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NUMERICAL STUDY ON THE MODIFICATION EFFECT OF THE SEAT LOAD ACTING ON A SOLDIER DURING THE BLAST WAVE DERIVED FROM IED EXPLOSION

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Abstract

The structure of a vehicle located in the explosion area of an anti-vehicle mine or an IED is subject to a strong impact of a blast wave. The explosion of a mine produces a blast wave that travels in all directions at a speed greater than the speed of sound. The level of risk to the crew of a military vehicle depends on their distance from the place of detonation, on the vehicle's design and in particular on the design of the bottom of the hull and on the assembly and type of seats. The article provides the analysis of the impact of a side explosion on the crew of an armoured vehicle. Since the new classified version of the AEP-55 document, which defines the conditions for testing the resistance of military vehicles to explosions affecting their side, is not available, it was assumed in the numerical analysis that the charge weight of the explosive device is 100 kg TNT, placed between the central vehicle axles at the distance of 400 mm from the bottom and 1,000 mm from the lower board.

Two cases were analysed: one where the Hybrid III dummy was placed on the reference seat and the other where it was placed on a modified seat.

The analysis is conducted using the LS-DYNA explicit code. Only the vehicle's hull is considered with suspension and the turret is modelled with mass.

Keywords: *vehicle safety, mine resistance, Improvised Explosive Device, occupant safety, FEM analysis*

1. Introduction

Armed conflicts and numerous threats connected with them, for instance in the Near East, force the necessity of constant search for new design solutions of armoured vehicles. Special emphasis is placed on the protection of a vehicle and the crew inside it from the consequences of an attack with the use of landmines and Improvised Explosive Devices. Detonation thereof produces an explosion blast wave which, when reaching the vehicle's hull, loads it in a pulse way causing a significant acceleration within a few milliseconds. Inertial forces occurring this way cause body injuries, e.g. the injuries of limbs as well as the spine and head, which very often result in death. The current research based on analyses of consequences of actions conducted in Iraq and Afghanistan as well as guidelines concerning the requirements that modern designs should meet (NATO – STANAG 4569), are aimed at increasing the mine-resistance of military vehicles. Due to threats, it becomes the basic requirement for armoured vehicles.

The article presents an attempt to determine the current status of the topic regarding design solutions of the seats of armoured vehicles and conduct numerical analyses of the impact of the blast wave load on the seats of the KTO Rosomak vehicles. The numerical analysis of an example of a possible seat design modification, which renders it, that is possible limits the explosion consequences, was presented and conducted. In order to achieve the targeted aim, the MES finite elements method in LS-Dyna was used.

2. Threats to the crew of special vehicles and the ways of minimising them

The experiences of fights in Afghanistan and Iraq demonstrated the high effectiveness of IEDs, measured with the number of killed soldiers. The number of deaths caused by the IED activity in comparison to other causes of death was presented in Fig. 1 [1].

