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SEAT AS AN ELEMENT IMPROVING PHYSICAL PROTECTION OF SOLDIERS DURING EXPLOSION OF MINES UNDER THE ARMOURED MILITARY VEHICLES

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Abstract

This study presents possibilities to apply the numerical simulation of dynamic response for explosive (impulse) loads, caused by detonation of mine under the military armoured vehicle, acting on a crew member seating in chair, in order to determine methods to minimize the results of impact of vehicle body structure on the crew, mainly caused by it accelerations and overloads.

Furthermore, this article presents factors, which have impact on numerical model and detonation phases necessary to conduct the mentioned above simulation. Information on physical values acting on the soldier and injuries resulting from such actions are important to understand how important element, improving physical protection of soldiers during mine detonation below the armoured military vehicle, is a chair.

According to the dissertation "Development Of Lower Extremity Injury Criteria And Biomechanical Surrogate To Evaluate Military Vehicle Occupant Injury During An Explosive Blast Even" the most common injuries occurring during mine explosion under the military vehicles, eliminating soldiers from further service, include: sprain of vertebras, fracture of vertebra, light fracture of skull, brain shaking, brain concussion, fracture of tibia, damage to ilia, fracture of fibula bones. These injuries occur most often at the first two stages of explosion, called local and global effect.

Keywords: *military, explosive charge, explosion results, numerical model, injuries, safety*

1. Introduction

The experiences of Polish Armed Forces in current and recently finished warfare demonstrate important role played by individual equipment in protection of life and health of soldiers. The important role of elements of structure and elements of equipment of vehicles participating in military conflicts, exposed to results of explosions of mines under the vehicle or near such vehicle on daily basis, shall be also stressed. The factors, which have impact on improvement of safety of the armoured vehicle crews, may be specified and divided into three groups (Fig. 1).

