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DETERMINATION OF BOUNDARY CONDITIONS FOR THE OPTIMIZATION PROCESS OF BLAST MITIGATION SEAT SHOCK ABSORBERS

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Abstract: *The aim of this study was to define the boundary conditions existing during examination of the seat on a drop-tower. Within the work, the basic information about mine blast phenomenon and its influence on the crew of special vehicles were gathered and discussed. The necessary use of blast mitigation seats was indicated and the basic methods for testing their efficiency were presented. A seat without shock attenuation system was examined. The conducted research allowed for determination of the acceleration levels measured at selected points. It was noticed that even without shock absorbing system, the seat is capable of mitigating some amount of incoming energy due to plastic deformation. However, it was not enough to lower the acceleration to a human tolerable level. This highlights the need for shock attenuation system implementation and optimization in order to minimize the acceleration transferred to the passenger. The obtained results provide a basis for further work in this area. The gathered signals were compared with literature data describing vehicle acceleration during mine blasts. The drop-tower used during the study proved to be suitable for explosion impact simulations.*

Keywords: Drop-tower, Acceleration sensor, Blast mitigation seat, Protection of military vehicle crew.

1. Introduction

Experiences gained during military conflicts in Iraq and Afghanistan showed that explosions of improvised explosive devices (IEDs) were the most common cause of death and injury of soldiers (Krzystała et al., 2012). According to the current state of knowledge the physics of a mine blast process and its impact on the vehicle can be divided into four phases (Ramasamy et al., 2010). The first one is the formation of a explosion shock wave, which causes damage to the hearing and internal organs of passengers. The second stage relates to penetration of fire debris through the hull of the vehicle. During the third phase, rapid vertical acceleration is applied to the vehicle and local bending of the floor may occur. The fourth and last state is associated with the heat and toxic gases transferred into the interior.

Each of these stages is connected to a different kind of threat. Therefore, it is necessary to use diverse protective measures in order to keep the crew alive (Krzystała et al., 2012). These include the appropriate shape of the hull and armor of the vehicle (Krzystała et al., 2016). These measures allow the for partial dispersion of explosion energy and protection of passengers from mine and soil fragments. However, they do not provide sufficient protection during the third phase. The rapid acceleration causes permanent spinal injuries and involves the risk of head injury (Krzystała et al., 2012).

Nowadays, anti-explosive seats have become essential pieces of equipment in mine-resistant vehicles. They allow for significant reduction of shock impulses to 20-25 g, which is considered to be the maximum limit of human tolerance for acceleration in a vertical axis (Krzystała et al., 2012). Research on these types of seats are carried out around the world by governments of various countries and private companies (Kargus et al., 2008). According to the standard NATO AEP-55 Vol. 2 (2011), the newly designed seats shall be validated during field blast-off tests. However, at an early stage of product development, they are too expensive and do not provide sufficiently reproducible results (Cheng et al., 2010).

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Drop-tests have become a widely-used method during research on blast mitigation seats. Their operating principle consists of dropping the object from a desired height, which is then rapidly decelerated during impact with the ground or a special pulse-shaper (Kargus et al., 2008). It has been proved that these tests can be characterized with different boundary conditions than those occurring during the actual mine blast (Cheng et al., 2010). The main difference is the relative displacement between the seat and the dummy which exists during drop-tests and which is not present in real explosions under a vehicle. Consequently, this generates decompression of the spine and seat cushions. These phenomena lead to overestimation of the seat's effectiveness. Despite this, drop-tower tests can be successfully used to obtain reliable conclusions. The condition is that the above mentioned differences must be taken into account during the analysis of results (Cheng et al., 2010).

The application of drop-tests has great practical importance during the optimization and verification of the effectiveness of a designed seat (Kargus et al., 2008). An important issue is to determine the boundary conditions present during the study. The choice of the proper initial height and pulse-shaper construction has a large influence on the characteristics of the generated acceleration (Cheng et al., 2010). Moreover, a test of the un-damped seat shall be conducted and the obtained data can be used later for a comparison of different shock absorbing system solutions.

2. Methods

Accelerations were recorded using an automatic measuring system for the acquisition of rapidly changing voltage signals (Szmidt et al., 2011). The experiment setup consisted of a drop-tower, an un-damped seat and three ADXL001-500 accelerometers (Fig. 1a). They were placed on the falling carriage, the seatback and the seat cushion. According to NATO AEP-55 Vol. 2 (2011), the sampling frequency was set to 100 kHz. The signal was calibrated for zero offset error with the use of 100 ms pre-trigger data.

