Numerical Simulation of an Armoured Vehicle to Anti –Vehicle Mine Blast to Optimize the Structural Rigidity

D. R. Makwana
Scientist ‘C’
Vehicle Research & Development Estt.
Ahmednagar
drmakwana@vrde.drdo.in

Laxminarayan. K
Senior Manager
DesigTech System
Bangalore

Abstract
Protection against mine explosion is a key and unsolved problem related to the safety of vehicle & occupants. How to design the protective structure to minimize the damage from outburst and explosion is always a concerned problem. Blast proof vehicles play a vital role in protecting the soldiers (troops) and also to eminent scientists and technocrats working in projects for Nation building. This paper deals with the simulation & analysis carried out on the armoured hull of the tank. The purpose of special kind of vehicle design is to increase the vehicle and crew survivability by deflecting an upward blast from a landmine (or IED) away from the vehicle, while also presenting a sloped armour face. By presenting its armour at an angle, it increases the amount of material a projectile must pass through in order to penetrate the bottom and increases the chance of deflection. To reduce the vulnerability of the vehicle to anti-vehicle mine blast, one relies heavily on the numerical simulation to help design & optimize add-on armour systems. One of the greatest challenges faced during the evaluation of the vulnerability of the vehicle to mine blast, is not only assessing the structural response of the vehicle but also evaluating the damage caused to the vehicle, and also safety of the occupants due to the acceleration induced. This paper presents the results of a series of simulations performed with Radioss.

Keywords: Blast proof vehicles, Simulation of Armoured Vehicles, Mine blast, Radioss/Explicit

Introduction
The design of the vehicle plays a vital role in the blast propagation. The flat hull gives more face area to the blast and so gives more space to propagate the blast. Keeping the shape of the bottom hull in such a way as to cause minimum blast propagation and minimum damage to the occupants. A model of Armoured vehicle is developed for the simulation of blast. A charge of 10 kg TNT was used to load the vehicle model. And the effect of blast was simulated and the results were analysed. The difference between a detonation directly under the wheel or just outside the centre line of the wheel, can lead to significantly better outcome. There is a high risk of brain injury for an acceleration of 150 G for 2 ms [1]. The use of most modern materials like composite armour, ceramic armour, titanium armour will improve the structural rigidity of the vehicle [2].

A finite element model of the Blast proof vehicle is prepared using Solid Works-2010 & HW 9.0. Simulation of penetration events requires a numerical technique that allows one body (Penetrator) to pass another. Traditionally, these simulations have been performed using either Eulerian approach i.e. Non-deformable (Fixed) mesh with material advecting among the cells or using Langrangian approach i.e. deformable mesh, with large mesh deformations. The Radioss/Explicit software has played a vital role in the blast simulation of the model using 10kg charge of the explosive under the belly of the vehicle at the distance of 450 mm. The model is assigned properties of High hardness Steel. At the bottom of the vehicle, the armour thickness is presumed as 14 mm and rest of the body is assigned the thickness of 8 mm armour steel.

Model Geometry
The model used in the present analysis is modified version of armoured vehicle. This model has been validated against experimental data for ‘blast and it represents a real vehicle. The hull is designed in such a
way as to reduce the effect of the blast. The turret, hatches and interior bulkheads have been removed as they have negligible effect on the response of the vehicle hull in the first few microseconds, which is the duration of the interest here. The wheels and the drive shafts have also been removed to simplify the model. These components play a vital role in the response of the vehicle and in the local deformation of the hull (e.g. the wheels can absorb and deflect a significant amount of the blast). But the loading model used in the analysis is incapable of explicitly modeling their effect on the blast. The engine and transmission block along with their attachment points are also hidden. For the purpose of assessing the blast effect, the vehicle envelope is considered for further loading and analysis. The dimensions of the vehicle model are 5950mm X 1995mm X 1995 mm (LXBXH). The complete vehicle model is shown in fig.1.

The armoured steel plate having thickness of 14 mm is used for the bottom of the model. It reduces the risk of damage due to blast pressure and fragmentation intrusion into the crew compartment.