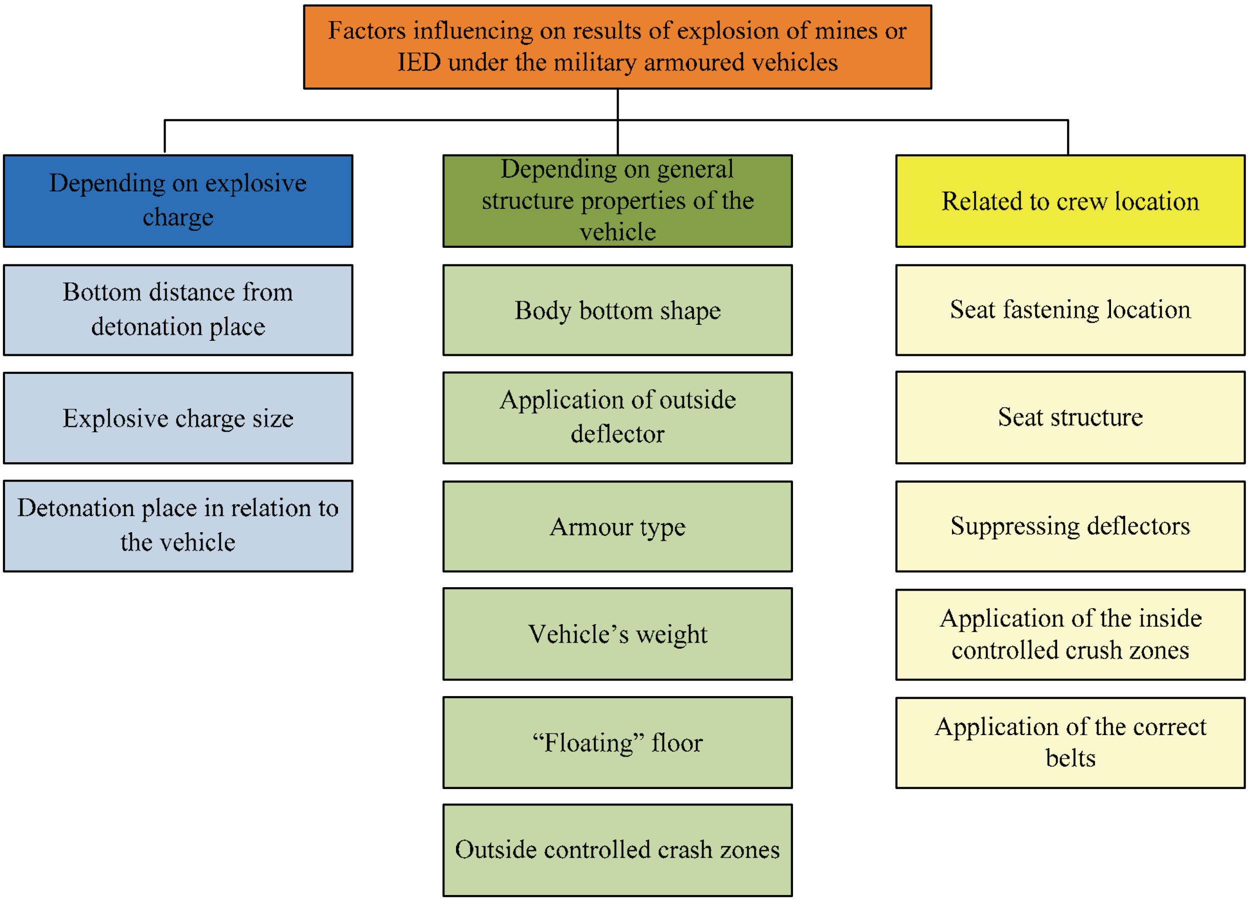

Fig. 1. Specification of factors, which have impact on result of explosion of mines under the military armoured vehicles
Source: Author's studies

As arrangement of convoys on the main transport routes within the responsibility area is the main task of the Polish Military Force in Iraq and in the current mission in Afghanistan, there is high danger from the improvised explosive charges, which are more and more often used together with antitank mines in order to increase the explosion force. The current rigid structure of the driver's seat, as well as assault group seat does not secure the increased physical protection for soldiers.

This study presents analysis of impact of the seat as one of elements improving protection, which up to the current days is not used in the armoured vehicles used by military forces, and analysis of numerical simulation of dynamic response for explosive loads.

2. The analysis of results of mine explosion under the military armoured vehicles, which have impact on the numerical model

At least the minimum number of physical values (forces, moments and accelerations) presented on Figure 2 for the specific type of vehicle with specific general structure properties and for various versions depending on detonation place and explosive charge size shall be determined in order to conduct the correct simulation of the seat's structure.

When the permitted accelerations, forces and moments acting during explosion under the military armoured vehicle are exceeded, it may, in the worst case, results in death or permanent damage to health. However, application of the additional protection in the form of a seat, properly selected fastenings and locations for such fastenings, shall decrease a risk of loss of life and shall allow decreasing a risk of injuries eliminating soldiers from further service.

