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Simulation of an Armoured Vehicle for Blast Loading

Sanjit Mahajan* and R. Muralidharan#

*Defence Land Systems India Limited, Faridabad - 121 102, India
#Hinode Technologies Private Limited, Chennai - 600 030, India
*E-mail: mahajan.sanjit@mahindra.com

ABSTRACT

Occupant safety in an armoured vehicle is of paramount importance. Most serious threat to armoured vehicles comes in the form of explosion of buried charge or an improvised explosive device. The use of numerical methods in the validation process of light armoured vehicles reduces the number of prototypes required and decreases the design time. This paper elucidates the process by which one such validation using numerical methods was done. The process of finite element method used for simulation of blast is a prominent method of numerical method of simulation. The finite element model (FEM) process starts with discretisation. By discretisation or meshing, Shell (Quad/Tria) and solid (Tetra/Hexa) elements are generated. The FEM thus created is provided with relevant material model / properties and loading and boundary conditions. The loading conditions are adopted from STANAG 4569 Level II standards. Local deformation, global displacement, stresses and time history of displacement of particular areas of interest are obtained as results. Comparison results include the effect of with and without thermal softening under blast. Based on the results and comparison, suggestions regarding re-engineering the vehicle are presented.

Keywords: Occupant safety; Improvised explosive device; IED; Finite element model; FEM

1. INTRODUCTION

There is a multitude of papers that describes the process of interaction of blast wave from explosive charges on vehicles and armours[6-9]. However, impact of improvised explosive devices (IED) and mines on light armoured vehicles is one of the most common causes for the loss of lives of soldiers taking part in conflicts[5,10]; although, one could notice that, the literature regarding interaction of blast wave from IED and mines with the crew of wheeled light armoured vehicle are rather less in number[10]. Generally, vehicles that are deployed to fight infantry are designed to bear up against a variety of ballistic threats. Fair amount of protection against ballistic threats can be obtained by following simple rules. But, obtaining optimum protection against a case, such as, landmine explosion under a light armoured vehicle, is rather difficult to achieve[1]. Performing simple experimental tests to obtain parameters required for numerical simulations, and conducting extensive numerical simulations based on the results from experimental tests is a reasonable approach to such an optimal design.

2. ARMOURED VEHICLE

2.1 General Arrangement

The vehicle basically consists of a front and rear chassis frame and hull structure protecting the occupants including the driver. The hull is a special designed structure for higher protection against blast.

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2.2 Latches, Hinges, Locks

In the immediate aftermath of a blast, it is important that the locks, latches and hinges do not give away. Otherwise this would result in hostile situation of exposure of occupants to the adversities.

3. PROCESS OF BLAST

The overall energy transfer process during blast can be divided into three phases as shown in Fig. 1; the first phase includes the detonation of blast followed by the shock wave propagation resulting in high amplitude and high frequency vibrations resulting in local deformation of the armoured vehicle bottom structure. The final phase will be the global displacement of the vehicle.

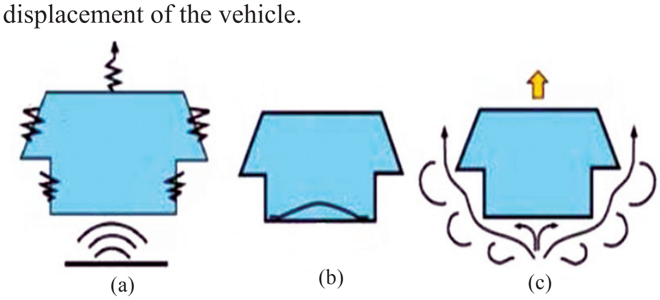


Figure 1. Blast process phases: (a) Blast wave, (b) local deformation at the bottom of the vehicle, and (c) global displacement of the vehicle.

