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DESIGN AND DEVELOPMENT OF SEAT (SOLDIER) AGAINST MINE BLAST IMPACT

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Abstract: Explosive devices are serious threats for armoured vehicles and occupants. Following detonation of a high explosive, blast loads, which are transferred through shock waves to the vehicle hull, might potentially cause severe injuries on the body parts. The soldiers are extensively exposed to the opponent's activities while the troop carriers in service more and more frequently do not provide sufficient protection of the crew. The detonation of these threats creates high intensity blast waves that were transmitted to the occupant through vehicle structures and seats. Minimizing the occupant's casualty can be achieved by properly dissipating the shock waves exerted to the vehicle. The aim of this study was to verify the mine blast resistance of the prototype wheeled vehicle according to STANG 4569 as well as various position of seats and TNT blast. The study was contribute to the understanding of numerical simulation for dynamic response of human dummies seated in armoured vehicles subjected to land mine by comparing the performance of Hybrid-III 50th percentile ATD in numerical simulation with that of the standard set by NATO (USA) organization. Therefore, force and acceleration data were collected from critical body parts; tibia, pelvis, lumber spine, upper neck, and head of the mannequin in blast testing. The numerical simulations were performed in LS-DYNA using SPH blast loading method. The study used a model of the body of a soldier in the form of a Hybrid III 50th Dummy. From the results it was found that the seating position and charge position plays a significant role in reduction of the shock response towards the finite element dummy model.
Keywords: LS-DYNA, TNT, Blast Loading, Occupant Safety, Hybrid-III Anthropomorphic Test Device, Seating Position, Charge Position, SPH Method

INTRODUCTION

Typical land mines weights approximately 6 kg and during its detonation, the explosive releases large impulses that could deform and its shrapnel can penetrate the vehicle structures. The impulse generated from the explosion transfers to the occupant through mediums that are connected to the occupants such as the floor sections and seats. This type loading must be attenuated to a certain value and if failed, fatalities may occur to occupants.

The factors that can be used to attenuate the shock waves are studied. The three factors studies are the finite element dummy model seating height, explosive weight placement and the Hopkinson-Cranz blast scaling. First, a capsule was designed for the dummy placement [1]. Improvised Explosive Devices (IEDs), along with other types of roadside bombs and trinitrotoluene charge explosion (TNT) have accounted for over 60% of American combat casualties in Iraq.

In Afghanistan, the numbers are worse, with explosives accounting for 77% of field injuries and IEDs specifically accounting for 38% of all injuries and 32% of death [3]. Undercarriage landmine blast cause a significant threat to occupant safety in armoured personnel carriers. The blast wave interaction with armoured plates in the undercarriage is an important factor in the design process. Experimental studies provide valuable insight to the performance of armoured vehicles subjected to landmine blast. Some measures of performance include the resistance of the undercarriage against tearing of the armour plates, failure of the structural welds, and high accelerations of the footrest plate used by the occupants. Landmine blast experiments that involve the testing of the full vehicle are costly and time consuming, while numerical simulations provide a faster alternative to measure the vehicle performance under blast loads.

Figure 1. Acceleration and Pressure measurement of critical part of human body

The blast resistant under carriage armour design is an iterative process that is shaped by the successive use of numerical simulations. There are two major approaches for modelling blast loads.

The first approach involves the use of empirical equations obtained from blast experiments. This is referred to as the CONWEP method (CONventional

WEaPons). This technique is suitable for simulating structural members directly exposed to the blast wave, without any obstructions or shadowing effects.

The second approach is the Smooth Particle Hydrodynamic (SPH) technique that requires the modelling of the surrounding air with a volumetric mesh around the target structure. It allows the application of the Navier Stokes fluid dynamics equations for simulating the blast wave propagation.

Mine blast testing of armoured vehicles provides valuable insight into dynamic response of the body hull and makes possible to reveal weaknesses and strengths of the main structure under blast loading.

According to NATO AEP-55 standardization agreement, vehicle integrity shall be protected and injury level of occupant inside the vehicle should be no more than the given values for specific points on human body in a blast test. For this purpose, mannequins are utilized to do the occupant safety evaluation in both blast testing and numerical simulations.

While some research has been carried out on the blast mitigating systems for armoured vehicles, there is very little scientific understanding of responses of occupants in vehicles under blast loading [5]. The research was carried out to verify explosion resistance over a prototype vehicle LBPV (Light Bullet Proof Vehicle) class in accordance with the level STANAG 4569. The second priority was to identify the load in the most injury-endangered parts of the body, e.g. tibia, pelvis, lumber spine, upper neck, and head of the soldier.