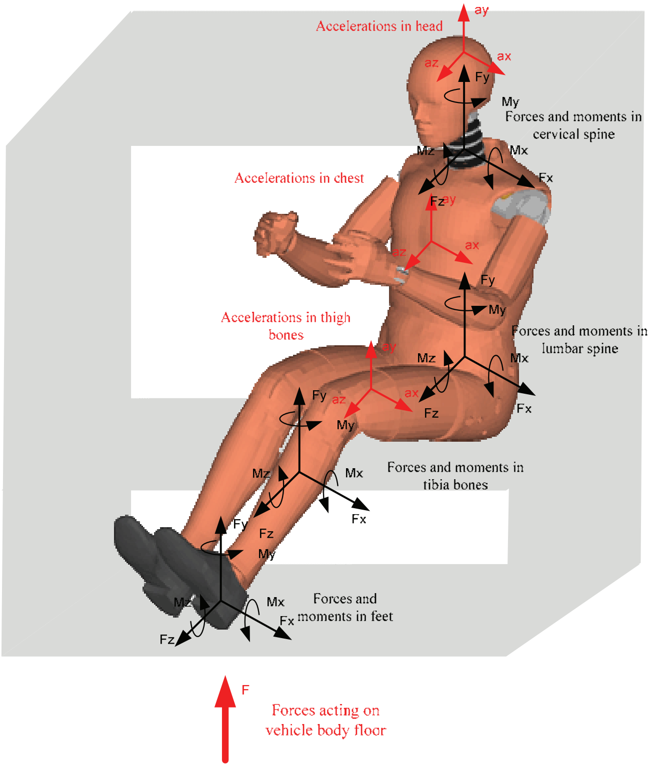

Fig. 2. Forces, moments and accelerations acting on the soldier during the mine explosion under the vehicle
Source: Author's studies

The most common injuries during mine explosion under the military vehicles, eliminating soldiers from further service, include [1]:

- Sprain of vertebras – recovery within three months,
- Fracture of vertebra – recovery within four month,
- Light fracture of skull – recovery within six months,
- Brain shaking – recovery within one month,
- Brain concussion – recovery within six months,
- Fracture of tibia – recovery within more than three months,
- Damage to ilia – recovery within more than three months,
- Fracture of fibula bones – recovery within more than three months.

The following diagrams present statistical data of mine explosion or IED under the military armoured vehicles:

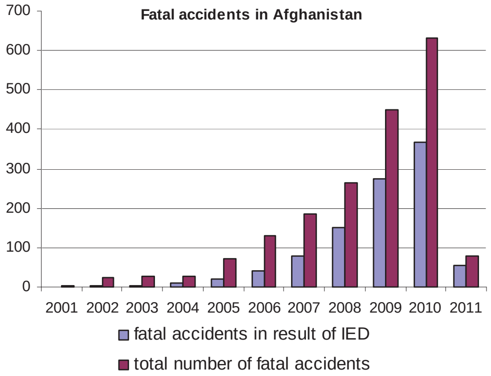

Fig. 3. Total number of fatal accidents of soldiers participating in mission in Afghanistan
Source: Prepared on the base of data from www.iCasualities.org

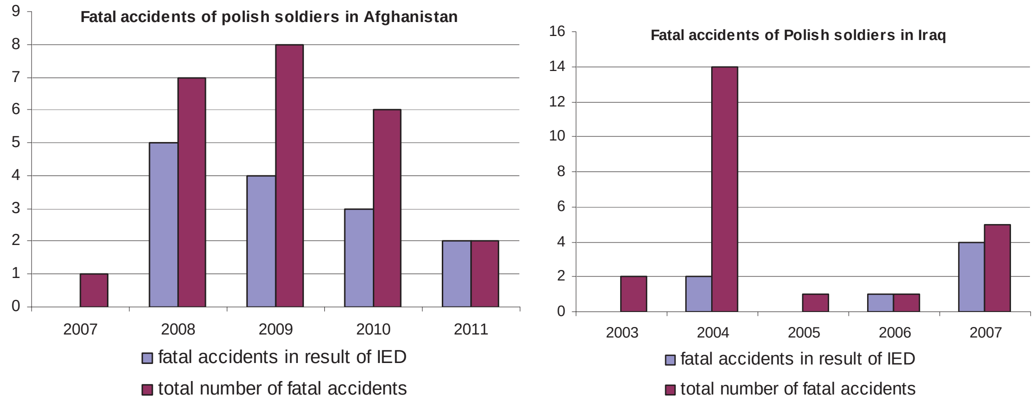

Fig. 4. Total number of fatal accidents of Polish soldiers participating in mission in Afghanistan and Iraq
Source: Prepared on the base of data from www.iCasualities.org

3. Phases of detonations necessary to conduct the numerical simulation

An explosion may be described as a series of effects acting on both vehicle and a crew. The short specification of effects is described below [7]:

Local effect – the first phase of explosion, acceleration of shock wave till it reaches the vehicle body bottom, then contact of the shock wave with the body, reflection of this wave and again acceleration through the vehicle structure where elastic and plastic deformations take place, depending on the vehicle’s structure. The very high amplitude and short duration of this effect cause transmission of high loads into feet and pelvis part of the crew’s member. This effect is ended after 50ms from initiation of detonation.

