Numerical modelling and experimental validation of the protective shield – protected plate – test stand system under a blast shock wave

Marian Klasztorny[1], Tadeusz Niezgoda[1], Paweł Dziewulski[1], Marek Świerczewski[1]

[1]Department of Mechanics and Applied Computer Science, Military University of Technology
2 Gen. S. Kaliskiego Street, 00-908 Warsaw, Poland
e-mail: mklasztorny@wat.edu.pl

Abstract

The study presents FE modelling and numerical simulation of a system for range testing of protective shields for logistic and light armoured vehicles. The SPS system consists of the ALF protective shield, the Armox 500T steel protected plate and the multiple-use portable range stand. The HE spherical charge is suspended centrally over the stand. FE modelling, numerical simulations and postprocessing were performed with Catia, HyperMesh, LS-Dyna, and LS-PrePost software. The 8-nodes brick finite elements were used taking into account friction and contact phenomena. Isotropic and orthotropic material models and advanced nonlinear equations-of-state for subsequent parts of the system were chosen with relevant failure and erosion criteria. The shock wave was modelled approximately using the LOAD_BLAST_ENHANCED option available in LS-Dyna system. The study also presents respective experimental range tests of the system for verification and validation purposes.

Keywords: sandwich structures, blast, experimental mechanics, numerical analysis, damage

1. Introduction

The study develops FE modelling and numerical simulation of the range stand [3] for testing the protective shields [4] for logistic and lightly armoured vehicles' bottoms. There are presented numerical simulations and range experiments of the ALF protective shield – ARMOX 500T protected plate – test stand system (SPS) as well as of the reference PS system composed of the protected plate and the test stand. Both systems are exposed to blast shock waves induced by 2 and 4,38 kg TNT explosion.

2. The range stand and the ALF protective shield

The multiple-use portable range stand [3] is composed of three closed steel frames, respectively graded and connected together with high strength erection bolts. The stand has been designed to be loaded by a HE blast shock wave up to 6 kg TNT. The main cross-sections of the SPS system are depicted in Fig. 1. The range stand rests on a 20 mm thick horizontal plate stiffening the subsoil.

The design requirements put on a shield are as follows: a shield ensures protection of vehicle occupants against blast and fragmentation of AT mines and IED devices up to 8 kg TNT, according to Ref. [2]; a thickness of the shield cannot exceed 76 mm; a shield surface mass density does not exceed 50 kg/m^2; a shield is composed of removable panels; the shield is incombustible, resistant chemically and to atmospheric factors; a vehicle bottom armoured steel plate is of 5÷7 mm thickness; material and manufacture costs are relatively low.

Based on preliminary design calculations and ballistic tests, the aluminium – hybrid laminate – foam shield, denoted with the ALF code, has been designed that satisfies the design requirements. The shield consists of the following main layers [4]: a 2 mm EN AW-5754 (PA11) aluminum sheet, a 9 mm SCACS hybrid laminate, a 50 mm ALPORAS aluminum foam, and a 9 mm SCACS hybrid laminate. The main layers are connected together using SOUDASEAL 2K chemo-set glue in the form of 2 mm thick additional layers. The shield is connected to the protected plate with a 2 mm glue layer as well.

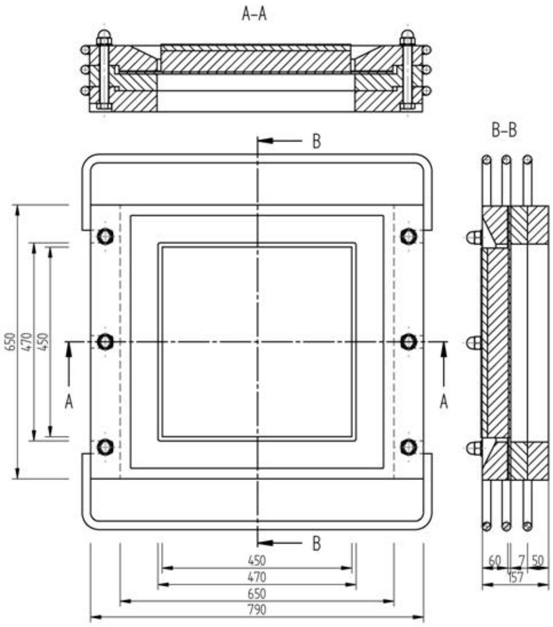

Figure 1: The SPS system and the main cross-sections [3,4]

The SCACS hybrid laminate plate, manufactured using the vacuum technology, is a 24-ply composite with the sequence of selected uniform cross-ply laminates based on an incombustible VE 11-M vinylester resin matrix, i.e. $\{[(0/90)_{GF}]_2, [(0/90)_{CF}]_4, [(0/90)_{AF}]_6\}_S$, where GF – SWR 800 glass fabric, CF – Style 430 carbon fabric and AF – Style 328/Kevlar 49 aramid fabric.

The HE spherical charge is suspended centrally over the stand at 400 mm distance from the top frame surface. The numerical simulations and experiments have been performed for 5 mm thick protected plates made of ARMOX 500T armoured steel.