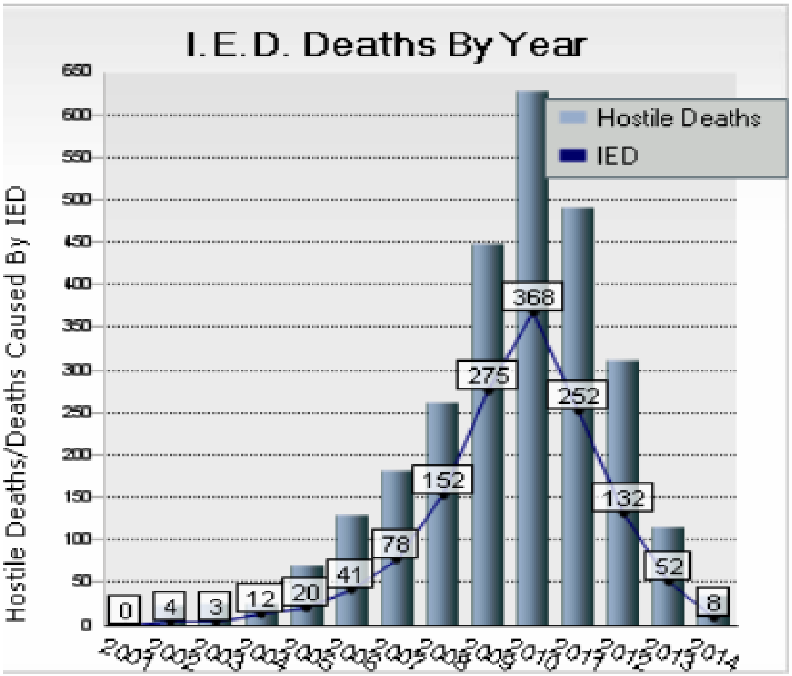

Fig. 1. The percentage share of IED when compared to other causes of death, caused by the actions of the enemy during OEF/ISAF missions in Afghanistan [1]

Military vehicles used during armed hostilities are subject to the activity of a blast wave resulting from the explosion of landmines or IEDs, which travels in all directions at a speed greater than the speed of sound. It surrounds the hull of a vehicle and causes vibrations, which are the reason for the overload in the vehicle's cabin [5]. Apart from that, the occupant of an armoured vehicle is exposed to a number of negative factors: increasing pressure, slivers that can get into the vehicle's cabin and acceleration reaching the amount of several hundred g [6, 7].

3. Explosion-proof seats – ways of protecting crews

Creating the design of a vehicle, which can survive an explosion, constituted only a partial solution of the problem. Ensuring safety for the crew inside a vehicle was a more important issue. Proper explosion-proof seats, which have to be closely adjusted to the design of a given vehicle, are key in that case. Many design solutions of seats in different configurations have been created so far. Seats can be mounted to the roof, hull or the floor of a vehicle (Fig. 2). This is a very important factor, which has an impact on the explosion-proof properties and occupant's safety. However, it should be kept in mind that explosion-proof seats are an integral part of a vehicle; therefore, the manner and place of mounting them must be adjusted to the design possibilities of a concrete model of an armoured vehicle. We can divide seats also in terms of their purpose: for the crew, for the commander, for the driver and for the shooter. Allen Vanguard, Jankel and Blasttech are recognised leaders offering specialised explosion-proof seats for armoured vehicles. From among other companies, also the following ones should be mentioned: Autoflug, Global Seating Systems, Armor Works, SJH Projects, BEA Systems, Martin-Baker, Vital Seating and Systems (VSS), Qinetiq.

a) b) c)

Fig. 2. Examples of explosion-proof seats: a) a seat mounted to the roof of a vehicle manufactured by Allen Vanguard [3], b) a seat mounted to the side of a vehicle manufactured by Allen Vanguard [3], c) a seat mounted to the floor of a vehicle manufactured by JANKEL [4]

4. Numerical model of a vehicle with an occupant

The numerical model was prepared for a simulation with the use of the LS-DYNA commercial code. This software allows for the non-linear simulation of the dynamic behaviour of systems. The view of the numerical model is shown in Fig. 3. Welds were not considered in this simulation. The vehicle's steel hull was modelled using the Johnson-Cook model implemented as MAT_15. Armox 500T ballistic steel was used. Properties required for the numerical model were obtained from the literature. Constants used for the constitutive model and the Mi-Gruneisen equation of state are shown in Tab. 1.