3.1 Blast Wavepropagation

This is caused by the aftermath of explosion of IED/ mine in fraction of a second. The explosion is caused by chemical reaction and due to it, the release of thermal energy and pressure caused by the rapid expansion of gases. A shock wave is caused by large dynamic explosive transformation of detonating agent (especially solid or liquid phase) to great volume of gases with high temperature[3].The wave thus created moves rapidly, predominantly in the vertical direction in case of buried explosive as the other directions offer resistance depending on the stiffness offered by the packing of the soil.

3.2 Local Deformation at the Bottom Structure of the Vehicle

Normally the bottom structure of most military vehicles is made by single armour layer to take care of hand grenade blast. In order to offer more protection, the structure should be designed in a specialised way which should be able to absorb a part of explosion energy. The bottom layer will see thermal softening and high plastic deformation because of the rapid yielding caused by shock wave and the effect of the conflagration due to blast.

3.3 Global Displacement of the Vehicle

As the movement of the shock wave caused by the blast gives the elements large kinetic energy. This causes the vehicle to fully displace. As the vehicles become lighter, the same blast threats impart larger global displacements[4]. This movement of the entire vehicle affects the accelerations of the occupants and hence, this response is critical.

4. SIMULATION CONDITION

The event of a blast starts off with the initiation of the chemical reaction and followed by explosion which is characterised by blaze and generation of shock wave. Then the armoured vehicle is impacted by the shock wave. Due to the shock wave the armoured vehicle bottom structure gets deformed locally followed by its global displacement. As the armoured vehicle is to be simulated along with smaller elements like hinges, latches and locks, the resultant finite element model would be huge and hence solution time would be considerable for the vehicle. So the vehicle is simulated for shock wave impacting the bottom structure and ending with global displacement of it. Also as the event of blast is milliseconds and the material undergoing high plasticity under dynamic conditions, explicit method finite element analysis is made use of.

5. THE FINITE ELEMENT MODEL

5.1 Elements Used

Meshing was carried out for each part using either Shell (4-noded Quad and 3-noded Tria) or Brick (6-noded Penta and 8-noded Hexa) elements. SHELL elements are used when one dimension is very less when compared with the other two and BRICK for geometries that are not thin (eg. latches and hinges). Since the requirement is to ensure adequately robust and not to have significant damage to the vehicle and also damage to the occupants are considered for future simulation, occupants are characterised as mass element. Other non-structural masses such as seat, vehicle and ammunition accessories are also added as lumped masses. Lumped masses are created with respect to its CoG locations and distributed to the mounts. Weld and rigid elements are created for connecting the parts; interfaces are created to capture the self and contact between the two or more parts. Revolute joints are created between the door hinges to get the rotary motion for doors once it is free of the bolting of the latch.

5.2 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 Fig. 2. Sizing of the element is decided based on possible high stress locations. 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 very mass[2]. The finite element model of the armoured vehicle and hinges are modelled as shown in Figs. 3 and 4.

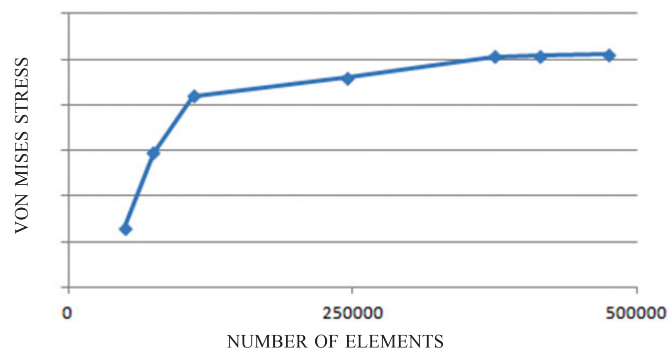


Figure 2. Mesh convergence study.