Global effect – as the vehicle's body absorb part of energy emitted by the shock wave, also the weight of vehicle has impact on absorption of this energy, e.g. process of lift-off from the ground. The vehicle starts to move up between 10 and 20 ms of detonation and reaches a maximum peak between 100 and 300ms. The reached vehicle height depends on mass of explosive charge and weight of vehicle. In this effect, a soldier not protected by additional means of protection is more exposed to injuries, even a loss of life, than soldier protected by e.g. special seat.

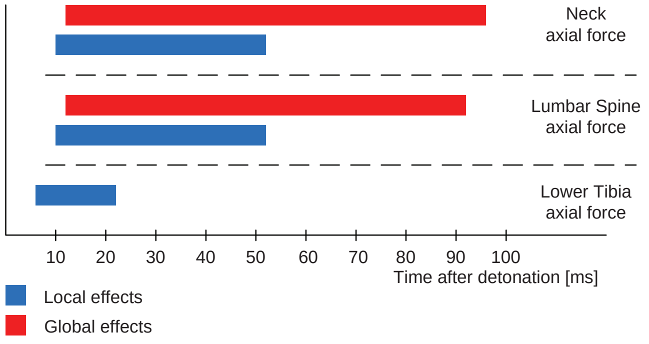

Fig. 5. The summary of overloads in local and global effect
Source: Prepared on the base of [1]

Free drop effect – after reaching the maximum height in the global effect, vehicle will freely drop down. The overloads will be again transmitted during this drop, but they are not as high as in the global effect.

Further effect – after drop of the vehicle on the ground, the vehicle’s crew is exposed to such factors as fire, toxic fumes, explosion overpressure and elements of vehicle falling into pieces.

As regards the mentioned above effects, computer simulation shall cover mainly the first two effects: local and global, such selecting the seat structure and fastening places to minimize results of impact of body structure on the crew, mainly caused by this accelerations and overloads.

4. The possibility to improve the crew’s survival by using a seat. The numerical simulations of dynamic response for explosion (impulse) loads

A significant difficulties and high costs of experimental research in the subject matter and development of computer analysis methods, both in structural analysis of structure and biomechanics of human body in shock loads conditions, cause that the computer simulation methods of the fast changing dynamic effects have played for some time important role in designing the better, more safe solutions [8-13].

The numerical simulations of extreme fast-changing phenomena, such as explosions under the armoured vehicle, are the specially demanding tasks. In such case, dynamic analysis by finite element method may be carried out only by method of explicit integration of dynamic equations, i.e. by *explicit* method [2].

The development of the numerical models of a seat for such analysis requires to undertake several important decisions - where information on the initial stage are fragmentary and with high margin of uncertainty.

Therefore, such variants of modelling shall be considered, which provide feedback of information covering as large as possible area of the assumed input data. The correlation of obtained results and initial assumptions will verify numerical models and allows deciding which detailed modelling technique are proper.

The following shall be mentioned among the key parameters, important for correct simulation of typical task of “fast dynamics” [3]:

- development of discrete object model – development of FE mesh reflecting both properties of structure as possible mechanisms of adjustment (mobility) of parts of a seat,
- adoption of model of a finite element appropriate for description of continuum and to the adopted simplifications of structure work modelling,
- adoption of the proper model of seat material constitutive law,
- adoption of method of modelling of loads and boundary/ initial conditions.

The specified above data are often determined in development of “typical” calculation method Anyway, in untypical, complex case, which is discussed in this study, it is necessary to consider several possible options in building of model and their applicability shall be thoroughly examined.