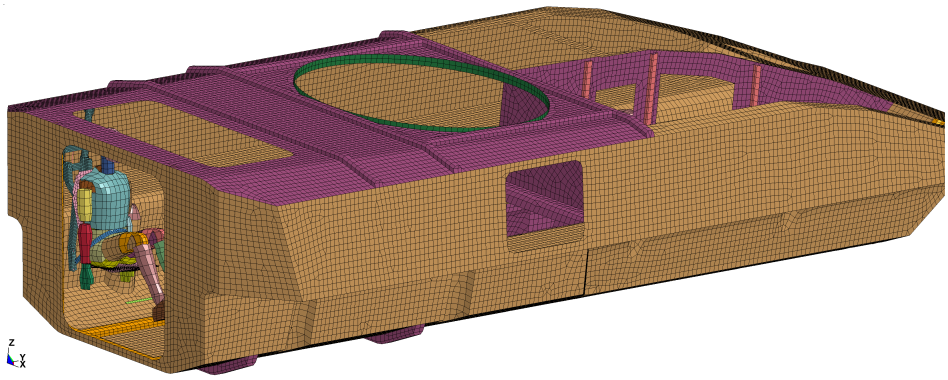

Fig. 3. The view of the model of an armoured transporter with a seat

The model does not include lower chassis, suspension, wheels and turret. These elements were simulated by mass elements attached to the structure with the use of interpolation constraints. The mass of the entire system was around 16 tons. The dummy used was a 50-centyle Hyrid-III male implemented separately into LS-DYNA. The Hybrid-III dummy was placed on the seat with footrest and seatbelt. The explosion between the middle axles of the vehicle in the distance of 400 mm from the bottom and 1000 mm from the lower board. Calculations were made for two variants of seat design solutions:

1. the original vehicle design (reference seat),
2. a modified one.

The design modification consisted in changing the manner of mounting a seat to the vehicle's hull. In that case, the seat was mounted to the roof of an armoured vehicle, thanks to which the impact of a shock wave during an explosion was significantly lower than in the case of the standard solution, in which the seat is mounted to the sideboard.

The dummy positioning is depicted in Fig. 4. It was placed on a rigid seat mounted to the wall of the vehicle. The simulated explosion centre was localised below the rear axle at 800 mm distance from the vehicle's bottom. Different explosive sizes were considered – 8 and 10 kg. Explosion was modelled using the CONWEP function implemented in LS-DYNA. The function generates pressure impulse on the vehicle's bottom. As gravity was also considered, the dummy was stabilised and after 100 ms detonation occurred. The total simulation time was 200 ms. Computations were conducted on the multiprocessor cluster in the Department of Mechanics and Applied Computer Science.

a) b)

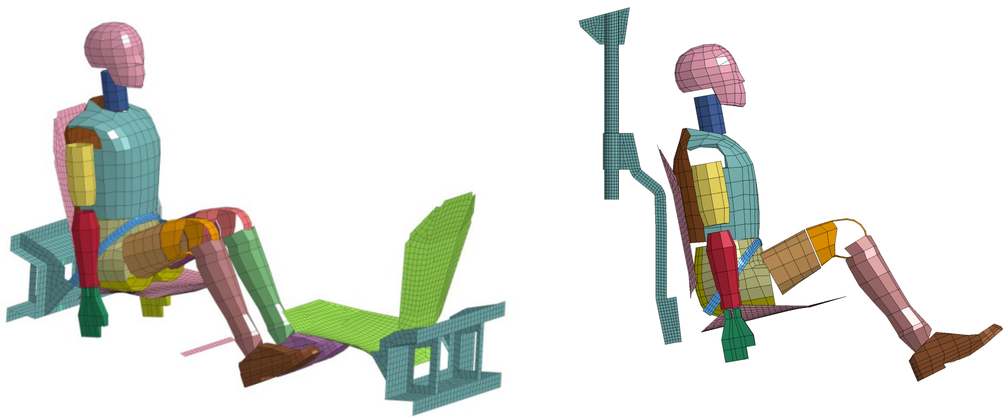

Fig. 4. Dummy positioning: a) the reference seat, b) a modified seat

Tab. 1. Material constants for Armox 500T steel and Mie-Gruneisen equation of state coefficients

	Name	Value
Johnson Cook	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, T_M	1800
	Room temperature, T_R	239
	Quasi-static threshold strain rate, EPS_0	0.001
	Specific heat, C_P	450
EOS	Gruneisen gamma $GAMMA_0$	1.93
	First order vol. correction A	0.5
	Initial internal energy E_0	0
	Initial relative volume V_0	1

5. Numerical simulation results

As a result of simulations, the deformation of the vehicle hull and behaviour of the Hybrid-III dummy were observed. For each load case, several parameters were calculated:

- acceleration in the vertical direction of the pelvis,
- longitudinal force in the lumbar spine,
- longitudinal and lateral force in the neck,
- longitudinal force in tibia.

As previously mentioned, the termination time for the analysis was 200 ms.