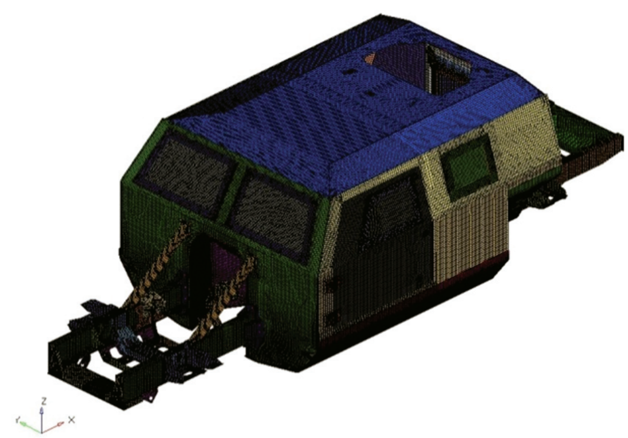


Figure 3. Armoured vehicle: Finite element model.

5.3 Material Model

Quenched, tempered and bullet resistant steel material as per MIL standard having yield strength between 1100 MPa to 1500 MPa is used for the armoured vehicle and in simulation, for isotropic elasto plastic material John Zeril material model is found to be more suitable and widely accepted. This material model expresses stress as a function of strain, strain rate and temperature. A typical stress strain curve is shown in Fig. 5. Young's modulus of 210000 MPa, poisson ratio of 0.3 and density of 7850 kg/m^3 along with hardening exponent and parameter is used for the simulation.

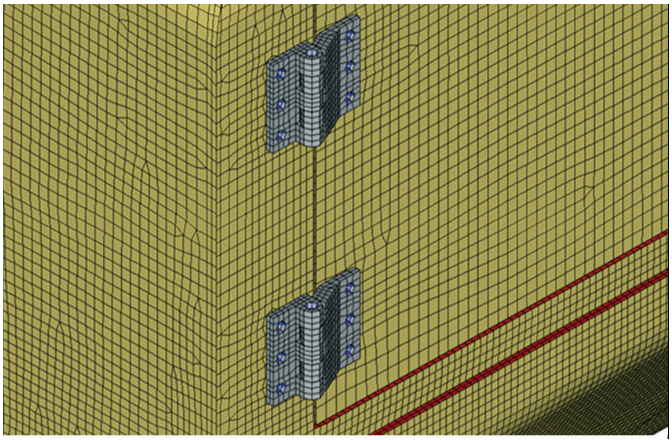


Figure 4. Hinges and weld elements.

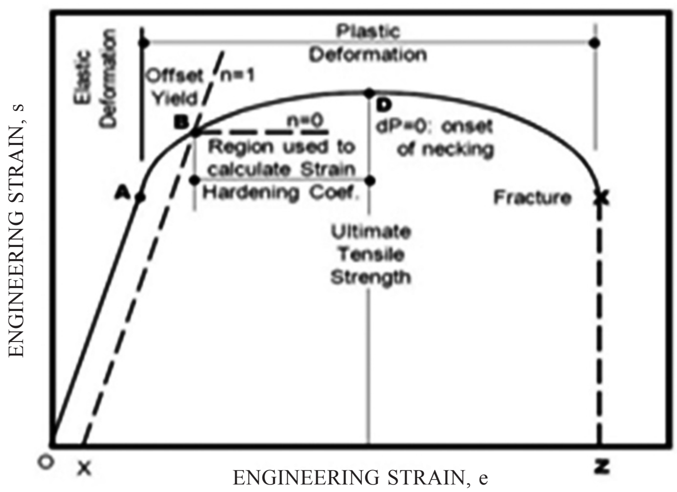


Figure 5. Material curve.

The components which are likely to be in elastic deformation range (within yield) are provided with young's modulus, poission's ratio, and density is input for materials. Segregating and separating the components into elastic and elasto-plastic also reduces the elapsed time.

5.4 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 loading curve is deduced for the loading caused by the blast of 6 kg TNT charge as per STANAG 4569 Level II. Figure 6 illustrates the transient load of duration of few milli seconds due to the blast of the charge.

6. RESULT

The response of the armoured vehicle for this transient load is studied in the form of local deformation, global displacement and stresses.