**Finite Element Model**

The CAD/CAE software package was used as a pre-processor to build the solid model and finite element mesh of the vehicle. The vehicle hull is meshed using shell elements (4 node elements). The model mesh consists of 7338 nodes and 7350 shell elements.
The structure of the hull is armoured steel having hardness in the range of 440-470 BHN. Here, MAT_ELASTIC is used as the material card. The values for card format are as under.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass density - Rho</td>
<td>7830 kg/m³</td>
</tr>
<tr>
<td>Young’s modulus – E</td>
<td>2.1 E 11 N/m²</td>
</tr>
<tr>
<td>Poisson’s ration – Nu</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Charge**

The Properties of TNT explosive are taken as:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1630 kg/m³</td>
</tr>
<tr>
<td>Detonation velocity</td>
<td>6930 m/s</td>
</tr>
<tr>
<td>Chapman – Jougat pressure</td>
<td>21.0 GPa</td>
</tr>
<tr>
<td>Internal Energy density</td>
<td>7.0 GPa</td>
</tr>
</tbody>
</table>

The explosive ignited at the center. The evolution of the explosive after ignition is described by the Jones-Wilkins-Lee (JWL) equation of state, which defines pressure as: [3]

\[
p = A \left( 1 - \frac{\omega}{R_1 V} \right) e^{-\frac{r_1 V}{r_1}} + B \left( 1 - \frac{\omega}{R_2 V} \right) e^{-\frac{r_2 V}{r_2}} + \frac{\omega E}{V}
\]

Where, \( V \) is relative volume, \( E \) is internal energy, \( \omega, R_1, R_2 \) are constants and the values of constants are:

\( \omega = 0.3, A=371.213 \text{ GPa}, B= 3.2306 \text{ GPa}, R_1= 4.15, R_2=0.95 \)

Critical shock energy for TNT is 83.5 J/cm² [4].

**Loading Model**

The vehicle hull model is developed using HyperMesh and the simulation of blast loading is done by RADIOSS/Explicit. The model is used to predict the maximum damage area due to the blast of 7 kg TNT. The data gathered from the blast simulation is used to develop an empirical model, which accounts the effects such as size of charge of TNT, location of charge, properties of material etc.

By using HyperMesh/RADIOSS pre-processor the input data like element thickness, properties of material are assigned to the vehicle model. The position of the TNT is shown in the fig.3 (a) & 3 (b).
Results

The blast is a microsecond phenomenon. The von-Mises stress values as shown in Fig. 5 (a) and (b) are for start of detonation and for end of detonation.
The explosion is the phenomenon of rapid release of stored energy. When a blast propagates, it carries temperature & pressure with it. This energy is released in part as thermal radiation; the rest manifesting as shock waves that are combinations of air blast and ground shock. The Air blast is the main damaging mechanism. Air blast has a primary effect, which is the dynamic pressure or drag load. The first effect is caused by the air blast, which propagates at supersonic velocity, and compresses air molecules on its path. The shock waves undergo diffraction as they interact with various surfaces, thus increasing or decreasing in pressure.[5] The stress wave phenomena indicates that at low impact velocities, stress may be below yield strength of material so that only elastic stress waves are generated and for high velocity impacts, stress will exceed yield strength and inelastic as well as elastic waves will be generated.[6] The pressure decays exponentially in time and with radial distance from the epicenter and eventually becomes negative, creating suction forces. The secondary effect is the ground shock that produces motions similar to high intensity, short duration earth quakes.

The following effects can be characterized from the blast wave. Magnitude of the overpressure or the peak pressure during the overpressure phase of blast wave. Impulse or duration of the overpressure. Impulse is the area under the over-pressure time curve. Duration measures how long the over pressure phase of the blast wave lasts.
As shown in Fig. 6(a) to 6(d), the initial blast of the vehicles gives very high-rise due to the blast wave propagation and as time progresses, the blast wave becomes weaker. The blast wave propagates at very high speed and the value of the blast goes up to 3.575 N/mm². The fragments try to penetrate the armour plate and to deform the hull. The Max values for Von-Mises stress are coming around the contours of the vehicle due to stress concentration in that region. Generally, the axle will be fitted in that contoured space so the blast effect will be neutralized. The buried charge has lower peak impulse at the centre, but its higher shoulder values are also supporting large plate deformations [7].

Due to blast, all the fragments will try to generate a shockwave towards the V-hull. The blast of the vehicle is a millisecond/micro-second phenomenon. In the effect of the variation in acceleration and duration on tolerance capacity of human being, it is seen that beyond 100g > 0.01 sec is fatal.[8]
Conclusion

The only armour grade that is currently in use for structural applications is rolled homogeneous armour (RHA). RHA has a density on the higher end of the metals spectrum and hardness on the lower end. When blast fragments impacts RHA, it can be deformed relatively easily because of its ductility [9]. Ductility provides an indication of a material’s resistance to penetration, such as a fragment, and its ability to absorb energy from a blast. A higher ductility allows a greater deformation of the metal, thus permitting the penetrating object to proceed farther through it. The converse is true for the materials with low ductility where the object may damage the face of the metal, but would not penetrate far. In addition, the inherent strength and ductility of metals allows them to absorb blast energy while possibly maintaining structural integrity.

REFERENCES

[1] Kevin Williams, Numerical simulation of light armoured vehicle occupant vulnerability to anti-vehicle mine blast