Deformation of the vehicle and behaviour of the Hybrid-III dummy in the subsequent moment of time in the case of the reference seat are shown in Fig. 5. Plots of the calculated Hybrid-III dummy parameters during the detonation are depicted in Fig. 6-7.

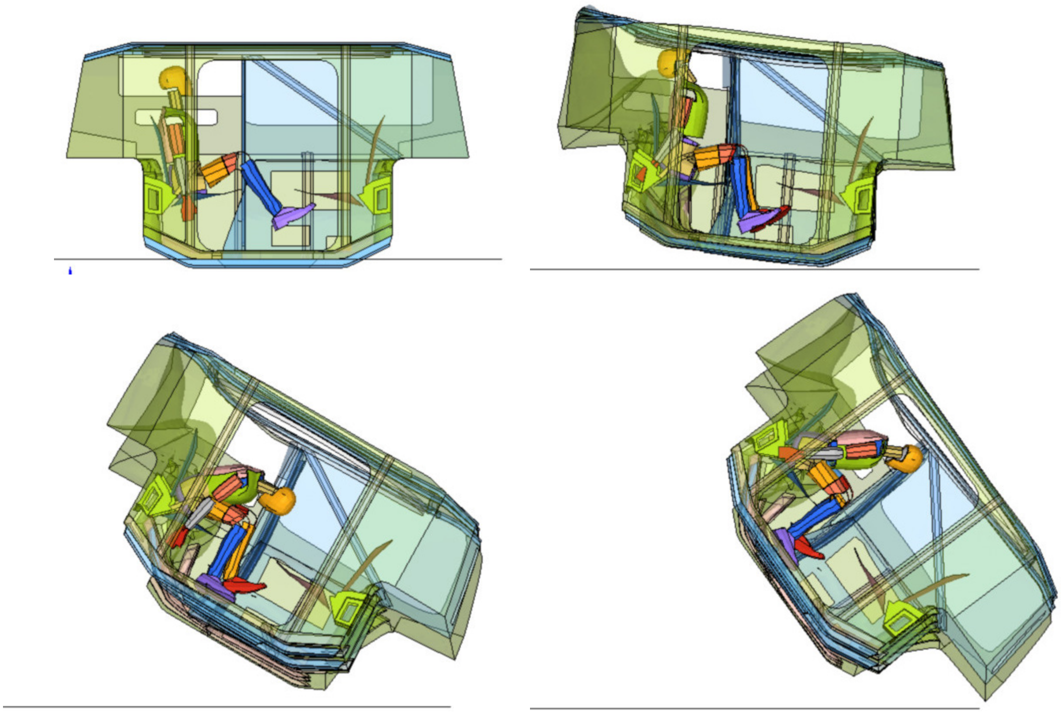

Fig. 5. Hull deformation and dummy behaviour for the subsequent moments of time during the detonation of 100 kg of TNT (reference seat)

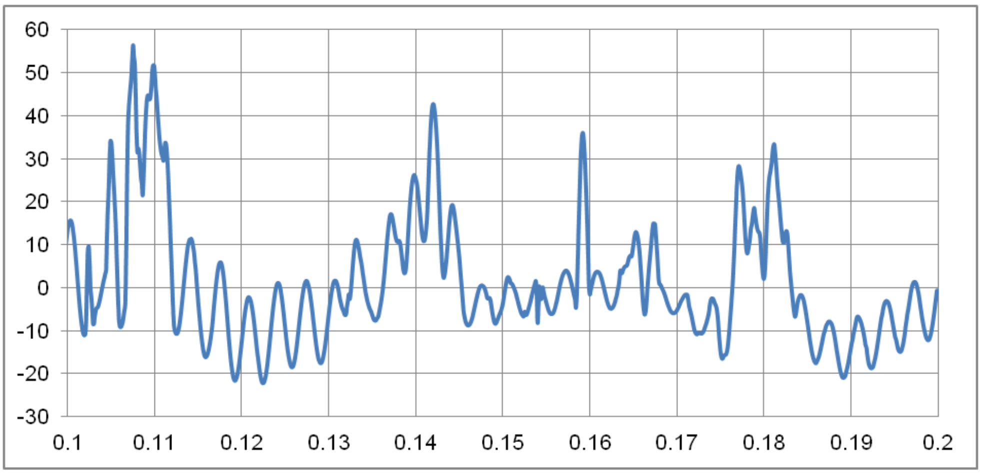

Fig. 6. Pelvis vertical acceleration [g]