6.1 Local Deformation

At this stage, response to occupants inside the vehicle not considered. The local deflection at the

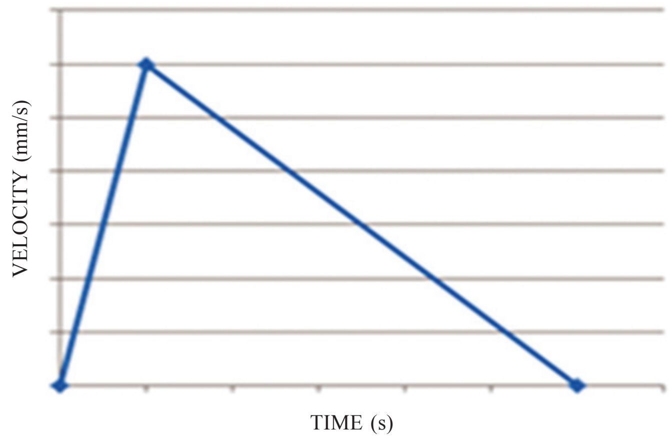


Figure 6. Loading curve.

bottom of vehicle at first few milliseconds shown in Fig. 7 for the central hull loading.

6.2 Global Displacement

The global displacement in response to the loading applied as velocity profile shown in Fig. 8. The displacement of the vehicle is seen higher where ever loading is provided.

6.2.1 Loading

The maximum displacement is noted when un-symmetric loading done below driver seat compared to symmetric loading at the centre of the hull.

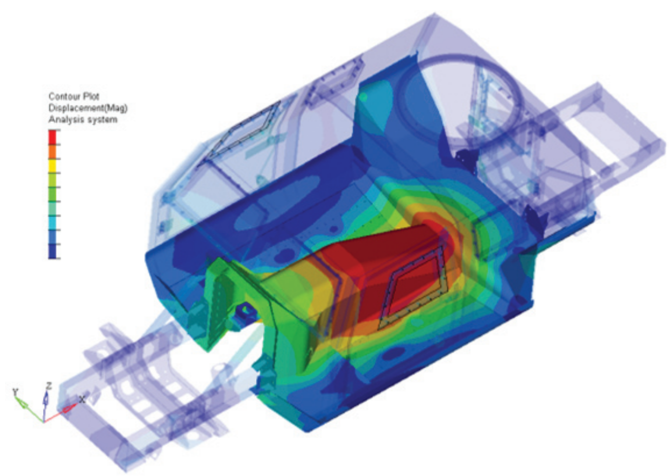


Figure 7. Local deformation of the vehicle.

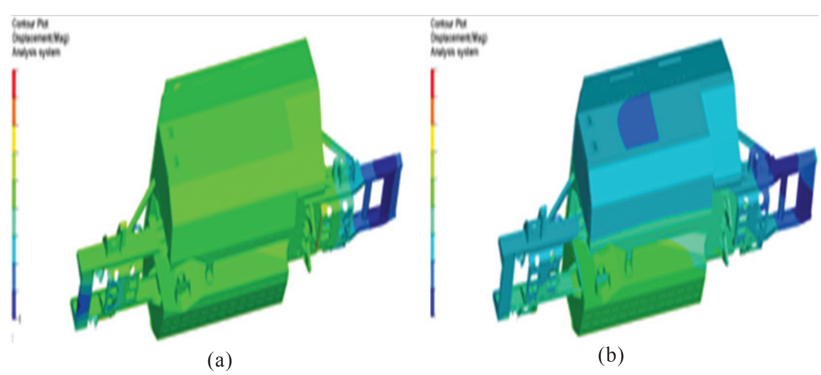


Figure 8. (a) Loading at centre hull and (b) Loading at driver side.

6.2.2 Thermal Softening

The deflection and displacement is more for the vehicle due to thermal softening at centre hull loading condition. The similar deflection pattern observed with thermal softening as shown in Fig. 9, as in case of unsymmetrical loading at driver side.