It is also necessary to consider application of shell element models (“medium-thick” shell”) and solid element models. It is also necessary to undertake the justified decisions as regards applicability of models of elements of the first order or higher order (so-called elements with linear or parabolic shape functions). However, in the most cases a range of deformations and distortions of the analyzed object is so large that it excludes in practice elements of the higher order. The linear elements with full integration are therefore applied. If conditions of analysis requires optimizing calculation, resources it may be necessary to apply the reduced integration only.

It is also necessary – assuming analysis of destruction of seat in extreme conditions – to select model and range of description of material nonlinearity. It is necessary to select correct constitutive law, including definitions of material sensitivity to strain rate, with simultaneous resignation (probably) from rheology description. The typical material model used in such description is a Johnson – Cook model [3].

The acquisition of material data is a separate problem. A part of material data can be adopted on the base on the previous calculation models of similar type. In order to obtain reliable results for the specific task it is necessary to conduct specific experimental tests. In order to obtain information on material behaviour within high deformation speed it is usually necessary to conduct material tests in typical laboratory conditions using the Hopkinson bar test [2]. It is also possible to develop not typical experiments with explosive charges.

The modelling of boundary conditions and loads results from assumptions adopted on seat physical model determination phase.

One of the main methods of explosive load simulation in FE programs is based on modelling fluid/structure interaction FSI using the so-called Euler space.

The Euler space (e.g. explosive charge with surrounding air) will be divided into the finite elements. The mash of such elements shall be relatively dense and regular to reflect as well as possible the real parameters of explosion / generated shock wave. In addition to determination of boundary conditions, physical properties, location of charge in relation to obstacle, etc., for all materials within the Euler space, it is necessary to define separate equations of state – equations describing relation between variables, which specify the examined thermodynamic system.

The possibility of very precise analysis of explosion (from detonation moment, through combustion of explosive charge and generation of shock wave, till the moment when the shock wave reaches the structure and starts to act on it) and wide range of applicability (when modelling the Euler space we can load with explosion structures with any complex geometry) are advantages of the described method of execution of loads. Its disadvantages include high numerical costs and high impact of orientation of the finite elements on the obtained results (irregular net can distort significantly shape of disturbance propagated in the given area).

There are also such methods of explosive load simulations where modelling of shock wave propagation is omitted. The Euler space is not then defined in the numerical analysis, which reduces numerical costs of the conducted calculations.

One of such methods was implemented in LS-Dyna software in a form of procedure named CONWEP. This procedure generates – after defining location of the point explosive charge in space and determination of weight of such charge, as TNT weight equivalent – on the base of Equation (1), pressure field variable in time, with which the analyzed structure is then loaded.

$$p(t) = p_I(t)\left(1 + \cos^2\alpha - 2\cos\alpha\right) + p_R(t)\cos^2\alpha\,, \tag{1}$$

where:

p – resultant pressure, p_I – pressure on front of declining wave, p_R – pressure on front of reflected wave, α – angle between normal to front of incident wave (shock wave) and normal to the loaded surface of the analyzed structure, t – time.

Changes in p_I and p_R in time are described by Friedlander equation (2):

$$p_I(t) = p_{SI}^{+}\left(1 - \frac{t - t_a}{T_p}\right)\exp\left(-a\frac{t - t_a}{T_p}\right), \tag{2a}$$

$$p_R(t) = p_{SR}^{+}\left(1 - \frac{t - t_a}{T_p}\right)\exp\left(-b\frac{t - t_a}{T_p}\right), \tag{2b}$$

where:

p_{SI}^{+} – maximum static overpressure on front of declining wave, p_{SR}^{+} – maximum static overpressure on front of reflected wave, t_a – time in which shock wave reaches the examined structure, T_p – positive phase duration (Fig. 6), a, b – coefficients which characterize the impulse.

Fig. 6. presents typical form of pressure impulse (in some distance from explosion centre), determined using the presented above relations.

The simplicity of definition and relatively low numerical cost are the main advantages of this method. Unfortunately, it has also its disadvantages / restrictions, e.g. it cannot be used in case of complex geometry of the loaded structure.