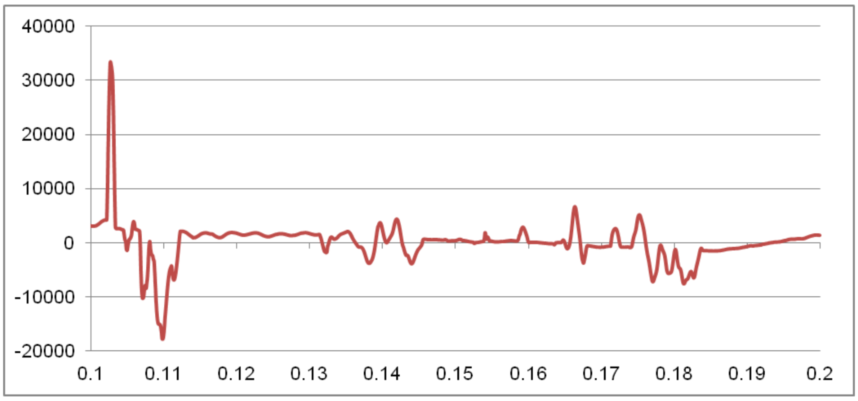

Fig. 7. Longitudinal force in the lumbar spine [N]

The deformation of the vehicle and behaviour of the Hybrid-III dummy in subsequent moment of time in the case of the modified seat are shown in Fig. 8. Plots of calculated Hybrid-III dummy parameters during the detonation are depicted in Fig. 9-10.

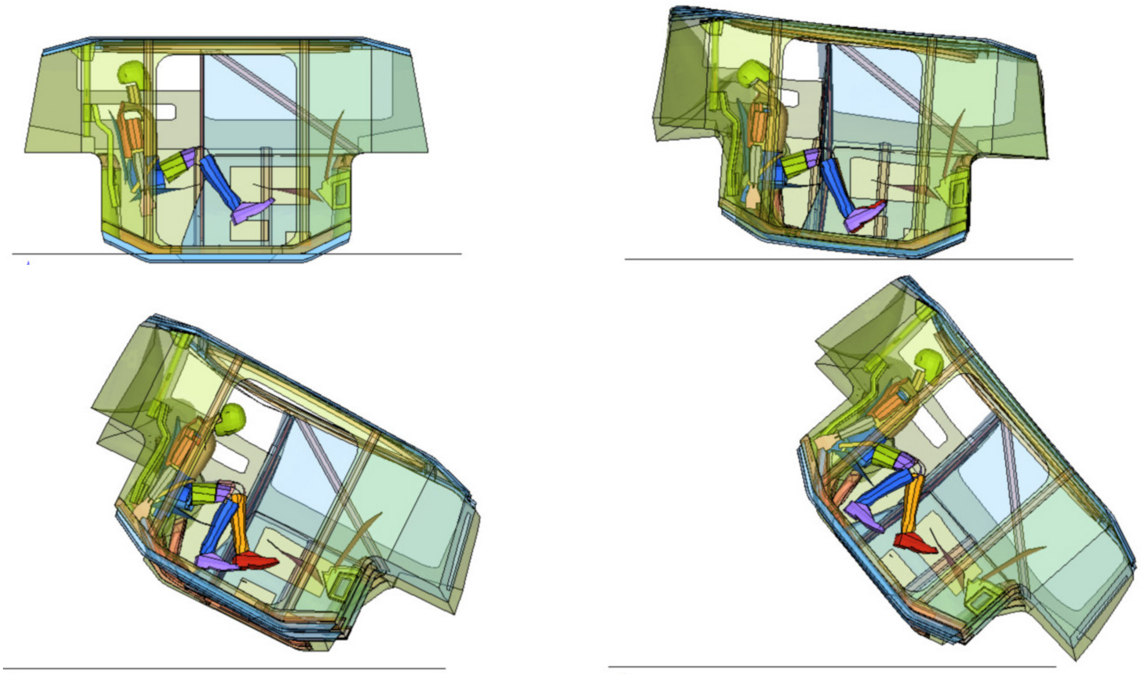

Fig. 8. Hull deformation and dummy behaviour for the subsequent moments of time during the detonation of 100 kg of TNT (modified seat)