6.3 Stresses on Various Components

The stresses on various components are observed for central hull and driver side loading. Higher stresses are seen at the attachment locations of the mass at the centre of the armoured vehicle. Leading to reinforcement of the location.

6.4 Model Energies

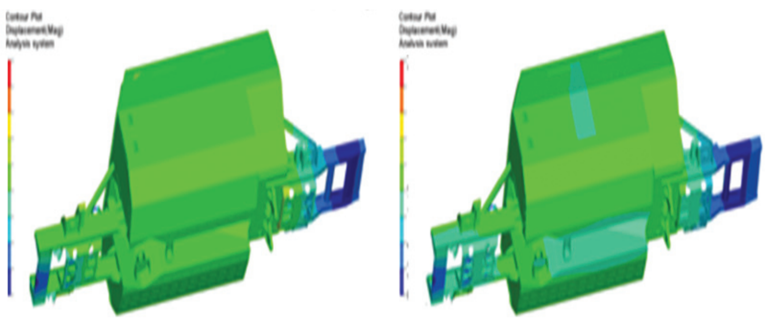
Figure 10 shows 3 different types of energies stored in model.

(i) Hourglass energy, (a spurious deformation mode of a FE Mesh resulting from excitation of zero-energy DOF) is minimised using full integration methods

(ii) The kinetic energy rises gradually and reaches peak then decreases until the loading reaches zero

(iii) Internal energy is the energy contained within the system due to the external forces.

These plots are monitored for the trend of solution.



(a) (b)

Figure 9. (a) Without thermal softening and (b) With thermal softening

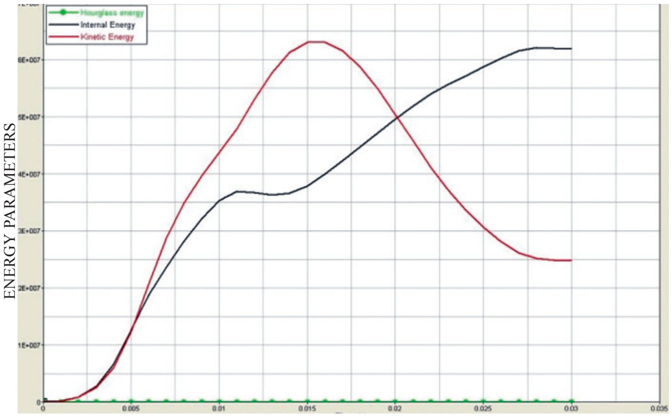


Figure 10. Energy plot.

6.5 Time History Data

Figure 11 shows the time history data that includes displacement, velocity and acceleration plot for top, middle, and bottom of A-pillar (LHS) and relative displacement plot of top with respect to bottom of A-pillar (LHS).