The principal aim of this paper is to contribute to the understanding of numerical simulation for dynamic response of human dummies seated in armoured vehicles subjected to land mine. Many techniques and materials have been proposed in the literature to mitigate the blast pressure and energy, but only two techniques are predominantly used at present for minimising the acceleration imparted to the vehicle compartments resulting from explosion of land mines. In the first, the occupants are separated from the vehicle floor using roof hanging and wall mounted seats. In second, specially designed energy absorbing seats, circular tubes, square tubes, frusta, struts, honeycombs, and sandwich plates are used to decrease the loads acting on the occupants.

Some other techniques such as the thin walled cylinder, upward convex hull and polyurea coating were also reported for mitigating the acceleration but no experimental study has been reported on acceleration mitigation using foam. The charge was placed at various position and checked the effect on the crew seated on seat.

LITERATURE REVIEW

Khalis S.et al. [1] Described that Explosion from an anti-tank mines or improvised explosive devices are recognized as one of the lethal threat towards occupants inside an armored vehicle. In this paper, three factors such as occupant seating height, charge weight placement and the Hopkinson-Cran z blast scaling were studied using numerical simulations. Design of experiment (DOE) was utilized to determine the ranks and interactions between each factor from the most influential on the results to the least affects towards the results. From the results it was found that the seating position plays a significant role in reduction of the shock response towards the finite element dummy model.

Adam M. et al. [3] with casualties mounting overseas due to Improvised Explosive Devices (IEDs) and other roadside bombs, improving the safety of armoured vehicles for service personnel overseas is of paramount importance. The hypothesis is that through the manipulation of the mass ratio, stiffness and damping properties of a dual-hull system, the safety of current Mine Resistant Ambush Protected (MRAP) vehicles can be greatly improved.

The results show that, in comparison to the standard single-hull vehicle, the dual-hull vehicle reduces head injury criteria by 95.7%, neck compression by 78.3%, chest acceleration by 97.5% and leg forces by an average of 97%. Further work should focus on developing a realistic structural interface between the hulls and evaluating it using simulation, followed by fabrication and testing of limited test articles and full-vehicle systems.

Edyta K. et al. [4] studied to elaborate identification method of crew overload as a result of trinitrotoluene charge explosion under the military wheeled vehicle. The aim of this research was to verify the mine blast resistance of the prototype wheeled vehicle according to STANG 4569 as well as the anti-explosive seat. Within the work, the original methodology was elaborated along with a prototype research statement. This article presents some results of the experimental research, thanks to which there is a possibility to estimate the crew's lives being endangered in an explosion through the measurement of acceleration as well as the pressure on the chest, head and internal organs.

Atil E. et al. [5] described that Explosive devices are serious threats for armored vehicles and occupants. The objective of this paper is to contribute to the understanding of numerical simulation for dynamic response of human dummies seated in armored vehicles subjected to land mine by comparing the performance of Hybrid-III 50th percentile ATD in numerical simulation with that of full-scale blast testing.

Therefore, force and acceleration data were collected from critical body parts; tibia, pelvis, lumber spine, upper neck, and head of the mannequin in blast testing. Those data were compared with numerical simulation results. The numerical simulations were performed in LS-DYNA using CONWEP blast loading method. It was found that the numerical simulation results are in accord with those obtained from blast testing.

Steps adopted in modelling

(1) Acceleration in response to blasts originating from the bottom of Mine-Resistant Ambush-Protected (MRAP) vehicles must be lessened if there is to be any useful change to protect vehicle's occupants.

(2) We had assembled these seat to the floor, side wall and hanging to the roof of the vehicle. Also in this study we vary the position of the mine blast along with varying weight of ammunition like 6 Kg, 10 Kg, 20Kg, 40Kg TNT etc.

(3) In the numerical tests, there was determined behaviour of the carrier structure and tests dummies during explosion of an explosive charge placed on the bottom side of the vehicle.

(4) A hemispherical shape of a charge was adopted for calculations. Due to a significant distance of the charge from the vehicle as well as simple geometry of the carrier side, LOAD_BLAST_ENHANCED procedure implemented in LS-DYNA system was used to generate a pressure wave representing the structure loading.

(5) The analysis will be carried on LS-DYNA V-R11.0 (SPH) with CONWEP method.

(6) We have to optimize best arrangement of seat structure with minimum shock to the solider body.