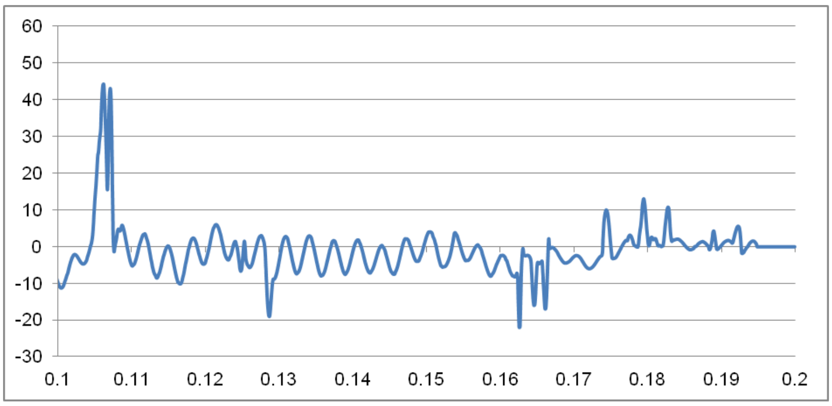

Fig. 9. Pelvis vertical acceleration [g]

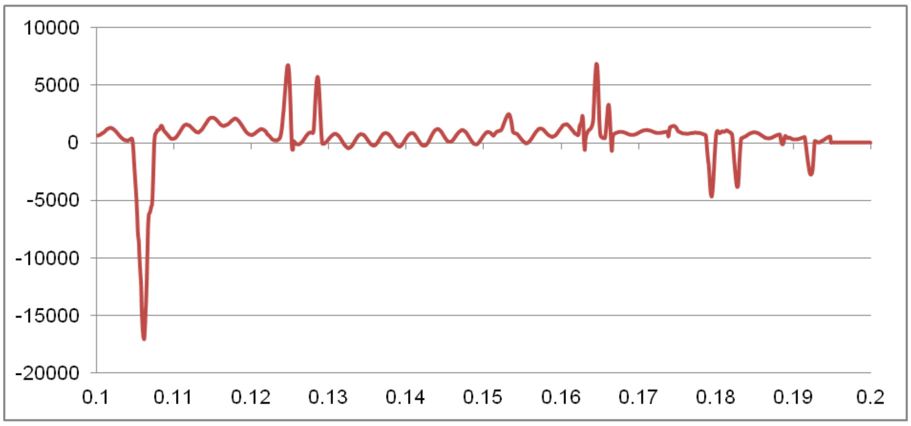

Fig. 10. Longitudinal force in the lumbar spine [N]

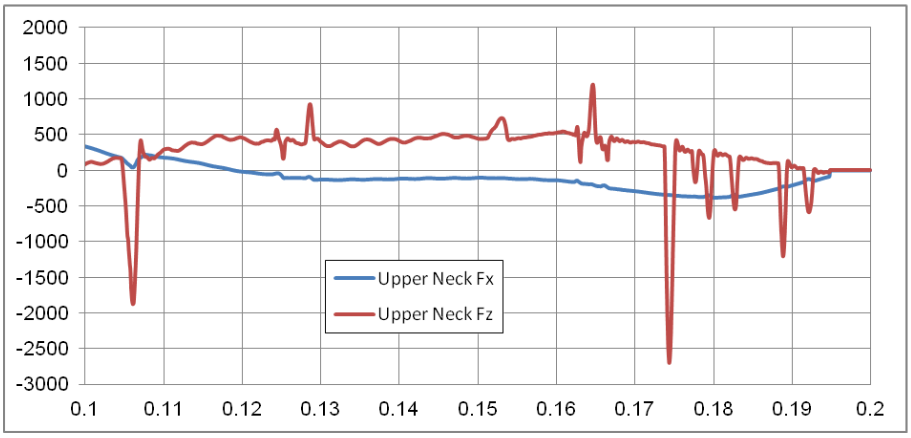

Fig. 11. Longitudinal and lateral force in the neck [N]