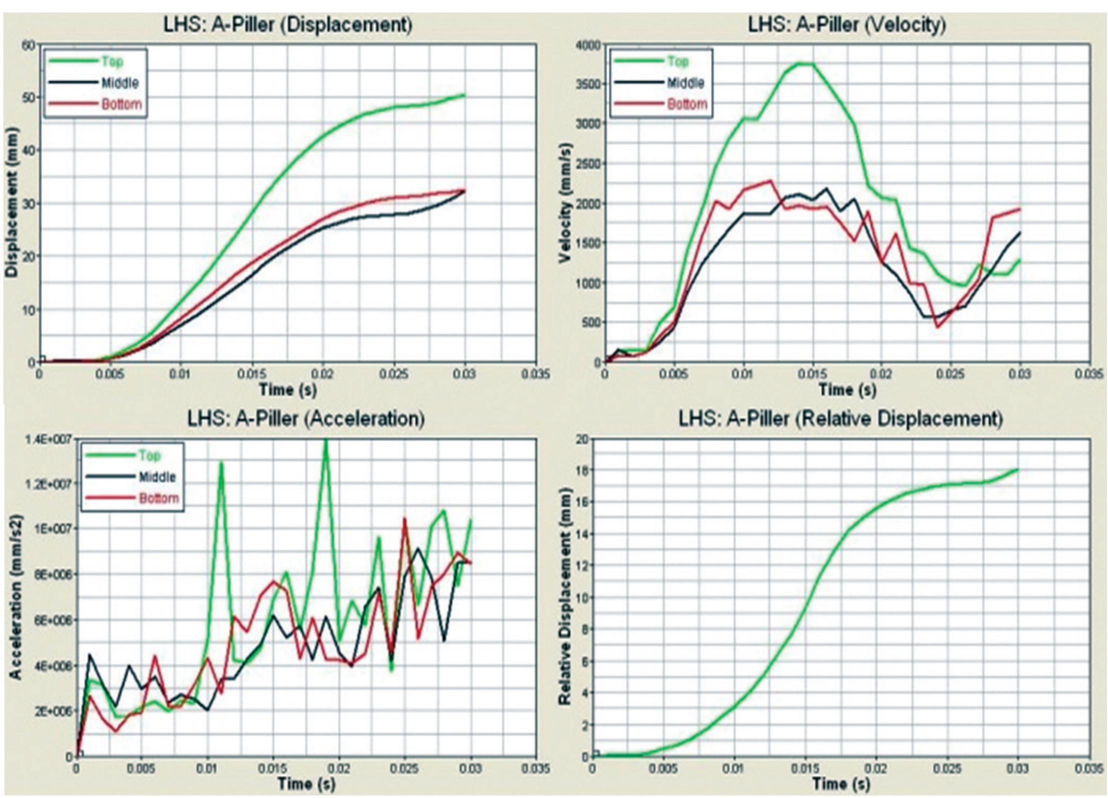


Figure 11. Displacement, velocity, acceleration plots.

7. SUGGESTION AND MODIFICATION

From the results of blast at centre of the hull and below the driver location and the influence of the thermal softening, the bottom structure material specification was upgraded. Also reinforcement was done for the hinges and latches

As a next step in simulation, it is envisaged to have the simulation of dynamic blasting of the charge. In order to have the effect of forces/load on the occupants due to the blasting the armoured vehicle model could have the dummy model of the occupants. Coupled with complex blast dynamic simulation and inclusion of occupants and automation of these analyses would go a long way of achieving the prototype-less simulation in future.

8. CONCLUSIONS

The response of the armored vehicle during blast was studied through explicit finite element simulation in detail. Also comparative study was carried out for driver side and centre loading for deflection and stresses. Based on the results, the latches, hinges were reinforced; the effect of thermal softening was useful in refining the bottom structure.

The numerical simulation provides better insight of the vehicle response and to focus into the critical areas (hot spots) for design modifications. This study show cases multiple objectives of effect of blast at different locations, use of different material, also material behaviour of with and without thermal softening. This attempt is to demonstrate its efficacy vis-a-vis physical testing, leading to prototype-less, virtual simulation.

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CONTRIBUTORS

Mr Sanjit Mahajan holds a Bachelor's in Mechanical Engineering from PTU, Jalandhar and PGDBA in Operations from Symbiosis. Currently he is working as a Manager – R&D at DLSI. He has got a rich experience of 10 years in Vehicle design & development (Drive Away Chassis – Suspension and Brakes, CAE and Vehicle Dynamics).

He has carried out the internet survey related to blast simulation and has evolved the overall outline of the paper along with the information of the 3 phases of blast namely blast wave generation, local deformation and global displacement of the vehicle, along with freezing the conditions of blast i.e. idealising the blast as a shock wave

Mr R. Muralidharan is working as Head - Operations at Hinode Technologies Pvt. Ltd. He holds a Bachelor's degree in Mechanical Engineering from PSG College of Technology, Coimbatore and has been in CAE simulation area for over 25 Years.

In the current study, he has finalised of the frame work of the paper, drawing out the specifications for Finite Element Model, the documentation of the simulation and results along with conclusion by were done by him.