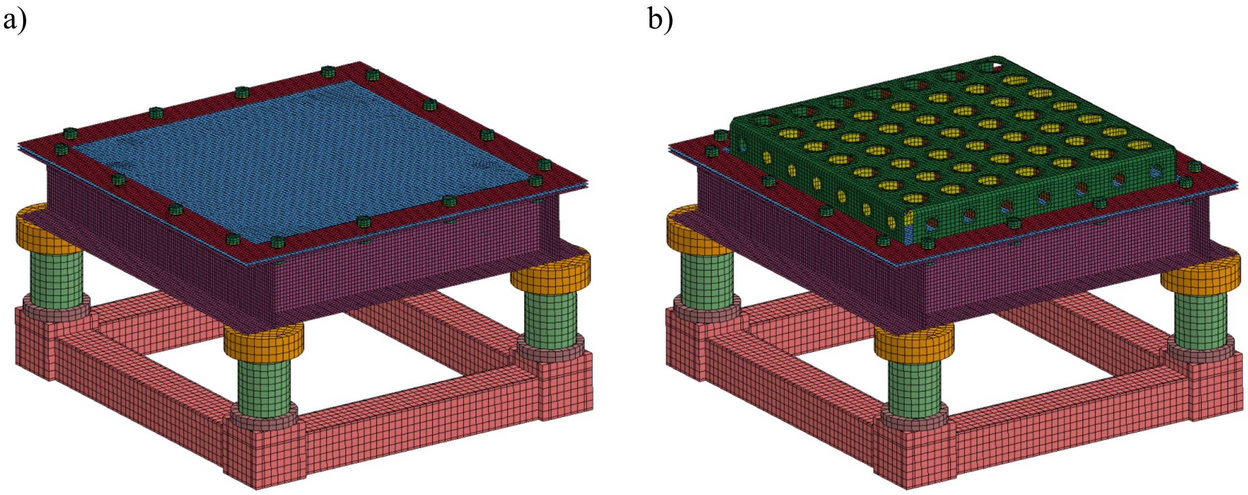

Fig. 4. Isometric view range stand with fixed panels for two variants a) reference system, b) system with the protective shield

The original notation of input data assumed in FE code LS-Dyna as well as the system of units used in the numerical modelling and simulation (kg, mm, msec, K, GPa, kN) were kept in the description of the materials.

In order to build the numerical model, the following material models were used:

– MAT_JOHNSON_COOK for the reference steel plate. The Johnson–Cook strain and the temperature sensitive plasticity material are used in the case of problems where strain rates vary over a large range and adiabatic temperature increases due to plastic. The material data for Armox 500T steel is presented in Tab. 1.

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	1.0
Flow stress: A B N C M	2.03 0.504 1.0 0.001 1.0
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	-0.4 1.7 0.5 0 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_24 (MAT_PIECEWISE_LINEAR_PLASTICITY). This is an elastic-plastic material with the declaration of any strain curve σ-ε and any depending on the strain rate. Structural steel was used to produce parts of the proposed shield. The material data for this steel is presented in Tab. 2.

Tab. 2. Material constants for steel used for the construction of the protective shield

Parameter	Steel
Mass density, RO	7.85e-6
Young's modulus, E	207
Poisson's ratio, PR	0.3
Yield stress, SIGY	0.215
Tangent modulus, ETAN	1.4
Plastic strain to failure, FAIL	0.25

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

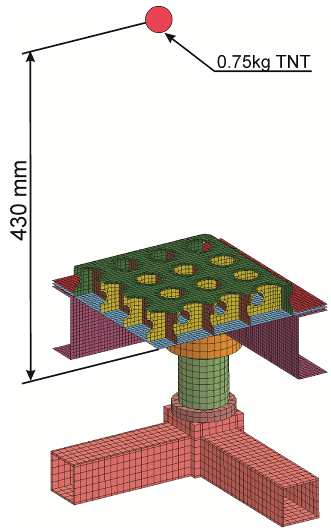

Fig. 5. Isometric view of the position of explosive charge in relation to the protection shield

4. Range tests of the openwork shield against 0.75 kg TNT blast shock wave

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

The conditions for the experimental test are listed below:

- a spherical charge made of the SEMTEX HE material equivalent to 0.75 kg of TNT with reference to the pressure criterion,
- a detonator placed centrally in the sphere,
- the central free suspension of the HE charge at 430 mm distance from the top surface of the range stand (typical distance of the vehicle bottom plate from the AT mine hidden under the ground surface).

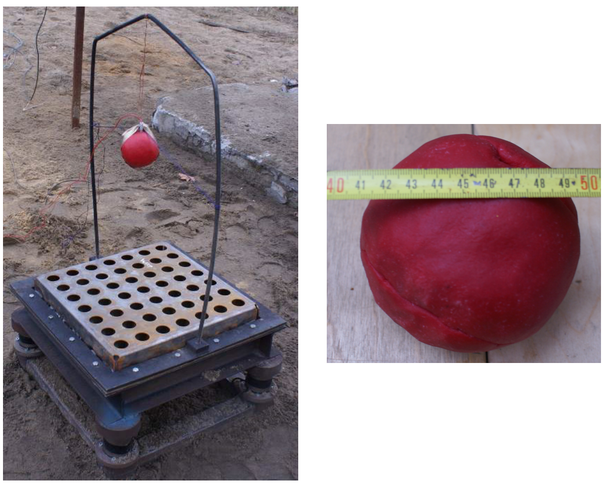

Fig. 6. The protective shield before the 0.75 kg TNT blast test

a) 

b) 

Fig. 7. The protective shield after the 0.75 kg TNT blast test: a) the isometric view, b) the front view

The photo documentation of the experimental blast test is presented in Fig. 6-7. Fig. 6 shows the shield before the 0.75 kg TNT range test together with the shape and size of the explosive charge. Fig. 6 illustrates the shield after the detonation of 0.75 kg TNT spherical charge hanged centrally over the stand at the 430 mm vertical distance.

The following damage has been observed:

– perforated inserts have large plastic deformations,
– the perforated metal exterior has a large plastic deformation with a very unusual behaviour of increasing the thickness of the protective shield,
– medium plastic deformations and no damage in the protected plate.

Tab. 3. The plastic deflection of the steel plate d [mm] at the central point of the protected plate after 0.75 kg SEMTEX

Variant	d [mm]
Reference variant witness steel plate	32.0
Openwork shield	25.5

4. Simulations of dynamic processes

Impact in the form of the 0.75 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 presented 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	33.5	32.0	0.35
parallel rows	27.5	25.5	0.47

The 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 following formula:

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

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

The quantitative conformity of the numerical and experimental failure in the variants of the protective shield is assessed positively. To sum up, the experimental validation of the numerical modelling has been assessed positively with the possibility of further improvement of the numerical models.

5. Conclusions

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

- The openwork shield demonstrates high relative energy absorption and has the key parameters, which are competitive on the market, i.e. thickness, mass per unit area, price.
- The design assumptions made for the range stand have been confirmed experimentally.
- The openwork protective steel impact of the shock wave increased dimensions like the auxetic material.

The results corresponding to the selected protective panel and selected HE charge are useful for the validation and verification of the numerical model of the protective shield. After the positive validation and verification, it is possible to conduct the numerical research for other blast conditions or optimise protective panels (for example different thickness of the plate). Compared to the experiments, the simulations are much cheaper and render it possible to predict the time-histories of displacement/velocity/acceleration, the effective stress and plastic strain. Such approach enables a fast and cheap design of the protective shield for the required protection level.

Acknowledgments

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