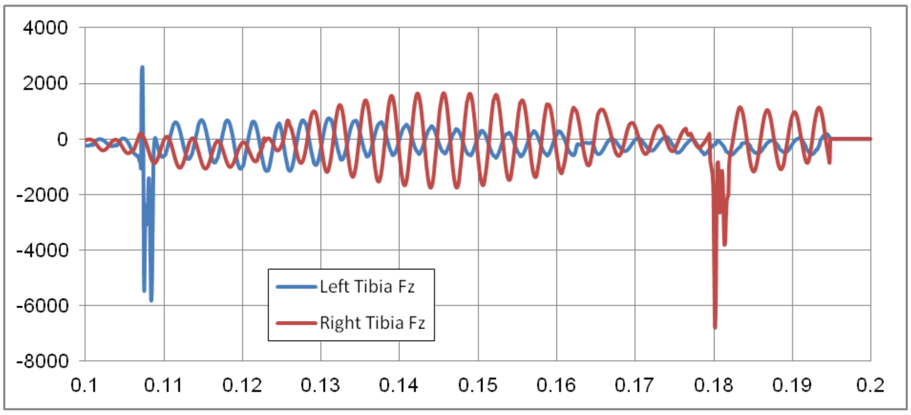

Fig. 12. Longitudinal force in both tibia [N]

In Table 2 there are the results of maximum values of forces and accelerations in pelvis, lumbar spine, upper neck and tibia.

Tab. 2. Comparison of influence of emissions of different types of transport

Variant	Pelvis „Z" acceleration [g]	Lumbar Fz [N]	Upper Neck Fz [N]	Upper Neck Fx [N]	Tibia R Fz [N]	Tibia L Fz [N]
reference seat	50	33000	5500	-220	5400	-26700
modified seat	44	-16200	-2700	-450	-6700	-5370

6. Conclusions

The size and place of the detonation of an explosive assumed in the numerical analysis caused the strong local and global impact on the vehicle and a soldier. Significant hull deformations and the visible effect of the rolling of the hull resulted in the great overload in the anthropometric points of the dummy's body. The analysis of the dummy's behaviour in the case of the reference variant allowed for the observation of multiple bumps of the head against the vehicle's roof than in the case of the modified variant, which undoubtedly increases the possibility of the compression injury of the cervical spine.

The application of the modified seat during a side explosion decreases the forces and accelerations acting on Hybrid III, which demonstrates the correctness of assumptions made while designing the assembly manner.

The next step, which can have an even greater impact on decreasing the overload acting on a soldier, would be the application of four- or five-point belts and additional energy-absorbing elements regarding the way of mounting a seat to the hull.

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References

[1] Brzozowski, R., Guła, P., Sanak, T., *Obrażenia powybuchowe tkanek miękkich. In: Bezpieczeństwo wojsk w aspekcie zagrożeń wynikających z użycia improwizowanych urządzeń wybuchowych (IED),* Wyd. Akademii Obrony Narodowej, pp. 117-124, 2014.
[2] Gzik, M. et al., *Modelowanie ciała żołnierza na potrzeby analizy biomechanicznej wpływu obciążenia pochodzącego od fali uderzeniowej*, XI Konferencja Naukowa Majówka Młodych Biomechaników im. Prof. Dagmary Tejszerskiej, pp. 33-34.
[3] https://www.allenvanguard.com.
[4] http://old.jankelts.com.
[5] Krzystała, E., Kciuk, S., Mężyk, A., *Identyfikacja zagrożeń załogi pojazdów specjalnych podczas wybuchu*, Wydawnictwo Naukowe Instytutu Eksploatacji – Państwowy Instytut Badawczy, Gliwice 2012.
[6] Krzystała, E., Mężyk, A., Kciuk, S., *Analiza zagrożenia załogi w wyniku wybuchu ładunku pod kołowym pojazdem opancerzonym,* Zeszyty naukowe WSOWL, No. 1(159), 2011.