In process of practical application of computer simulation for designing, e.g. new solutions for seat structures, the first numerical analysis allow for preliminary assessment of the adopted assumptions and models. It is necessary on this phase to have a possibly wide experimental spectrum of seat structure (and dummy/ man) response expressed by typical mechanical values.

The analysis of injuries/ trauma which can be experienced by the assault soldier in the armoured vehicle in explosion moment, conducted by modelling and computer simulation, is a complex process, requiring development/ preparation and proper use of not a single human model, but a whole series of models representing the structures of human body with various levels of details.

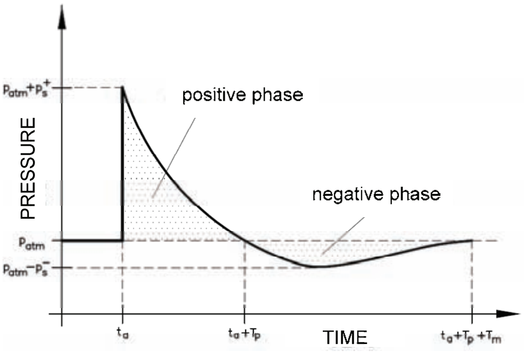

Fig. 6. Profile of pressure variation in time
Source: Prepared on the base of [14]

The main steps include:

- Development of real (physical) model of man (typical selection is a Hybrid III dummy) provided with measuring sensors relevant for the planned tests. E.g. in case of loads resulted from mine explosion under the vehicle – dummy shall be provided with force and moment sensors in the spine (at least one multi-axial sensor located in the lumbar spine) – which is not required in typical applications regarding road traffic safety) and such dummy shall be subject to loads resulting to mine explosion under the examined armoured vehicle, in which this dummy is placed. Due to the high costs of full-scale tests (using vehicle under which the charge explodes) it is necessary to reduce a number of such tests to the precisely selected cases. The experimental tests can be partly conducted using the significantly cheaper solutions, i.e. special station, e.g. "*drop-tower*" type [5], where it is possible to reconstruct the load conditions acting on the seat, similar to conditions after explosion. It is possible in such situation, at small costs, to perform several tests for a wide spectrum of loads, which allows to conduct correct validation of simulation models used then in searching new, better (improving crew safety) construction solutions,
- Usage of dummy simulation model used in experimental tests for virtual/ simulation reconstruction of conditions of real explosion experiment and consistency of signal values/processes determined in simulation with the recorded ones /model simulation/,
- The analyze of variations of conditions of explosion impact on the human body in order to identify the most probable areas and mechanisms of injuries. The selection of the proper criteria to analyze the injuries [6, 7],The analysis of explosion impact on the base of the selected main sizes of dummies – representing relevantly: average (50-centile) and big (95-centile) representative of human population – it seems that in the discussed case the use of 5-centile model is not justified,
- Development/ usage/ adaptation of the specialized human body models – so-called *Human models* (or its part) for the detailed analysis of injuries of previously identified elements/ parts of the human body structure. It shall be stressed now that it is necessary to conduct calculations and consider their results both using the dummy models (for which it is possible to compare directly results of experiments and simulations), and special human body models, as the seat task is to protect human body, not a dummy (the available dummies reflect only the selected properties of human body – in particular, the standard Hybrid-III dummy was prepared for specific tasks in assessment of efficiency of passive safety systems in road vehicles during typical road accidents similar to the head-on collisions),
- The detailed assessment of results of explosion on the human body - values of the so-called injury criteria [6, 7] in function of various variants of structure solutions of the vehicle's seat/cabin.

5. Final conclusions

The seat as element of system soldier's protection against results of explosions is an complex object, which may fulfil its task with various efficiency. The main advantage from designing the "own" seat is possibility of its optimization by several cycles of design – production – testing. The completion of such cycle in own centres is an huge benefit. The production of successive prototypes and then series production in Poland means flexibility in adaptation of product to changing requirements and obtained field experience, giving also benefits resulting from utilization of the state-of-the-art techniques and technologies in the domestic economy.

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