METHODOLOGY ADOPTED FOR ANALYSIS

— Modelling of vehicle

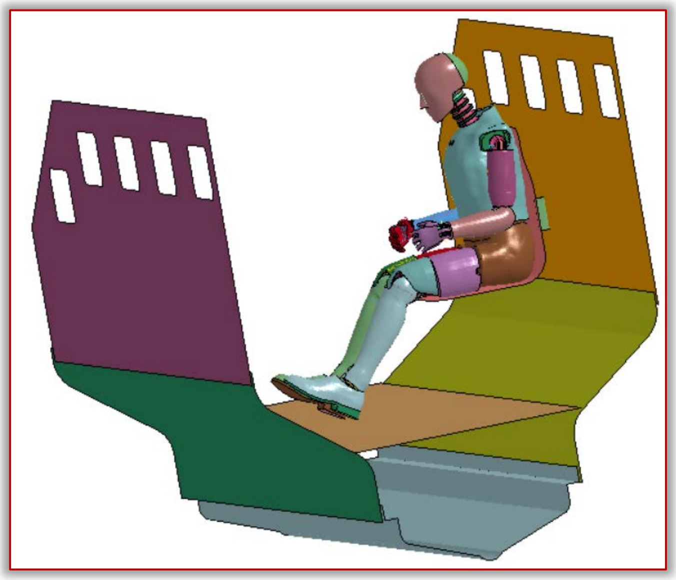

Figure 2. Modelling of Vehicle

— Blast Loading Method and Conditions

The detonation of an explosive charge releases blast energy resulting in disturbances in the surrounding air, which grows into a blast wave system led by a shock front. This physical phenomenon can be simulated through two essential techniques in the commercial finite element method, LS-DYNA; CONWEP and Smoothed Particle Hydrodynamic (SPH). The first method calculates conventional blast loading effects on structures from the equations and curves.

To adequately collect force and acceleration data from body members of the Hybrid III dummy inside the vehicle subjected to land mine explosion, the calculation should continue at least 200 milliseconds. For TNT, Hemispherical Shape was used. The radius of TNT was 25 mm and placed 300 mm below hull.

— Finite Element modelling

Finite element model involves vehicle body, hull and power pack components as well as structural parts and seat mechanism. Hull plates and hull subsystem parts were modelled using BelytschoTsay shell elements with two integration points.

Seat mechanism consists of seat frame, seat belts, cushion, and main plate tension apparatus. Seat frame, belts and tension apparatus were modelled with shell formulation, while cushion was generated using hexahedral solid elements.

The entire model consists of 339,638 shell elements and 62,178 solid elements. LSTC's rigid Hybrid-III 50th percentile dummy was preferred as a mannequin due to its compatibility with blast simulation models. Figure 5 illustrates finite element modelling details of the entire vehicle and Hybrid III test dummy as well as detonation point.

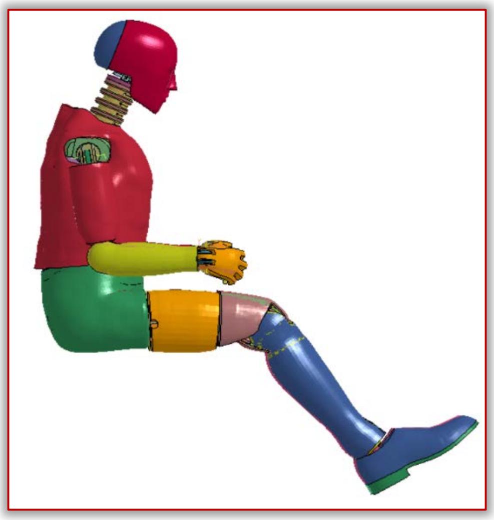

Figure 3. Hybrid-III 50th percentile dummy

— Material Model

Energy absorbing capability is a fundamental property of a cushion material. The fact that cushion could absorb respectable shock energy, which is transmitted from structural parts of vehicle to the seat mechanism during mine blast has a direct impact on the magnitudes of the acceleration and force acting on the human body.

In the experiment, the ability of cushion in absorbing energy is obtained by measuring hysteresis, which is demonstrated by the area between load deformation curves for loading and unloading conditions through MAT_FOAM keyword function.

The TNT equivalence may depend on a number of parameters such as charge size, scaled distance, detonation speed, Chapman-Jouguet pressure; and for a given explosive the pressure and the impulse calculations may require different TNT equivalence values.

Therefore, it is difficult to handle non-TNT types of explosives with the CONWEP approach. In contrast, the SPH method allows the adjustment of material properties and the equation of state parameters for various non-TNT explosives. The keyword for TNT is HIGH_EXPLOSIVE_BURN.

The material model was used for the armour and mild steel structures in the vehicle model by activating *MAT_PIECEWISE_LINEAR_PLASTICITY material function.

— Contact Algorithm

*CONTACT_AUTOMATIC_NODE_TO_SURFACE function was assigned for the contact between Hull of the vehicle and blast wave. *CONTACT_AUTOMATIC_GENERAL function was thus selected for the contact between seat components and human dummy. Another possible contact interference might take place between seat frame and cushion. To prevent this, *CONTACT_NODES_TO_SURFACE keyword function was adopted. Also contact between various parts of vehicle structure used as *CONTACT_TIED_SURFACE_TO_SURFACE.