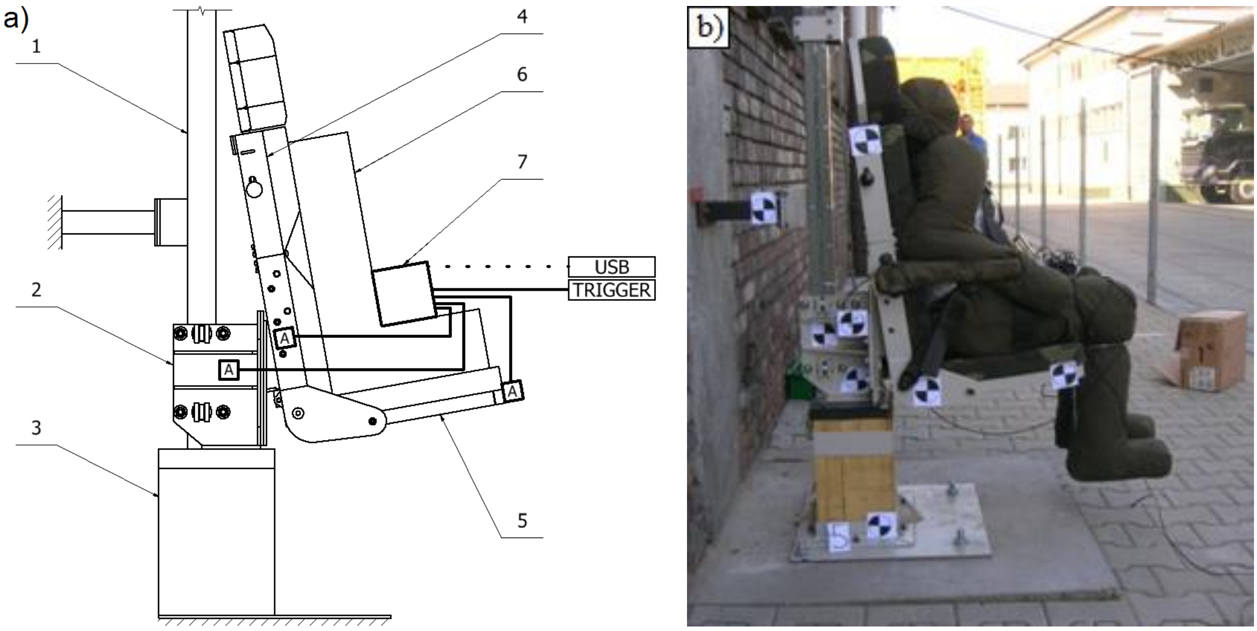

Fig. 1: Experiment setup: a) physical model, b) real object (1 – rail, 2 – carriage, 3 – bumper, 4 – seatback, 5 – seat cushion, 6 – 80kg load, 7 – analyzer, A - accelerometers).

The test stand consisted of a carriage, which moves along a vertical sliding guide (Fig. 1b). The mounting method of the seat to the carriage was the same as in a real vehicle. After dropping, the whole assembly was decelerated on a bumper made of wood and rubber. The purpose of this element was to shape the input acceleration pulse whose duration, according to Cheng et al. (2010), should not exceed 10 ms.

The initial height of the carriage was set to 3 m. This height was chosen to provide the input acceleration value of at least 300 g (Krzystała et al., 2012). Interaction between the seat and the passenger was modeled in a simplified manner by placing weights on the seat with a total mass of 80 kg. The use of a more advanced anthropomorphic test device (ATD) was not possible due to the considerable risk of damage caused by the lack of a shock absorbing system.

The results were compared by calculation with the use of FEM model prepared in LS-Dyna software. It consisted of approximately 800 000 elements. In order to simplify calculation following assumptions were made. The dummy was replaced with lumped mass of 80kg connected to seat cushion, so it was assumed to be a rigid body. Only 80 ms of simulation was performed. The carriage and seat were placed 100 mm above the bumper. The initial velocity of system was set to 7.5 m/s. It was calculated according to energy conservation principle, assuming that carriage was falling from 3 m. The piecewise linear plasticity material model with bilinear stress-strain interpolation was used for all metallic parts.