Table 1: The numerical (N) and experimental (E) values of the maximum plastic deflection at the midpoint of the examined plate

system	2 kg TNT		4,38 kg TNT		δ_d [%]
	N	E	N	E	for 2 kg TNT
PS	13,5	12,8	48,9	–	0,15
SPS	-1,0	0,2	10,7	16,0	0,25

3. FE modelling and numerical simulation

The FE models were developed with CATIA and Altair HyperMesh software. The Lagrangian domain was limited by two planes of symmetry of the SPS/PS system. For all simulations the LS-Dyna nonlinear explicit solver was used. The 8-nodes brick finite elements with one integration point were used taking into account contact and friction phenomena. The FE PS model has about 98 000 DOFs, whereas the FE SPS model – about 282 000 DOFs.

The blast shock wave was modelled approximately using the LOAD_BLAST_ENHANCED option available in LS-Dyna V971/R4/Beta system [1]. The following material models for subsequent parts of the SPS/PS system have been selected [1]: ARMOX 500T steel, PA11 aluminum: MAT_15 (MAT_JOHNSON_COOK), EOS_GRUNEISEN equation-of-state; St3 steel, 10.9 bolt steel and hardened range subsoil: MAT_ 24 (MAT_PIECEWISE_LINEAR_PLASTICITY); woven fabric composites: MAT_161 (MAT_COMPOSITE_MSC); ALPORAS aluminium foam: MAT_26 (MAT_HONEYCOMB); SOUDASEAL glue: MAT_27 (MAT_MOONEY-RIVLIN_RUBBER).

Figure 2 presents the FE model of the SPS system. Exemplary results are shown in Fig. 3.

4. Experimental range tests

Figure 4 presents failures in the ALF shield after 2 kg TNT explosion. Values of the maximum plastic deflection at the midpoint of the examined plate for both systems are given in Table 1. The relative error related to the simulated deflection is calculated from the formula

$$\delta_d = \frac{|d_{num} - d_{exp}|}{L} \cdot 100\ \% \qquad (1)$$

where: d_{num} – the maximum plastic deflection in the numerical simulation, d_{exp} – the maximum plastic deflection in the experiment, $L = 470$ mm – the reference length (width of the square hole in the stand body).

5. Main conclusions

Numerical simulations and experiments described in this study have confirmed the following final conclusions. The range stand is resistant up to 6 kg TNT blast shock wave. The structural concept of the SPS system's parts have fulfilled all the requirements. The ALF protective shield has appeared as a high energy-absorbing system. The ALF shield ensures protection on level 3b [2]. For larger HE charges (more than 2 kg TNT) the glue connection of the protective shield to the protected plate has to be replaced with the bolt connections. Experimental verification ($\delta_d = 0{,}15\%$ and $0{,}25\%$) and validation ($\delta_d = 1{,}13\%$) of the FE numerical modeling of the PS and SPS systems has been assessed positively.

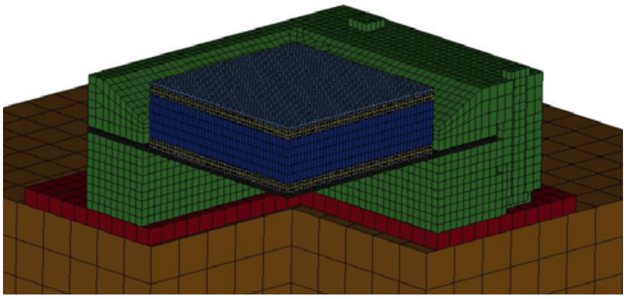

Figure 2: A quarter of the model of the SPS system

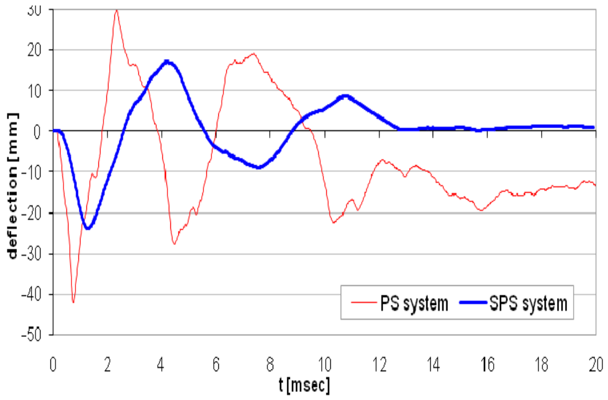

Figure 3: The vertical deflection vs time at the midpoint of the protected plate in reference to the PS and SPS systems under the2 kg TNT blast shock wave

Figure 4: The protective shield – protected plate subsystem removed from the SPS system after the 2 kg TNT explosion

References

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[2] *NATO MAS Standarization Agreement* (STANAG 4569): Procedures for evaluating the protection levels of LV and LAV vehicles for KE and artillery threats, 2004.

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[4] *Patent Application*: Klasztorny, M., et al., An aluminium – composite – foam shield for protection of military vehicle bottoms against mines and IED [in Polish], Warsaw, 2010.