— High Explosive (EOS)

The evaluation of the explosive after ignition is described by the Jones-Wilkins-Lee (JWL) equation of state, defined with the keyword *EOS_JWL in the LS-Dynacode. The JWL equation of state defines the pressure as a function of the relative volume V and initial internal energy per volume E0 as given in (2)

$$p = A[1- W/(R1*V)]*e-(R1*V)+B[1- W/(R2*V)]*e-(R2*V)+[(W*E0)/V]$$

The input parameters are represented by A, B, R1, R2, W, and E0. A and B have dimensions of pressure, while the dimensionless parameters are R1, R2, and W. E0 represents the initial internal energy.

The volumetric ratio is expressed by V = (v/ v0), where vo is the initial volume. The exponential terms are the high-pressures mall-volume terms, and usually the user chooses R1, R2 ~ =4 to make the two terms important indifferent regions.

Table 1. JWL equation of state parameters for TNT

ρ0 (kg/m3)	D (m/s)	PCJ (GPa)	E0/V (GPa)
1630	6930	21.0	7.0

A (GPa)	B (GPa)	R1	R2	W
371.213	3.231	4.15	0.95	0.3

— Boundary and loading conditions

There are no constraints, because in the event of blast the vehicle is globally displaced. Only condition is that the vehicle is blasted against gravity/self-weight of the vehicle, so gravity is included.

The unladed weight of the vehicle is 4000 kg and along with load it will goes to 5000 kg. It is applied at centre of gravity of the vehicle along with gravity.

The loading curve is deduced for the loading caused by the blast of 6 kg TNT charge as per STANAG 4569 Level II.

The transient load of duration of few milliseconds due to the blast of the charge.

— Convergence Study

Analyses were carried out for different element sizes by gradually increasing the number of elements until convergence occurs. Convergence was found to occur at around 4,00,000 elements as shown in Figure 4. Sizing of the element is decided based on possible high stress locations.

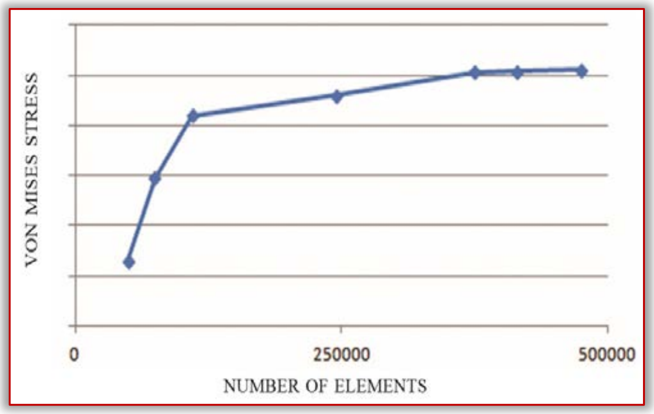

Figure 4. Mesh Convergence study

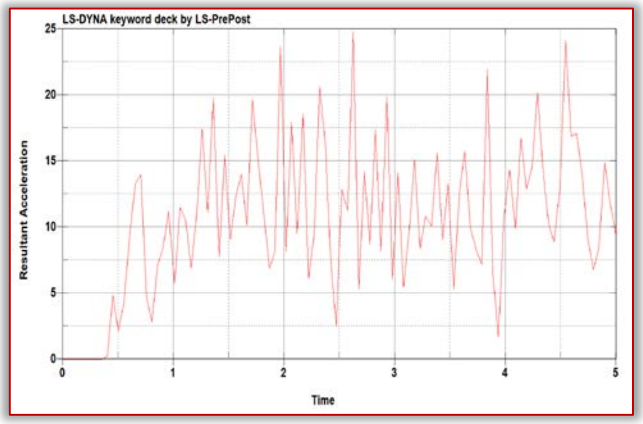

Figure 5. Nodal acceleration at seat

A great deal of attention is given to those components that are located between the inner and the outer vehicle floor. These components reduce the impact by their vary mass.

The finite element model of the armoured vehicle and hinges are modelled with shell element.

CONCLUSION & DISCUSSIONS

A number of approaches to the numerical assessment of the influence on the occupant of a vehicle under a mine blast have been shown in this report. A numerical simulation of a finite element dummy response when subjected to blast loading was modelled and verified.

The result shows that the position of blast and arrangement of seat greater impact on dummy. The interaction between two factors that is significant to the simulation results are the interaction between seating arrangement and charge position factors. Identifying these significant factors is important so that any improvement to reduce the blast acceleration could be done according to these factors and the improvement would yield better results.

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