3. Results and discussion

The dependence of the acceleration from its time measured at selected points of the system was presented in Fig. 2. In order to analyse the results of data only linked directly to impact deceleration, all signals were processed with the use of a filter CFC-180 Hz recommended by the SAE standard J211-1 (1995). This enabled filtering out the part of the signals associated with the mechanical vibration on high frequency, which were not investigated.

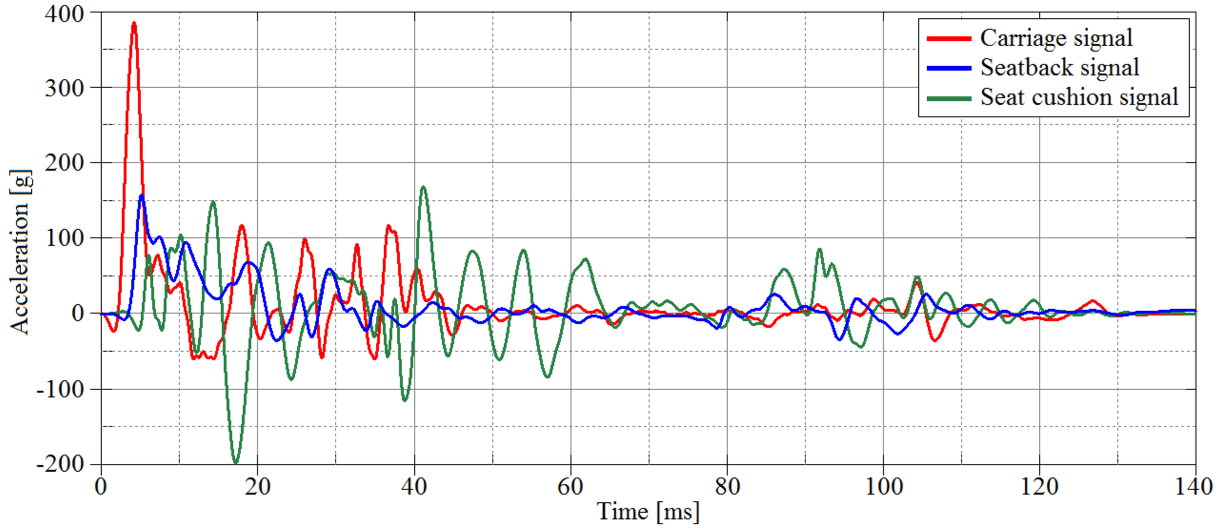

Fig. 2: Acceleration recorded during experiment at selected points of the system.

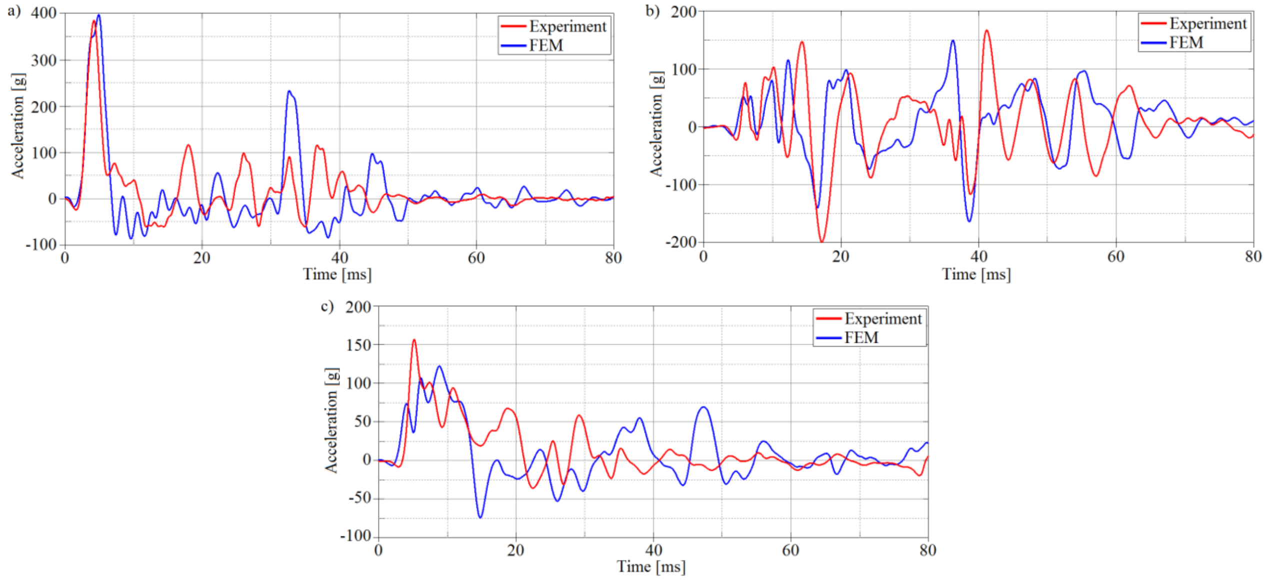

Fig. 3: Comparison of experimental and FEM results for: a) carriage, b) seat cushion, c) seatback.

Comparison of FEM and experimental results (Fig. 3) showed a good convergence between them. Divergence for input signal recorded for the carriage (Fig. 3a) did not exceed 10 % for initial, highest peak. The acceleration amplitude range and signal shape obtained during numerical simulation for another two measuring points (Fig. 3b-c) were in satisfactory correlation with the experimental data.

Simplifying assumptions and not taking into account the energy lose due to friction between drop-tower guide and carriage were the main reasons of differences between results.

Carriage acceleration reached 380 g, which thus exceeded the assumed minimum value of 300 g. This proved there had been an accurate choice of initial height. The pulse duration of platform acceleration did not exceed 10ms. Thus showing, the drop-tower allowed for the generation of acceleration impulses similar to those occurring during a mine explosion under the vehicle.

Acceleration recorded for the seatback did not exceed 160 g. Despite the lack of a shock attenuation system, partial reduction of input acceleration occurred. The reason for this was the presence of relative displacements between elements, which were caused by strains in bolted connections and small deformations of the seat construction.

Oscillations of the seat flap, with an approximate amplitude of ± 200 g, were observed. This was due to the design of the seat bottom part, which is fixed to the seatback by means of two rotational kinematic pairs. They increase functionality of the seat, but also lead to greater displacements, and thus the acceleration, recorded during impact.

4. Conclusions

The acceleration characteristics of a carriage during an impact correlates well enough with the basic parameters of impulse generated by a mine blast. Therefore, a drop-tower can be successfully used for testing anti-explosion seats.

The chosen value of initial height allowed for achievement of an input acceleration of 380 g, which is well above the assumed minimum. This indicates the possibility of a reduction in initial height during further research.

The identified acceleration of the seatback turned out to be lower than the input pulse. This implies that despite the lack of a shock absorbing system, the seat construction provides a partial reduction of acceleration transmitted to the passenger. However, obtained values are still an order of magnitude larger than the level of human tolerance to the acceleration in the horizontal axis. Therefore, implementation and optimization of the shock attenuation system is a necessary condition, so that the seat can ensure a sufficient level of protection during mine explosion.

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References

Cheng, M., Dionne, J. and Makris, A. (2010) On drop-tower test methodology for blast mitigation seat evaluation. International Journal of Impact Engineering, 37, pp. 1180-1187.

Kargus, R., Li, T., Frydman, A. and Nesta, J. (2008) Methodology For Establishing The Mine/IED Resistance Capacity of Vehicle Seats, in: Proc. 26th Army Science Conference, Army Research Laboratory, Orlando.

Krzystała, E., Kciuk, S. and Mężyk A. (2012) Identification of hazards to the crew of special vehicles during an explosion. Scientific Publishing House of The Institute for Sustainable Technologies, Gliwice.

Krzystała, E., Kciuk, S. and Mężyk A. (2016) Minimisation of the explosion shock wave load onto the occupants inside the vehicle during trinitrotoluene charge blast. International Journal of Injury Control and Safety Promotion, 23:2, pp. 170-178.

NATO AEP-55, Volume 2 (2011) Procedures For Evaluating The Protection Level of Armoured Vehicles - Mine Threat.

Ramasamy, A., Masouros, S., Newell, N., Hill, A., Proud, W., Brown, K., Bull, A. and Clasper J. (2010) In-vehicle extremity injuries from improvised explosive devices: current and future foci. Philosophical Transactions of The Royal Society B, 366, pp. 160-170.

SAE J211-1 (1995) Instrumentation for Impact Test, Part 1, Electronic Instrumentation.

Szmidt, P., Kciuk, S., Mężyk, A. and Krzystała E. (2011) Autonomous measurement system for the acquisition of rapidly changing voltage signals. PL Patent, 219525.